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Aerospace Medicine and Human Performance

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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.

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May 21 – 25, 2023
Sheraton New Orleans Hotel, New Orleans, LA

May 5 – 9, 2024
Hyatt Regency Chicago, Chicago, IL

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Upcoming FAA Seminars

These are offered by the FAA AME Program office.

March 20-24, 2023	Oklahoma City, OK	Basic
May 23-26, 2023	New Orleans, LA	AsMA
June 12-16, 2023	Oklahoma City, OK	Basic

Visit https://www.faa.gov/other_visit/aviation_industry/designees_delegations/designee_types/ame/seminar_schedule/ for more information.

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AEROSPACE MEDICAL ASSOCIATION
93rd ANNUAL SCIENTIFIC MEETING

MAY 21 – 25, 2023

- **Early Bird Registration runs January 1 – 31 (Mail registrations must be postmarked with a January date)**
- **Advance Registration runs February 1 – May 12.**
- **NO CANCELLATIONS OR REFUNDS AFTER MAY 12.** ***A $50 ADMINISTRATIVE FEE IS APPLIED TO ALL CANCELLATIONS***

WE STRONGLY ENCOURAGE ONLINE REGISTRATION:

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You **MUST** be an active member of **AsMA** in order to register at the member rate. **Registration fee does not include membership dues.**

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NAME			DEGREE/CREDENTIALS
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☐ **Please indicate if this is an address change to your AsMA Membership Record**

First time attendee, or new member? YES ☐ NO ☐ Special dietary requirement: ____________________

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REGISTRATION FEE	EARLY BIRD† 1/1 – 1/31	ADVANCE 2/1 – 5/12	AT-THE-DOOR 5/21 – 5/25	REGISTRATION FEE REMITTED
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☐NON-MEMBER	$725†*	$850*	$950*	
☐NON-MEMBER PRESENTER	$625†*	$750*	$850*	
☐RESIDENTS	$325†	$400	$400	
☐STUDENTS	$75†	$125	$125	
☐FAA-AME SEMINAR§	$325†	$400	$400	
			REGISTRATION FEE SUBTOTAL →	

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†***EARLY BIRD REGISTRATION MUST BE PAID IN FULL (INCLUDING ALL EVENTS AND MEAL FUNCTIONS) AT THE TIME OF REGISTRATION.***

§FEE COVERS AsMA OVERHEAD COSTS. CME CREDIT FOR THE FAA SEMINAR AND AsMA SESSIONS ATTENDED IS INCLUDED.

(See reverse for workshops & events)

NOTE: WORKSHOPS ARE LIMITED *** REGISTER EARLY

WORKSHOP DATE/NAME	FEE	Total Fee
☐ Sun., May 21, 8:00 am – 11:30 am Workshop: "Aerospace Medicine Faculty Development" (MAX 75)	$85	
☐ Sun., May 21, 8:00 am – 4:30 pm Workshop: "Altitude Decompression Sickness – Pathophysiology, Diagnosis, Treatment, and Mitigation" (MAX 75)	$175	
☐ Sun., May 21, 9:00 am – 4:30 pm Workshop: "Establishing Peer Support Programs Across All Aviation Sectors (MAX 75)	$150	

EVENTS *(NOTE: Advance Purchase Only requires tickets to be purchase during Early Bird & Advance registration – no tickets for these events will be sold onsite)*	# OF TICKETS	FEE PER TICKET	TOTAL FEE
☐ Sun., May 21, AsMA Welcome to New Orleans **(NOTE: All Attending Event Must Have Tickets)**		$15	
☐ Mon., May 22, 6:00 am, Richard B. "Dick" Trumbo 5K Fun Run/Walk *(**Advance Purchase Only**)*		$15	
☐ Mon., May 22, Aerospace Human Factors Association Luncheon *(**Advance purchase only**)*		$50	
☐ Mon., May 22, Civil Aviation Medical Association Luncheon *(**Advance Purchase Only**)*		$50	
☐ Mon., May 22, Society of US Air Force Flight Surgeons Luncheon *(**Advance Purchase Only**)*		$50	
☐ Mon., May 22, Society of US Army Flight Surgeons Luncheon *(**Advance Purchase Only**)*		$50	
☐ Mon., May 22, US Navy Luncheon *(**Advance Purchase Only**)*		$50	
☐ Mon. May 22, Fellows Dinner *(**Advance Purchase Only**)* **(MUST BE A FELLOW OR GUEST OF AsMA FELLOW)**		$90	
☐ Tues., May 23, Associate Fellows Breakfast *(**Advance Purchase Only**)*		$50	
☐ Tues., May 23, AsMA Annual Business Meeting *(**Advance Purchase Only**)* **(Free Attendance; Ticket required for meal**)		$50	
☐ Tues., May 23, Reception to Honor International Members		$25	
☐ Wed., May 24, Canadian Society of Aerospace Medicine Breakfast		$50	
☐ Wed., May 24, Aerospace Nursing & Allied Health Professionals Society Luncheon		$50	
☐ Wed., May 24, Aerospace Physiology Society Luncheon		$50	
☐ Wed., May 24, Iberoamerican Association of Aerospace Medicine Luncheon		$50	
☐ Wed. May 24, Society of NASA Flight Surgeons Luncheon		$50	
☐ Thur., May 25, Space Medicine Association Luncheon		$50	
☐ Thur., May 25, AsMA Honors Night Banquet **(Black Tie Optional)**		$90	
	SUBTOTAL OF EVENTS		
TOTAL AMOUNT DUE (Registration Fee Subtotal + Workshop + Subtotal of Events)			

PAYMENT MUST ACCOMPANY FORM. ALL PAYMENTS ARE IN U.S. DOLLARS.

REGISTRANTS SUBMITTING VIA FAX MUST INCLUDE CREDIT CARD INFORMATION.

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FAX TO (703) 739-9652. PLEASE REMEMBER TO INCLUDE BOTH SIDES WHEN FAXING.
*****USE ONLY ONE METHOD TO REGISTER*****

May 21 - 25, 2023
Sheraton New Orleans
New Orleans, Louisiana

The WING of AsMA
AsMA 93rd Annual Scientific Meeting

REGISTRATION FORM

Please read the entire form before filling out or registering online. Fill out a separate form for each registrant.
Advance Registration closes *May 1, 2023*. No refunds *after May 1, 2023.*
Enter the TOTAL NUMBER of tickets and TOTAL DOLLAR AMOUNT on the line after each activity.
Send your advance registration directly to THE WING or register online.
DO NOT include with your spouse's/sponsor's AsMA registration.
__PLEASE NOTE: All prices are in U.S. dollars. Only U.S. funds will be accepted for Registration.__

NOTE: Registration is mandatory for participation in Wing activities.
Register before May 1, 2023 to save $5 each on dues & registration. After that date, dues & registration will be $40 each.

Wing Dues (May 2023 – May 2024) $35.00 /$40.00 $__________
______New Member 2023 _____Renewal _____2023 Dues Previously Paid

Compulsory Registration Fee $35.00/$40.00 No.____ $__________

Monday, May 22, 2:30 – 4:30 PM
The WING Welcome Reception for Registrants only **INCLUDED** No.____ $ 0.00

Tuesday, May 23, 8:30 AM – 12:00 PM (Meet in Lobby @ 8:15 AM)
Swamp Adventure – High Speed Airboat Tour* $75.00 No.____ $__________
*SEE IMPORTANT DISCLOSURES

OR

Tuesday, May 23, 8:30 AM – 12:00 PM (Meet in Lobby @ 8:15 AM) $55.00 No.____ $__________
Swamp Adventure - Swamp Boat Tour

OR

Tuesday, May 23, 9:30 AM – 2:00 PM (Meet in Lobby @ 9:30 AM)
Self-Guided St. Charles Streetcar Tour
Pay as you go … No.____

Wednesday, May 24, 10:00 AM – 1:00 PM (Meet in Lobby @ 9:30 AM)
Annual Wing Bruncheon & Business Meeting
New Orleans School of Cooking $50.00 No.____ $__________

Thursday, May 25, 8:45 AM – 12:30 PM (Meet in Lobby @ 8:45 AM) $65.00 No.____ $__________
Mardi Gras Museum & Mask Making Class

TOTAL $________________

Name ____
Last Name First Name Spouse's/Sponsor's Name
Address ____

City ________________ State __________ ZIP _________ Country ________________

Phone ______________________ E-Mail________________________________

Affiliation (please circle one): Army Navy Air Force Corporate Civilian International Exhibitor

Register ONLINE at : www.thewingofasma.com

OR

Mail this form and your check (payable to Wing of AsMA in US DOLLARS) to:
Brenda Clinton, Treasurer 10603 Derby Mesa Ct – Colorado Springs, CO 80924

The Wing of AsMA
Annual Meeting and Tour Information

<u>WELCOME RECEPTION</u>
Monday, May 22, 2:30 – 4:30 PM

Connect with old friends and make some new ones in a relaxed environment at our annual Welcome Reception. *<u>Remember to bring a small gift reminiscent of your home city, state or country for the gift exchange and please include a short note letting the recipient know who/where the gift is from</u>*. ***New members and first-time attendees <u>don't</u> bring a gift as we are very happy to <u>welcome</u> you to THE WING!***

This year's Welcome Reception will be held in **THE SHERATON NEW ORLEANS HOTEL** ***"Grand Couteau" Room.***

<u>TOUR #1 – Swamp Adventure – Airboat Boat Tour* *(Gators!!)*</u>
Tuesday, May 23, 8:30 AM – 12:00 PM $75.00

Meet at 8:15 AM in the Lobby at The Sheraton New Orleans Hotel.

We've chartered an airboat for an exhilarating adventure. You will experience an educational swamp tour and a high-speed airboat ride. Airboats are driven by a 454 Chevy Engine that will produce speeds up to 35 miles an hour. The boats are propelled by a huge fan that will blow air from the back of the boat more than 200 miles an hour. Airboats ride in inches of water and go where traditional boats cannot go! These boats were designed to take you to inaccessible areas of the swamp, which you cannot reach otherwise.

Tips included. After return to the hotel, lunch is on your own.

*Airboat tours are performed in an open boat. If it rains, you will get wet AND you may get wet without rain, too. In case of inclement weather, the airboat tour may be shortened or replaced with the covered tour boat swamp tour. ***<u>BECAUSE OF THE NATURE OF THE AIRBOAT RIDE, PREGNANT WOMEN OR PEOPLE WITH NECK OR BACK PROBLEMS CANNOT PARTICIPATE. HEARING PROTECTION IS PROVIDED BY THE COMPANY. YOU CAN PURCHASE INEXPENSIVE RAIN PONCHOS AT THE SWAMP TOUR SNACK SHOP.</u>***

<u>TOUR #1A – Swamp Adventure - Swamp Boat Tour *(Gators!!)*</u>
Tuesday, May 23, 8:30 AM – 12:00 PM $ 55.00

Meet at 8:15 AM in the Lobby at The Sheraton New Orleans Hotel.

You will be very comfortable on this swamp tour boat. Complete with roof, restroom, cushioned seats and windows that can be raised or lowered during cold or rainy weather, along with plenty of standing and walking room. The slow drift of the swamp tour boat through moss draped trees and small waterways will provide ample opportunity for viewing and photography. The tour will be fully narrated. Most captains are natives of the Barataria Swamps with a background in gator hunting, fishing and trapping.

Tips included. After return to the hotel, lunch is on your own.

<u>TOUR #2 – Self-Guided St. Charles Streetcar Tour</u>
Tuesday, May 23, 9:30 AM – 1:00 PM $ Pay as you go

Meet at 9:30 AM in the Lobby at The Sheraton New Orleans Hotel.

You and other adventurous Wing members will meet and navigate your way to the St. Charles Streetcar. Don't worry, we'll help get you started, but be sure and register so we know who all will be taking this self-guided independent tour. The St. Charles Streetcar can be boarded a couple of blocks from the hotel. Bring cash. Expect to pay $1.25 cash to get on the streetcar (but we recommend that you buy a daily pass for $3.00). The ride takes about 45 minutes each way to ride along St. Charles Street. The route gives you a grand view of some of New Orleans' most beautiful and interesting homes, the Central Business District, Audubon Park, plus Tulane and Loyola Universities. We suggest looking at the stops ahead of time and hopping off to browse in the shops or eat in one of the darling cafes along the way. If you like to explore on your own or with a small group and don't mind handling your own agenda, this tour is for you. Pay as you go for what you want. This tour is one ***<u>you</u>*** design as you go.

<u>ANNUAL WING BRUNCHEON & BUSINESS MEETING</u>
<u>NEW ORLEANS SCHOOL OF COOKING</u> **$ 50.00**
Wednesday, May 24, 9:30 AM – 1:00 PM
524 St. Louis Street – New Orleans, LA 70130

Meet in the lobby at 9:30 AM. We can either walk together (0.4 miles or about 12 minutes) or order a ride share to one of The Wing's favorite activities. We'll enjoy a demonstration class where we will "Watch – Learn – Eat". The lesson and meal includes: starter, entrée and dessert. We will learn about New Orleans folklore and how to make tasty dishes that are easy enough to make at home. Our Annual Wing Business meeting will be held in this delightful setting. Of course, there's a lovely shop where you'll find so many fun and unique New Orleans cooking items. This will be a great culinary learning experience with delicious food and a great business meeting. Dietary options are available – Vegan, Gluten Free & Vegetarian. Please email to: **asmawing@gmail.com** if you request one of the dietary alternatives by **MAY 8, 2023.**

Tips are optional but can be given easily and discreetly at your table.

<u>TOUR #3 – Mardi Gras World & Mask Making Class</u> **$ 65.00**
Thursday, May 25, 8:45 AM – 12:30 PM
Meet in the lobby at 8:45 AM – Transportation is "on our own." We'll share taxis / ride shares and caravan together. It's about **1.5** miles over there. Too far to walk and too close to charter a bus!

Get ready for a Behind the Scenes Tour of Mardi Gras World. The Wing gets to see a special side of Mardi Gras that no one else gets to see! We kick-off with a 15-minute introductory movie. Then, we have an hour walking tour through Mardi Gras World's working warehouse where their artists make over 80 percent of the Mardi Gras props, floats and fun. Be sure to bring your camera and take advantage of the many photo ops.

Next, we'll enjoy a private Mask Making Class. One of Mardi Gras World's certified artists will lead us through designing our very own Mardi Gras mask. They provide all of the magic we need to create our masterpieces, including a premium felt backed mask, glitter, feathers and more. Once our creations are complete, we might agree to wear our works of art as a fun accessory to Honor's Night! We'll head back to the hotel and lunch is on your own.

<u>WING HOSPITALITY ROOM AND REGISTRATION</u>:
"Grand Couteau" Room
Registration Hours:
Sunday, May 21: 1-5 PM
Monday, May 22: 10 AM-1:30 PM

Hospitality Room Hours:
Sunday: 1-5 PM ***Monday: 10 AM-1:30 PM***

Register Online at: <u>www.thewingofasma.com</u>

or send your completed form and check to:
Brenda Clinton, Treasurer
10603 Derby Mesa Ct
Colorado Springs, CO 80924

AsMA 93rd Annual Scientific Meeting

"Aerospace and the Next Generation"

Sheraton New Orleans Hotel
New Orleans, LA, USA
May 21 - 25, 2023

REGISTRATION IS OPEN!

Go to https://www.asma.org/scientific-meetings/asma-annual-scientific-meeting/register-for-meeting-and-hotel-room and click the link to register for the meeting.

Advanced Registration starts February 1 and will continue until May 12, 2023.

Expanding Girls Awareness in Science and Engineering Month

Susan Northrup, M.D., M.P.H., FAsMA

Ten months into my tenure as President, I've come to realize the most significant challenge of the role is coming up with monthly columns that are interesting and thought provoking. Last month, I used National Heart Month as my inspiration. I thought I'd try that again. There are a bewildering number of days, weeks, and month-long themes in March—from National Peanut Lovers Day March 1st to World Back Up Day March 31st. A couple stood out to me: Hug a GI Day March 4th, National Dentists Day March 6th (which they share with National Oreo Day), Doctor's Day March 30th, and finally, Make Up Your Own Holiday Day March 26th. It is also Women's History Month, National Ethics Awareness Month, and Expanding Girls Awareness in Science and Engineering Month to name a few. And how can I leave out Pi Day? We do have a lot to celebrate and some themes resonate with me.

I recently had the opportunity to sit down with the Women in Aviation Singapore Chapter. They are a relatively new chapter, but so full of excitement and drive to open the field of aviation to not just girls and young women but to all youth. Forty women strong, they are a group of pilots, engineers, security specialists, and air traffic controllers, ranging from general aviation to major aircraft manufacturers and government representatives. They asked really good questions and gave me many interesting viewpoints that made me think about communication processes and novel ways of considering issues. If you ever have the opportunity, I recommend you consider meeting with groups that bring varying viewpoints. It should come as no surprise the Expanding Girls Awareness in Science and Engineering Month got my attention after meeting with this group. Think what we could do!

National Ethics Awareness month reminded me of AsMA's efforts in providing opportunities to meet state requirements for annual ethics training for licensure. AsMA was one of the first organizations to recognize the need and met it head on with ethics panels and discussions in Council and other societies. One more example of what our Association does for us.

Finally, how much fun could we have with Make Up Your Own Holiday Day? Maybe it is time for a National Aerospace Medicine and Human Factors Day. It is certainly something to ponder….

And, just as a reminder, registration is open for our Annual Scientific Meeting. Remember the price goes up the longer you wait! See you in May!

DOI: https://doi.org/10.3357/AMHP.943PP.2023

CONTACT DETAILS:
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Hypoxia Altitude Simulation and Reduction of Cerebral Oxygenation in COPD Patients

Lukas Dehe; Felix Hohendanner; Emin Gültekin; Gordon Werth; Alexander Wutzler; Thorsten Onno Bender

BACKGROUND: Chronic obstructive pulmonary disease (COPD) is highly prevalent and often associated with chronic hypoxia. Previous studies have shown alterations of cerebral oxygenation and cardiac repolarization in COPD patients (GOLD stage II–IV). Airplane travel is common in patients with COPD; however, the clinical effects of a diminished oxygen partial pressure in aircraft cabin environments at cruising altitude remain elusive. The aim of this study was to assess changes of cerebral oxygenation as well as parameters of cardiac repolarization during a hypoxia altitude simulation combined with mild physical activity in these patients.

METHODS: Patients with COPD and healthy subjects (10 per group) randomly selected from the Charité outpatient clinic conducted a hypoxia altitude simulation test which consisted of three phases. The regional cerebral oxygen saturation (rSO_2) of the frontal cortex was measured at rest using near-infrared spectroscopy (NIRS). Furthermore, oxygen saturation (S_pO_2), blood pressure, and heart rate values, as well as a 12-lead-ECG, were recorded. Subsequently, a mild treadmill exercise program (25 W) was divided into 10 min of normoxia (pre-hypoxia), 30 min of mild hypoxia ($F_IO_2 = 0.15$), followed by a second 10-min period of normoxia (post-hypoxia). Meanwhile, mentioned parameters were recorded in 2-min intervals. P, PQ, QRS, QT, QTc, QTd, T-peak-T-end interval (TpTe), and corrected TpTe (TpTec) were measured on three ECG complexes, each at baseline, at the end of the normoxic phase, and at the end of the hypoxic phase.

RESULTS: A total of 10 patients with COPD and 10 control subjects were included in this study. S_pO_2 was significantly lower in COPD patients throughout the whole test. Frontal cerebral rSO_2 was significantly lower in the left hemisphere during hypoxia altitude simulation in COPD patients (59.5 ± 8.5 vs. 67.5 ± 5.7).

CONCLUSIONS: We show reduced left frontal cerebral oxygenation during hypoxia and mild exercise in patients with COPD, suggesting diminished altitude resilience and altitude capabilities. Preflight hypoxia assessment might be recommended to patients with severe COPD.

KEYWORDS: airplane travel, hypoxia, COPD, NIRS.

Dehe L, Hohendanner F, Gültekin E, Werth G, Wutzler A, Bender TO. *Hypoxia altitude simulation and reduction of cerebral oxygenation in COPD patients*. Aerosp Med Hum Perform. 2023; 94(3):102–106.

Chronic obstructive pulmonary disease (COPD) is a chronic disease of middle and older age[2] and is marked by chronic inflammation, progressive obstruction of the airways, and destruction of lung tissue.[14] COPD is known to be a common disease with a prevalence of 13.1% worldwide[5] and is associated with significant morbidity and mortality. It is among the leading causes of death worldwide, with up to 3.23 million deaths in 2019.[18]

Since the number of passengers traveling by commercial airlines worldwide is increasing every year, with more than 4.5 billion passengers in 2020, the number of passengers with pre-existing condition like COPD is rapidly increasing.[13] The rising number of passengers aboard larger aircraft and long-distance

Lukas Dehe and Felix Hohendanner contributed equally.

From the Department of Anesthesiology and Operative Intensive Care Medicine, the Department of Cardiology, and the Occupational Medicine Center, Charité–Universitätsmedizin Berlin, Berlin, Germany; the German Heart Center Berlin, Berlin, Germany; and the German Center for Cardiovascular Research (DZHK), Berlin, Germany.

This manuscript was received for review in April 2022. It was accepted for publication in December 2022.

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flights make emergencies more likely, especially for patients with chronic conditions like COPD.[11]

Due to a reduced oxygen partial pressure at cruising altitude, cabin pressure is adjusted to the ambient pressure of a maximum of 8000 ft (244 m) above sea level to maintain oxygen supply for the passengers and crew. According to Dalton's law, this is equivalent to a fraction of inspired oxygen (F_IO_2) of 15.1% at sea level.[3]

Cabin pressure and reduced oxygen partial pressure at cruising altitude are usually well tolerated by healthy passengers but might pose a risk for passengers suffering from COPD.[3,7] As compared to sea level, at 8000 ft, oxygen saturation decreases by 4.4% points in healthy passengers. However, this reduction is markedly more pronounced in patients with COPD and often accompanied by dyspnea.[15]

Cerebral oxygen desaturation is associated with decreased muscular strength, impaired coordination, and unconsciousness and, therefore, of particular interest. In healthy subjects cerebral oxygen saturation is known to be reduced under hypoxic conditions and further reduced during physical exercise.[16] In COPD patients with chronic hypoxemia, cerebral oxygen saturation was significantly reduced under normoxic conditions and further reduced during physical exercise.[10] The prevention of commercial in-flight passenger emergency situations is paramount for the current high volume and low threshold international travel using airplanes. Yet alterations of the regional cerebral oxygen saturation (rSO_2) of the frontal cortex and thus safe travel of airplane passengers with COPD still remain elusive. The aim of the present proof of concept study was to reveal whether mild hypoxia is associated with a reduction of cerebral oxygen saturation in these patients. In addition, parameters of cardiac de- and repolarization were assessed to elucidate the role of hypoxia on cardiac electrophysiological properties.

METHODS

Subjects

Following approval by the local ethics committee (EA 2/031/14) of the Charité-Universitätsmedizin Berlin and by the Federal Data Protection Agency, volunteer patients from the local COPD outpatient clinic at Charité-Universitätsmedizin Berlin were recruited between April 2015 and September 2017. The subjects of this proof-of-concept study were 17 adult patients who presented with COPD (GOLD stage II–IV; biometric characteristics of the study cohort can be found in **Table I**). Due to premature termination of the exercise protocol, six subjects met exclusion criteria and one subject's ECG was invalid [see the CONSORT diagram in supplemental **Fig. A**, found online at https://doi.org/10.3357/AMHP.6102sd.2023). Spirometry results were recorded (FEV_1, FVC, Tiffeneau-index) or spirometry was conducted before the standardized treadmill protocol. The control group consisted of 10 adult, healthy volunteers without history of previous lung disease. In addition, control patients had to produce a valid air worthiness certificate. Exclusion criteria included patients with long-term home oxygen therapy. Patient age, gender, body mass index, COPD GOLD stage, spirometry results, and pre-existing medical conditions, i.e., arterial hypertension, diabetes mellitus, peripheral artery disease, atrial fibrillation, asthma, obstructive sleep apnea syndrome, and chronic kidney failure, were used to characterize the study population and to identify possible confounders. Furthermore, chronic medication was assessed.

Table I. Biometrical Characteristics.

PARAMETER	COPD (*N* = 10)	CONTROL (*N* = 10)	*P*-VALUE
Age (yr)	66.0 ± 6.7	60.2 ± 7.9	0.089
Sex (Male)	6 (60%)	6 (60%)	1
BMI (kg · m−2)	26.6 ± 5.4	24.1 ± 2.3	0.315
COPD GOLD Stage			
II (%)	8 (80%)		
III (%)	1 (10%)		
IV (%)	1 (10%)		
Spirometry			
FEV1 (% vom Soll)	55.6 ± 17.1		
FEV1 (L)	1.6 ± 0.4		
FVC (L)	2.9 ± 0.6		
FEV1/FVC (%)	55.6 ± 9.4		
Pre-existing medical conditions			
Arterial hypertension	7 (70%)	1 (10%)	0.023
Peripheral artery disease	0	0	
Atrial fibrillation	0	0	
Diabetes mellitus	1 (10%)	0	0.739
Chronic kidney disease	0	0	
Sleep apnea	0	0	0.739

BMI: Body mass index, COPD: Chronic obstructive pulmonary disease, FEV: Forced Expiratory Volume, FVC: Forced vital capacity.

Regional cerebral oxygenation was chosen as primary outcome parameter. Secondary outcome parameters were S_pO_2 (%), heart rate (bpm), mean arterial pressure (mmHg), and ECG parameters: P (ms), PQ (ms), QRS (ms), QT (ms), QTc (ms), QTd (ms), T-peak-T-end interval (TpTe; ms), and TpTed (ms).

Procedure

Patients with COPD and control subjects without lung disease underwent a modified hypoxia-altitude simulation test (HAST) which consisted of three phases. First, rSO_2 of the frontal cortex was measured at rest using near-infrared spectroscopy (NIRS; Equanox, Nonin Medical Inc., Plymouth, MN, USA) at a wave length of 730–880 nm. Results were measured using a NIRS X-100 Monitor (Nonin Medical Inc.). Furthermore, oxygen saturation (S_pO_2), blood pressure, and heart rate values were recorded every 2 min as well as a 12-lead continuous ECG (Propaq CS, Welch Allyn, Skaneateles Falls, NY, USA). As for ECG parameters, P, PQ, QRS, QT, QTc, QTd, and TpTe were measured on three ECG complexes each at baseline, at the end of 10 min of mild exercise, and at the end of HAST. Severity of dyspnea was documented using the Borg CR10 scale at all phases.

Subsequently, a mild treadmill exercise program (GE Healthcare eBike Ergometer, Chalfont St. Giles, United

Table II. Comparison Between COPD Patients and Control During All Phases of HAST.

	BASELINE			PREHYPOXIA			HYPOXIA		
PARAMETER	COPD	CONTROL	*P*-VALUE	COPD	CONTROL	*P*-VALUE	COPD	CONTROL	*P*-VALUE
S_pO_2 (%)	96.0 ± 1.4	97.5 ± 1.1	0.023	95.7 ± 1.6	97.4 ± 1.1	0.019	84.6 ± 7.6	91.6 ± 1.3	0.004
rSO_2 left (%)	66.9 ± 5.8	70.1 ± 5.1	0.247	67.6 ± 5.5	70.8 ± 5.6	0.165	59.5 ± 8.5	67.5 ± 5.7	0.035
rSO_2 right (%)	69.0 ± 6.1	69.5 ± 5.0	0.971	69.8 ± 6.4	70.2 ± 5.0	0.971	62.1 ± 8.5	66.0 ± 4.1	0.190
HR (bpm)	88 ± 5	76 ± 14	0.043	98 ± 13	81 ± 12	0.003	110 ± 16	85 ± 10	<0.001
MAP (mmHg)	88 ± 12	87 ± 14	0.853	89 ± 12	88 ± 13	0.853	96 ± 13	84 ± 17	0.143
ECG									
RR (ms)	687 ± 98	813 ± 128	0.029	612 ± 71	761 ± 105	<0.001	553 ± 73	720 ± 89	<0.001
P (ms)	101 ± 11	109 ± 10	0.143	86 ± 13	106 ± 12	0.002	91 ± 8	101 ± 9	0.029
PQ (ms)	155 ± 20	164 ± 16	0.247	138 ± 10	160 ± 16	0.003	139 ± 11	157 ± 15	0.009
QRS (ms)	86 ± 9	90 ± 14	0.912	81 ± 10	89 ± 15	0.165	78 ± 9	89 ± 15	0.075
QT (ms)	356 ± 18	377 ± 25	0.043	337 ± 23	365 ± 20	0.009	321 ± 25	361 ± 21	0.002
QTc (ms)	431 ± 19	421 ± 26	0.579	431 ± 19	420 ± 23	0.353	432 ± 14	426 ± 20	0.353
QTd (ms)	31 ± 2	27 ± 6	0.393	32 ± 11	27 ± 10	0.393	24 ± 6	29 ± 9	0.105
TpTe (ms)	81 ± 13	76 ± 14	0.393	81 ± 0.8	76 ± 10	0.353	78 ± 15	74 ± 17	0.529
TpTec (ms)	98 ± 16	85 ± 16	0.075	104 ± 10	88 ± 14	0.004	104 ± 17	88 ± 20	0.075

HAST: Hypoxia-altitude simulation test, S_pO_2: oxygen saturation, rSO_2: regional oxygen saturation, HR: Heart rate (bpm), MAP: Mean arterial pressure, ECG: Electrocardiogram.

Kingdom) at 25 W was divided into 10 min of normoxia (F_IO_2 = 0.21, pre-hypoxia) and 30 min of mild hypoxia (F_IO_2 = 0.15), simulating a normal walk on an airplane. The hypoxic gas mixture (compressed liquid gas, Linde, Munich, Germany) consisted of 15% oxygen and 85% nitrogen. The fraction of inspired oxygen of 15% at sea level was used to simulate conditions as they are observed at 8000 ft (2438 m) above sea level. Gas flow was reduced to 25 $L \cdot min^{-1}$ (pressure regulator, FDR-200F-40-PG, Linde) and guided to a ventilation bag. It was then inhaled through an airtight CPAP mask (Fisher&Paykel Healthcare Ltd, Auckland, New Zealand). A one-way valve between the ventilation bag and the CPAP mask ensured the inspiration of the hypoxic gas mixture. Absolute and relative termination conditions according to the American Heart Association[8] are shown in supplemental **Table A** (found online at https://doi.org/10.3357/AMHP.6102sd.2023).

Statistical Analysis

Descriptive analyses and statistical testing were performed using SPSS Version 24 (SPSS, Chicago, IL, USA). For variables failing the normality test, a Mann-Whitney U-Test was used to assess differences between groups (COPD vs. control). The Wilcoxon signed-rank test was used to assess significant alterations within the group during HAST. For supplemental **Fig. B** (online at https://doi.org/10.3357/AMHP.6102sd.2023) 2-sided *t*-tests were used to investigate between group differences. Tukey's multiple comparisons post hoc test was used to determine statistical differences between mean values determined during normoxia and hypoxia in both groups. $P < 0.05$ was considered statistically significant.

RESULTS

Biometric characteristics are shown in Table I. Age, sex, and body mass index did not differ between groups. Patients of the COPD group were more likely to suffer from arterial hypertension ($P = 0.023$) as compared to the control group.

Hypoxia significantly reduced oxygen saturation in both the control and COPD groups ($P < 0.01$). COPD patients showed a lower oxygen saturation during all phases of HAST (**Table II**), especially under hypoxic conditions, i.e., the reduction of oxygen saturation was more pronounced in COPD as compared to controls ($P < 0.01$; **Fig. 1**). Interestingly this was mirrored in cerebral oxygen saturation. As indicated in **Fig. 2**, regional cerebral oxygen saturation was significantly reduced in the COPD patients during modified HAST ($P < 0.05$; Fig. 2).

Mean arterial pressure during exercise did not differ between the groups, even though COPD was associated with a higher heart rate during HAST ($P < 0.01$; Table II, **Fig. 3**). Mean Borg-score between controls and COPD patients was not significantly different: one patient in each group reported slight dyspnea (Borg score 2) during the study. Moreover, we could not detect any gender related differences in oxygen

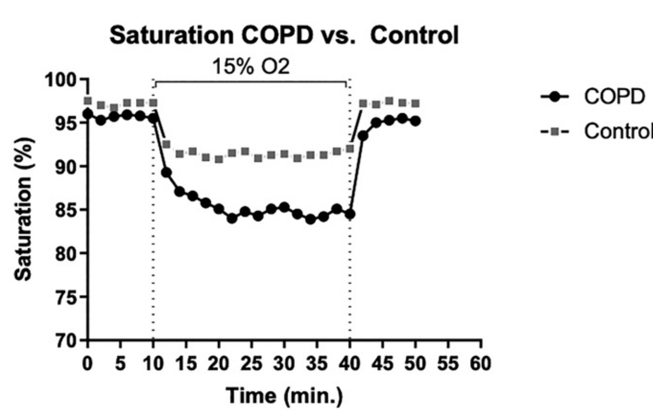

Fig. 1. Oxygen saturation during HAST. During the hypoxia-altitude simulation test (HAST), general oxygen saturation was significantly reduced under hypoxic conditions (F_IO_2 = 0.15; *N* = 10 control and *N* = 10 COPD patients).

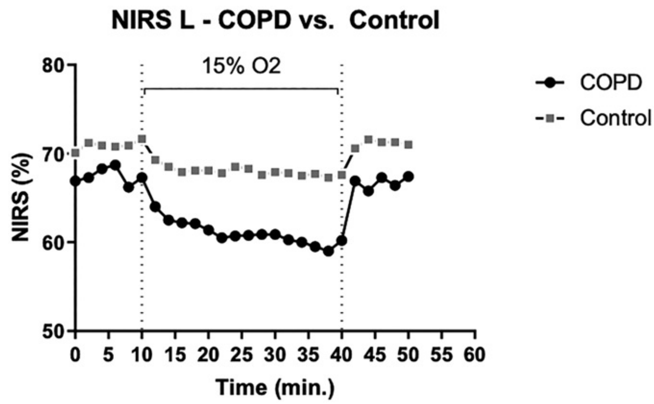

Fig. 2. Cerebral regional oxygen saturation during HAST. During the hypoxia-altitude simulation test (HAST), cerebral oxygen saturation was significantly reduced under hypoxic conditions ($F_IO_2 = 0.15$; *N* = 10 control and *N* = 10 COPD patients).

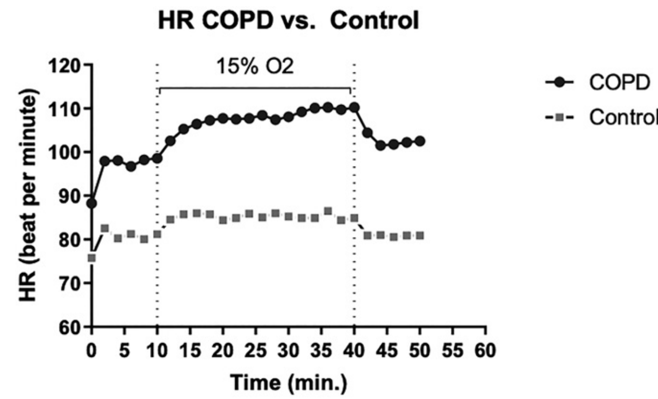

Fig. 3. Heart rate during HAST. During the hypoxia-altitude simulation test (HAST), heart rate was significantly increased, especially under hypoxic conditions ($F_IO_2 = 0.15$; *N* = 10 control and *N* = 10 COPD patients).

saturation, NIRS, mean arterial pressure, heart rate, or respiratory rate upon introducing hypoxic conditions within the COPD group.

Analysis of ECG features during mild exercise unveiled an increased heart rate (Fig. 3) and prolonged P waves and PQ times, findings that consistently translated into differences observed during hypoxia and mild exercise. However, in the present patient study, none of the relevant additional ECG properties analyzed, such as QTc intervals or TpTe, showed significant differences during hypoxia (Table II).

DISCUSSION

This proof-of-concept study of COPD patients (II–IV) undergoing a modified HAST suggests that COPD is associated with a decreased cerebral oxygenation in comparison to healthy volunteers. These results may raise concerns about a diminished altitude resilience and adequate oxygen therapy for COPD patients during flights since COPD patients are known to suffer from dyspnea during air travel.[7]

In accordance with previous studies, we were able to show a significant decrease in oxygen saturation in COPD patients. Due to a reduced pulmonary gas exchange, COPD can result in hypoxia and hypercapnia.[19] Gong et al. were able to show a significant reduction of oxygen saturation in normocapnic COPD patients undergoing a hypoxia-altitude simulation test.[9] In addition, there was a significant decrease in oxygen saturation in COPD patients during exercise in a diving chamber adjusted to 8000 ft (2438 m).[6] During a 5-h flight with a cabin pressure adjusted to 6000 ft (1829 m), oxygen saturation significantly decreased in COPD patients and further decreased during a 50-m walk test.[4]

Little is known about the impact of hypoxia on brain function during air travel. Since decreased cerebral oxygen saturation comes along with impaired coordination and unconsciousness, air travel may be a risk for these passengers. There is evidence that a lowered oxygen saturation by approximately 4 percentage points at 7000 to 8000 ft (2134 to 2438 m) played an important role in the development of discomfort. The cumulative prevalence of altitude-related malaise, muscular discomfort, and fatigue were directly related to altitude and inversely related to oxygen saturation.[12] Potential follow-up studies including the assessment of broader measures of neurological function are needed to address a potential impact of hypoxia on brain function in the setting of higher altitudes beyond the mere development of discomfort. Additional follow-up studies might also allow assessing gender related differences upon introduction of hypoxic conditions.

In healthy subjects cerebral oxygen saturation is known to be reduced under hypoxic conditions and further reduced while performing physical exercise.[16] In COPD patients with chronic hypoxemia, cerebral oxygen saturation was significantly reduced under normoxic conditions and further reduced while performing physical exercise.[10] Interestingly, our study suggests that hypoxia altitude simulation is associated with a decreased cerebral oxygen saturation in COPD patients.

Mild hypoxia has been associated with cardioprotective effects due to altered ATP-sensitive potassium channel activity related to proteins like SUR2A.[1] This has also been shown to translate into changes of the QT interval in a hypoxia animal model.[17] However, in the present patient study, none of the relevant additional ECG properties analyzed, like QTc intervals or TpTe, showed significant differences. Interestingly though, P wave duration differed between control and COPD upon exercise. This might potentially be related to a more pronounced increase of pulmonary pressures during exercise and could be associated with an increased (right) atrial volume in COPD as compared to control patients and underscores the fragility of these patients.

In conclusion, our study is the first to show reduced cerebral oxygenation during HAST and mild exercise in patients with COPD. These results suggest that alterations in cerebral oxygenation may limit the ability to fly in terms of altitude resilience in COPD patients.

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Typical Cockpit Ergonomics Influence on Cervical Motor Control in Healthy Young Male Adults

Ursula Heggli; Jaap Swanenburg; Léonie Hofstetter; Melanie Häusler; Petra Schweinhardt; Denis Bron

INTRODUCTION: Neck pain and injury are common problems in military high-performance aircraft and helicopter aircrews. A contributing factor may be the reclined sitting position in cockpits. This study aimed to determine the effect of typical cockpit ergonomics on cervical proprioception, assessed by using the cervical joint position error (cJPE).

METHODS: A total of 49 healthy male military employees (mean age 19.9 ± 2.2 yr) were examined. Measurements of the cJPE were obtained in the flexion, extension, and rotation directions in an upright and in a 30°-reclined sitting position. Each condition comprised three trials, with an additional 3-kg head load to mimic real world working conditions.

RESULTS: A smaller cJPE was noted in the 30°-reclined sitting position (mean cJPE = 3.9 cm) than in the upright sitting position (mean cJPE = 4.6 cm) in the flexion direction. The cJPE decreased significantly in all movement directions across the three trials; for example, in the flexion direction in the 30°-reclined sitting position: Trial 1/2/3 mean cJPE = 5.0/3.8/3.1 cm.

CONCLUSION: It seems that a reclined seating position has a positive influence on cJPE. However, the result is weak. In both sitting positions and all three directions, the first tests of the cJPE showed the highest values. Already after one or two further measurement runs, a significantly reduced cJPE was observed. This rapid improvement might indicate that an exercise similar to the cJPE test may improve the pilots' cervical proprioception and possibly reduce the risk of injury or pain.

KEYWORDS: joint position error, neck, proprioception, military aircrew, helicopter aircrew.

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The high prevalence of neck pain among military aviators has been well documented. It is a burdensome health problem especially in high-performance aircraft and helicopter aircrews.[1] In fact, two-thirds of helicopter pilots report neck pain[2] and about 90% of jet pilots report experiences of flight-related neck pain.[11] There have been investigations into the relationships between such work-related musculoskeletal symptoms, degree of disability, or physical fitness.[11,19] Rintala and colleagues suggest that moderate or even good overall physical fitness is insufficient to maintain occupational health among aviators.[19] Motor control of the cervical spine, which refers to the coordinated contraction of muscles controlled by the brain's motor cortex integrating proprioceptive, visual, and vestibular sensory information,[9] might be more relevant than overall physical fitness because of its importance for maintaining balance and withstanding external loading during daily activities.[9,20] This is even more true for military pilots because they have to move their heads extensively to keep track of objects in 3-dimensional space.[16]

A well-functioning proprioceptive system is an important prerequisite for good cervical motor control.[7] Proprioceptive dysfunction can adversely influence motor control[27] and significant proprioceptive dysfunction in the cervical spine can be an important factor for the recurrence or progression of neck pain.[7] Proprioception can be influenced by the alignment of the

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body position in relation to gravity and an additional load, e.g., a helmet.[8,13] In most high-performance jets, the ejection seat's backrest is backward-tilted to improve the pilot's tolerance of G forces.[16] In consequence, the pilot's head deviates from the upright position; the load on the cervical spine increases due to this biomechanical alteration. Therefore, good muscle coordination and stabilizing ability are required of the pilot.[2] However, how a backward-tilted sitting position effects the proprioception functioning of the cervical spine remains, to our knowledge, unknown. As for additional cervical loading, both military jet and helicopter aircrews wear helmets of approximately 2.5 kg (5.5 lb). In high-performance military aircraft, much higher loads can act on the cervical spine when experiencing G forces up to +9 G_z.[4] This extra load must be stabilized by the neck muscles.[1] Both additional load and the additional stabilizing muscle activity will increase pressure on the cervical spine. This might influence cervical proprioception and, in consequence, cervical motor control.

Despite cervical proprioception being an important topic, it has only been rarely considered among aviators. Therefore, this study aimed to determine whether there is a difference in cervical proprioception between a backward-tilted and an upright seating position, including the additional head loading of the typical aviation work environment.

METHODS

Subjects

Recruited were 49 healthy male military employees. The mean age was 19.9 ± 1.1 yr, weight 74.4 ± 11.4 kg, and height 179.4 ± 7.9 cm. The subjects were accustomed to additional axial loads on the cervical spine through regular wearing of a helmet. The exclusion criteria were: any current neck pain, age younger than 18 yr, and a score of more than 15% in the Neck Disability Index questionnaire.[24] All subjects were made aware of the purpose of this study before signing informed consent. This study was approved by the ethics committee and registered at ClinicalTrials.gov.

Procedure

The joint position error test provides a reliable measure of the proprioception of joints because it can detect any disturbance of cervical motor control.[6] After collecting demographic data (age, weight, and height), cervical proprioception was assessed using the cervical joint position error (cJPE) test. cJPE was assessed in an upright sitting position and in a 30° rearward-tilted sitting position. Some seats in fighter planes allow a tilt angle of 10–35°. To generate the greatest possible effect, we chose the most backward-tilted sitting position. In each of these two positions, the cJPE test was executed in three directions: flexion, extension, and rotation. Rotation was the mean of the left and right rotational directions. Each direction test comprised three measurement trials. The cJPE measurements were performed by an experienced physiotherapist who was thoroughly trained in the use of the measurement device; the physiotherapist announced each action. A calibration was required between each direction and repetition to ensure the subject's upright and comfortable head position before every measurement. The subjects' arms rested on their legs. To prevent bias, the order of body positions was changed every five subjects. The order of the three turns in different directions was not changed. For the comfort of the subjects, a 2-min break was allowed between changes of body position. To minimize movements of the subjects' upper body during the upright sitting position, an 8-cm diameter massage ball (Blackroll; Bottighofen, Switzerland) was placed between thoracic vertebra 2 and the backrest (**Fig. 1**). The measurement of proprioception can be influenced by the testing itself. Because most change is observed within the first three trials,[23] each body position and movement direction were measured three times. Subjects wore a hockey helmet weighing 3 kg with additional load. Helmet slippage was prevented using an antislippage cap.

Equipment

Revel and colleagues[18] developed the cJPE test to quantify the alterations in cervical motor control and proprioception in patients with neck pain. With eyes closed, the test subject must perform specific head movements (maximum active range of movement: flexion, extension, and rotation or lateral flexion) and return the head to the initial reference position with maximum precision.[18] After return of the head to the reference position, the subject reopened his eyes and, by looking at the screen of the laptop, received visual feedback on the magnitude and direction of his cJPE after each trial. In this study, we used a three-dimensional method. A cervical trainer sensor (SensCoordination 3D Cervical Trainer, Sensamove, Groessen, Netherlands) was used.[17] This sensor consists of an inertial measurement unit, a combination of accelerometers and a gyroscope connected with Bluetooth to a laptop. The laptop itself was placed on a table located 2 m from the subject, who could see the screen clearly. The cervical trainer's sensor was fixed to the front of the helmet using double-sided tape. The reliability and validity of the 3D Cervical Trainer has not been investigated. However, comparable measurement devices have been shown to be reliable and valid.[22]

Statistical Analysis

Descriptive statistics were used to summarize the baseline characteristics of the subjects. For all three movement directions, three separate ANOVAs with cJPE as the dependent variable (significance level, $P < 0.05$) were used. The independent variables were body position (upright and 30° backward tilted) and measurement trials (first, second, and third trial). Bonferroni post hoc tests were executed. All statistical analyses were performed using SPSS 25 (IBM, PASW Statistics, Chicago, IL, USA).

RESULTS

No adverse events were reported. The cJPE results of the three measurement trials in all three movement directions and both body positions are shown in **Fig. 2**, **Fig. 3**, and **Fig. 4**.

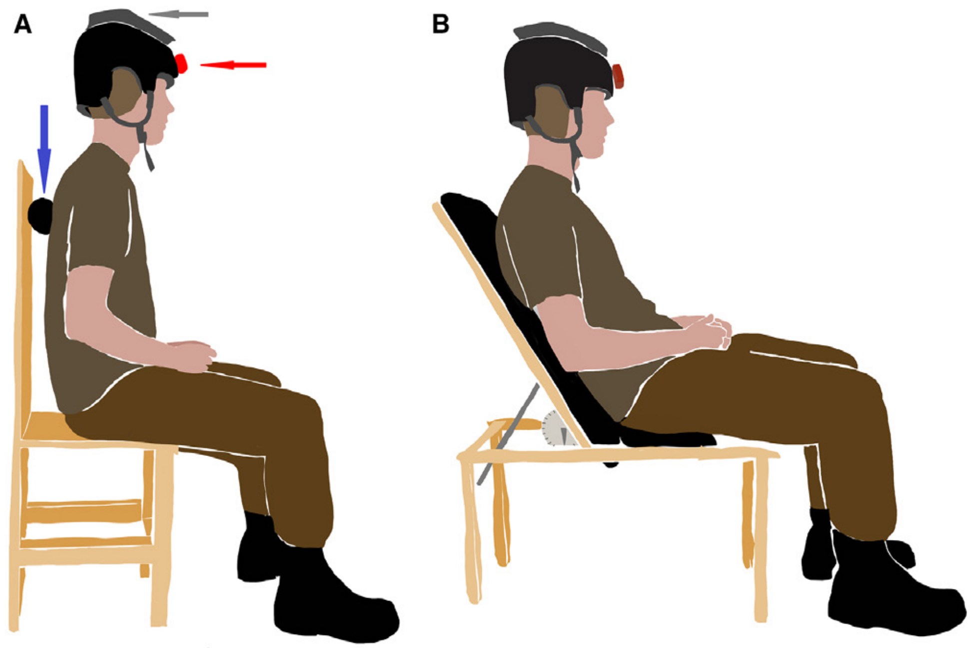

Fig. 1. A) Subject in an upright position wearing a 3-kg helmet. Gray arrow, extra weight; red arrow, sensor; blue arrow, ball placed at Thoracic 2–Thoracic 4. B) Subject in a 30° backward-tilted sitting position wearing a 3-kg helmet.

There was a significant effect of body positions [$F(1,288) = 4.263$; $P = 0.040$] and between measurement trials in the flexion movement direction [$F(2,288) = 18.935$; $P < 0.001$]. The 30° backward-tilted sitting position showed a lower cJPE compared to the upright position. There was no interaction between body position and measurement trial [$F(2,288) = 1.865$; $P = 0.157$]. Bonferroni post hoc tests revealed significant differences between the first and second trials ($P < 0.001$), the first and third trials ($P < 0.001$), but not between the second and third trials ($P = 1.000$). The cJPE was noted to decrease after the first trial.

There was no effect of body position [$F(1,288) = 2.147$; $P = 0.144$] and a significant main effect between measurement trials in the extension movement direction [$F(2,288) = 5.524$; $P = 0.004$]. There was no interaction between body position and measurement trial [$F(2,288) = 1.009$; $P = 0.366$]. Bonferroni post hoc tests revealed no differences between the first and second trials ($P = 0.060$), a significant decrease between the first and third trials ($P = 0.004$), and no change between the second and third trials ($P = 1.000$).

There was no main effect of body position [$F(1,288) = 0.572$; $P = 0.450$] and a significant main effect between the measurement trials in the rotation movement direction [$F(2,288) = 23.580$; $P < 0.001$]. There was no interaction between body position and measurement trial [$F(2,288) = 0.495$; $P = 0.610$].

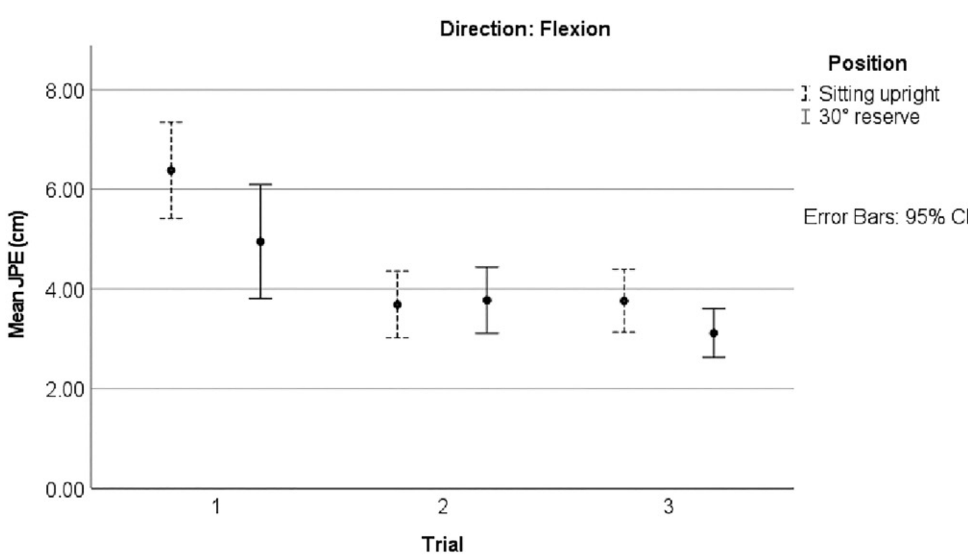

Fig. 2. Mean cJPE values in the flexion movement direction, in both body positions, in three measurement trials. cJPE: cervical joint position error; JPE: joint position error.

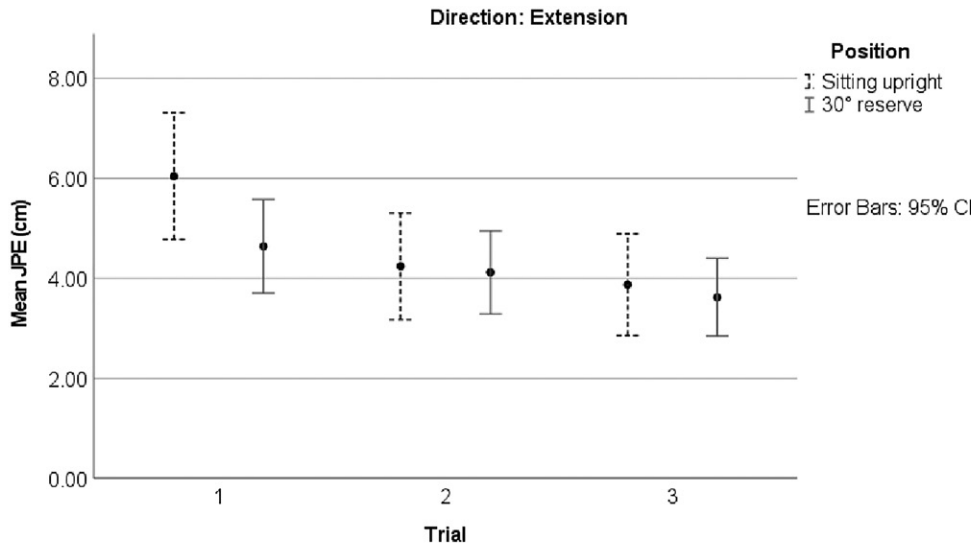

Fig. 3. Mean cJPE values in the extension movement direction, in both body positions, in three measurement trials. cJPE: cervical joint position error; JPE: joint position error.

Bonferroni post hoc tests revealed a significant decrease between the first and second trials ($P < 0.001$), between the first and third trials ($P < 0.001$), and no change between the second and third trials ($P = 1.000$).

DISCUSSION

In this study the cJPE was examined in two different body positions, during three measurement trials, in three cervical movement directions, all with additional axial cervical load. Two significant changes were observed: 1) cJPE was lower in the 30° backward-tilted sitting position in the flexion movement direction; and 2) cJPE decreased after the first measurement trial in the flexion and rotation movement directions in both body positions; in the extension direction cJPE decreased between the first and third measurement trials.

The cJPE was noted to be less in the backward-tilted sitting position during flexion movement, indicating better proprioception. This finding is unexpected, as a previous study showed different results. Yong and colleagues found that a forward head posture correlated with a greater repositioning error than a more upright posture.[26] However, the measurements were performed in a different posture: their subjects were measured standing, not sitting or in a 30° backward-tilted position. Possibly the upper body is better stabilized in a backward-tilted sitting position because of the support of the backrest. Other potential explanations are related to the fact that the cervical

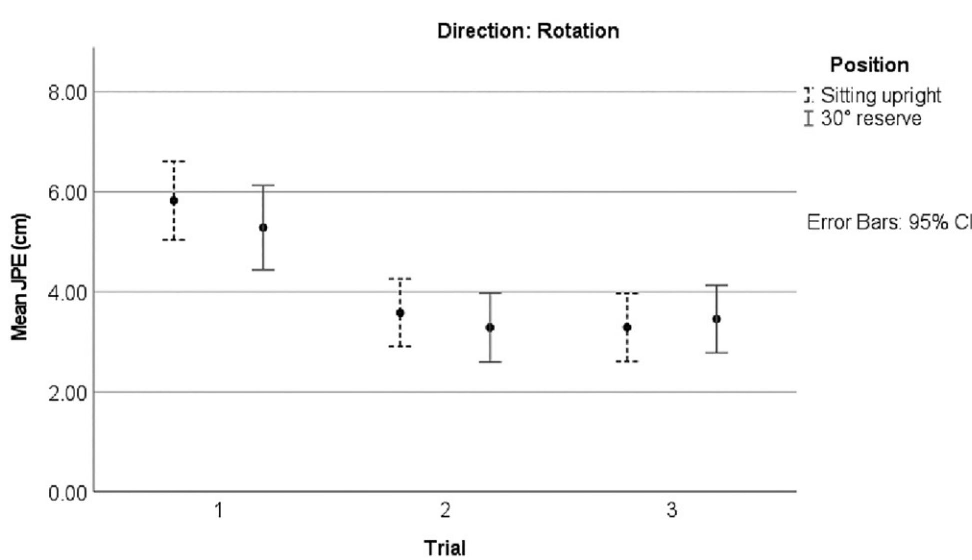

Fig. 4. Mean cJPE values in the rotation movement direction, in both body positions, in three measurement trials. cJPE: cervical joint position error; JPE: joint position error.

spine is already in a flexed position in a 30° backward-tilted sitting position, which leads to the lower neck muscles being stretched and the pressure on the cervical spine being increased.[12] Both stretching of the neck muscles and increased pressure plausibly lead to improved proprioception: the more a muscle is stretched, the better the proprioceptive response (higher frequency).[20] Hence, with this highly innervated soft tissue and the stretching position, even more position data is generated, which improves the accuracy of the head movement and which, in turn, leads to a better cervical proprioception in a backward-tilted body position. Next to the muscle stretching, the increased pressure on the spine due to the flexed position could also be an explanation for the lower cJPE. Compression at every cervical joint level is at least 1.6 times higher in flexion than in an upright posture.[14] The higher compression leads to an increase in proprioceptive input, which in turn leads to better cervical motor control.[20]

The fact that this lower cJPE only occurs in the flexion position could be related to the sum of the deep and superficial muscle forces on the neck. In the flexion position the sum of deep and superficial muscle forces is greater than in the other directions (extension and lateral flexion).[3] Thus, the pressure is greatest in the flexion direction, producing more proprioceptive input. The backward-tilted seating position seems to be more advantageous in terms of cervical motor control.

A final explanation could be the static analysis we conducted: we performed one ANOVA per direction. The significant result found in the flexion direction could come from the multiple tests. We tested the dependence of the results of the different directions with a correlation test, and high correlation values ($r = 0.46$ and 0.90) were found. This indicates that there is a dependence between the directions of movement, making the explanation that the significant effect is due to multiple testing less likely. However, a $P = 0.04$ remains weak and would not stand up to a Bonferroni correction.

The results of this study show that the position of the backrest in the cockpit does not change the cervical motor control as much as initially assumed. An aspect that was not considered is potential pilot fatigue, which can occur during a flight. The study subjects of this study were only for a very short time in the backward-tilted seating position. Premature fatigue can develop as pilots look at the display in front of them; in the backward-tilted sitting position, their heads are no longer supported by the headrest.[3] Moreover, in a backward-tilted sitting position, the cervical spine is not in a pure flexion position. Only the lower cervical spine experiences increased flexion, with an anterior translation of the head resulting in extension of the upper cervical spine.[5] This extreme end of motion situation leads to increased pressure on the C7–T1 disk and loading of the lower neck extensors,[4] which can also lead to fatigue and, in turn, negatively influence cervical motor control.[15] Therefore, the topic of a forthcoming study should be the influence of fatigue on the joint position sense using operationally relevant periods of positioning the head in the different seating angles.

Ambient temperature might also affect cervical motor control. Military pilots sometimes must operate in cold conditions at high altitudes or during winter. In 2014, Roope Sovelius[21] measured skin temperature over the trapezoid muscles, which is an indicator of muscle temperature. Exposure to cold and the resultant cooling of the skin and muscles before startup and takeoff produce increased muscle strain under negative G force in the neck area. He concluded that a preflight cooling effect may have an influence, in terms of more frequent cervical disorders among fighter pilots, in colder regions. Therefore, preflight warm-up should be a mandatory routine; it is important to prevent cooling of the muscles in a cold environment.[21]

Already after one or two measurement runs, a reduced cJPE was detected. Thus, the results of this study confirm the findings of cJPE habituation found in earlier studies.[23] However, to our knowledge, the fact that this habituation is also found in a backward-tilted sitting position and with extra cervical load is a new finding.

This fast improvement in proprioception should be utilized. It can be assumed that when a pilot starts a mission with a better proprioception, there is more room to compensate for negative influences such as fatigue or monotony of the head position. This was confirmed by a study that looked at the effects of 6 wk of training of the deep neck flexor muscles and of proprioception. Both interventions caused a reduction of cJPE.[10] This can be attributed to variations in body position, movement direction, and load, because specific motor control can be achieved through "constant variations of the exercises."[25] Pilots might benefit from exercising their neck muscles and proprioception. A recommended exercise should be as identical as possible to the cJPE test. Even just before launching a mission, short proprioception exercises might be recommended, such as sitting in the cockpit, fixating the velocity vector or waterline symbol in the head-up display in front, performing a maximum movement in one direction with eyes closed, then returning to the starting point. Pilots can then open their eyes to see the magnitude and direction of their cJPE before they start the next repetition. These exercises might not be suitable for emergency takeoffs but feasible for planned flights.

In conclusion, it seems that a reclined seating position has a positive influence on cJPE. However, the result is weak. In both sitting positions and all three directions, the first tests of the cJPE showed the highest values. Already after one or two further measurement runs, a significantly reduced cJPE was observed. This rapid improvement might indicate that an exercise similar to the cJPE test could improve the pilots' cervical proprioception and possibly reduce the risk of injury or pain. This assumption should be investigated in further studies.

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Temporary Incapacitation Rates and Permanent Loss of Medical License in Commercial Airline Pilots

Erik Hohmann; Reino Pieterse

INTRODUCTION: The purpose of this study was to report the temporary loss of medical license and pilot incapacitations in the United Arab Emirates from 2018–2021.

METHOD: The General Civil Aviation Authority database was searched for all reported temporary suspensions of license between 2018–2021 and the ICD-10 codes were extracted.

RESULTS: A total of 1233 incapacitations was reported with a mean license suspension of 148.4 ± 276.8 d. The mean days of suspension for the various medical specialties were 115.2 ± 188.4 for musculoskeletal conditions ($N = 392$), 189.3 ± 324.8 for medicine ($N = 335$), 101.6 ± 231.4 for surgery, 109.4 ± 223.5 for urology ($N = 93$), 90.3 ± 128.7 for ophthalmology ($N = 68$), 385.6 ± 594.3 for psychiatry ($N = 61$), 150.4 + 285.9 for ENT ($N = 59$), 419.4 ± 382.6 for obstetrics and gynecology ($N = 30$), and 44.9 + 39 for dermatology ($N = 21$). Permanent suspensions were as follows: total $N = 100$ (8.1%), musculoskeletal $N = 13$ (3.3%), medicine $N = 37$ (11%), surgery $N = 10$ (5.7%), urology $N = 10$ (10.7%), ophthalmology $N = 2$ (2.9%), psychiatry $N = 20$ (32.8%), ENT $N = 1$ (1.7%), obstetrics and gynecology $N = 4$ (13.1%), and dermatology $N = 3$ (14.3%).

DISCUSSION: Musculoskeletal conditions are the most common reason for temporary loss of medical license followed by medical and surgical conditions. The least common reason was dermatological conditions. The longest period of incapacitation was associated with psychiatric conditions followed by medical and ENT conditions. The annual calculated temporary incapacitation rate was 2.8% and the permanent suspension rate was 0.25%.

KEYWORDS: return to work, pilots, temporary medical license suspension, occupational health.

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Work and working conditions have a profound effect on an individual's health.[2] Perceived job insecurity, physical exposures to dangerous conditions, but also rotating shift work can result in mental and physical conditions and deteriorating health.[2] For example, shift work and long work hours have the potential to increase the risk of injury and obesity and result in a wide range of chronic diseases.[5] In long-haul truck drivers the risk for cardiovascular and metabolic disease was 3.7 times, respectively 4.31 higher when compared to the National Health and Nutrition Examination Survey sample of the general U.S. population.[14,22]

Airline pilots work in similar conditions which involve shift-work, circadian rhythm disturbances with exposure to mild hypoxia, reduced atmospheric pressure, low humidity, noise vibration, and cosmic radiation.[3] Butler and Nicholas performed a survey of more than 10,000 active and retired pilots in the United States and Canada and reported that there is an increased risk of melanoma, motor neuron disease, and cataracts.[3] However, the authors could not demonstrate an increased risk for other diseases such as heart disease, diabetes, and high blood pressure when comparing their data to the 1995 National Health Interview Survey.[3] Evans and Radcliffe have reported annual incapacitation rates in commercial airline pilots and

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have shown that accidents, cardiovascular, and musculoskeletal conditions were the most common reasons for temporary unfitness.[8] Parker and Snyder showed that 25% of airline pilot morbidity and long-term disability occurred because of cardiovascular reasons with no correlation to age followed by 11% for orthopedic and musculoskeletal conditions.[8] Long-term disability rates in a cohort of 2271 Canadian pilots were recorded between 1981 and 1990.[1,22] The main reason for a long duration of leave of absence were mental disorders (16%), circulatory (14%) and digestive (12%) system diseases, and musculoskeletal conditions (11%).[1,22] Currently there is insufficient updated information on medical conditions resulting in temporary loss of medical license and incapacitation. The purpose of this study was to therefore report the temporary loss of medical license and pilot incapacitations in the United Arab Emirates from 2018–2021.

METHODS

This study used data from the database of the General Civil Aviation Authority (GCAA) and the following data was extracted by an aeromedical officer of the GCAA: date of license suspension and reinstatement, age, gender, and ICD-10 codes. The data was then forwarded to the first author. The authors had no access to any other information and this process effectively de-identified personal data.[4] In general, registry data studies are exempt from IRB approval and our study design is in compliance with the World Medical Association declaration of Helsinki ethical principles for medical research amended by the 64th WMA General Assembly in 2013.[19] Admittedly, the available research data could be de-identified, but the likelihood of unauthorized access to the GCAA database by a non-GCAA employee is not possible.

The GCAA is the federal regulatory body of the United Arab Emirates, overseeing all aviation-related activities in the United Arab Emirates. The GCAA CAR MED regulations outline the medical provisions for licensing pilots and cabin crew.[11] If pilots were determined to be unfit, the responsible aviation medical examiner will upload a request for suspension of the medical license onto the GCAA website.[16] Once the report is uploaded onto the GCAA website, the license will be suspended with immediate effect. For medical conditions, a medical report will also be submitted to the GCAA which includes all applicable ICD-10 codes. Similarly, for reinstatement of an aviation license, the responsible aviation medical physician will upload a request for reinstatement. This request again includes all applicable ICD-10 codes, all applicable medical reports, and detailed operation notes from the treating specialist.[16]

The following inclusion criteria were applied: license suspension for all pilots registered with the GCAA between January 2018 to October 2021, age between 18–65 yr, and availability of ICD-10 codes for all license suspensions. Pilots were excluded if they voluntarily suspended their license. If there was no date of reinstatement, pilots were considered to have lost their license permanently. Medical and surgical pathology was categorized according to the ICD-1-PCS system (ICD10Data.com) and the following categories were used: dermatology, ear-nose-throat (ENT), obstetrics and gynecology, musculoskeletal, ophthalmology, psychiatry, surgical, and urology.

Statistical Analysis

Descriptive analysis was applied to demographic data. The mean, standard deviations, ranges, and 95% confidence intervals for the time of pilot incapacitation were calculated for the total number of cases. The data was then subdivided into nine subspecialties: musculoskeletal, medicine, surgical, urology, ophthalmology, psychiatry, ENT, obstetrics and gynecology, and dermatology.

For the individual subspecialties, similar pathology and ICD-10 codes were grouped and means and standard deviations were calculated. Pilots who did not return to work and had permanent license suspensions were excluded when calculating mean and standard deviation with subgroup pooling. All analyses were conducted using STATA SE for Windows (version 12.0; StataCorp, College Station, TX, USA).

RESULTS

Between January 2018 to October 2021, a total of 1233 pilots was reported to the GCAA for medical incapacity and their license was temporarily suspended. The mean age was 46.4 ± 10.4 yr. There were 1173 male pilots with a mean age of 46.9 ± 10.3 yr and 60 female pilots with a mean age of 37.1 ± 7.7 yr. The mean days of temporary suspension were 148.4 ± 276.8 d, ranging from 1–1257 d with a 95% confidence interval between 63–98.6 d. The largest number of pilot incapacitations was reported for musculoskeletal conditions and the lowest number was reported for dermatological conditions. The longest time of incapacitation was observed for pilots with psychiatric conditions and the shortest time was reported for pilots with dermatological conditions. Of the pilots, 100 did not return to work. **Table I** summarizes the period of incapacitation for the study period.

Musculoskeletal

There was a total of 392 pilots with medical conditions (**Table II**). The mean age was 46.2 ± 9.3 yr. There were 383 men with a mean age of 46.2 ± 9.4 and 9 women with a mean age of 47.6 ± 7 yr. The most common conditions were meniscus injuries (*N* = 39 with a mean suspension of 56.8 d), lumbar spine disc prolapse (*N* = 23 with a mean suspension of 184.5 d), and shoulder impingement (*N* = 19 with a mean suspension of 121.1 d). However, the most common reason for suspension was orthopedic trauma, with a total of 131 cases. The mean time of suspension was 115.2 ± 188.4 d. There were 13 pilots who did not return to work. The reasons were related to fractures in six cases, spinal conditions in three cases, and osteoarthritic and other degenerative conditions in four cases.

Table I. Period of Temporary Incapacitation for Pilots.

	N	MEAN DAYS	SD	RANGE	95% CI	DID NOT RETURN
Musculoskeletal	392	115.2	188.4	2–1446	96.3–134.2	13
Medicine	335	189.3	324.8	58–2170	151.7–226.9	37
Surgical	174	101.6	231.4	1–2025	64.9–138.4	10
Urology	93	109.4	223.5	2–1268	27.8–131.5	10
Ophthalmology	68	90.3	128.7	2–719	58.6–121.9	2
Psychiatry	61	385.6	594.3	6–2757	195.5–575.6	20
ENT	59	150.4	285.9	1–1727	75.3–225.6	1
Obstetrics/Gynecology	30	419.4	382.6	5–1390	268–572.7	4
Dermatology	21	44.9	39.6	9–162	25.2–64.6	3
Total	1233	148.4	276.8	1–2757	63.0–98.6	100

Medicine

There was a total of 335 pilots with medical conditions (**Table III**). The mean age was 49.5 ± 9.7 yr. There were 333 men with a mean age of 49.6 ± 9.7 yr and 2 women with a mean age of 39.5 ± 4.9 yr. The most common conditions were hypertension ($N = 60$ with a mean suspension of 101.6 d), sleep apnea ($N = 28$ with a mean suspension of 173 d), angina ($N = 27$ with a mean suspension of 217.5 d), diabetes mellitus ($N = 26$ with a mean suspension of 116.9 d), and arrythmias ($N = 26$ with a mean suspension of 170.6 d). The mean time of suspension was 189.3 ± 324.8 d. A total of 37 pilots did not return to work. The reasons were related to cardiac conditions in 10 cases, pulmonological conditions in 4 cases, gastroenterological conditions in 2 cases, neurological conditions in 9 cases, infectious conditions in 1 case (malaria), malignancies in 7 cases, and endocrinological conditions in 2 cases.

Surgery

There was a total of 174 pilots with surgical conditions (**Table IV**). The mean age was 45.3 ± 9.8 yr. There were 171 men with a mean age of 45.5 ± 9.7 yr and 3 women with a mean age of 32.7 ± 5.8 yr. The most common conditions were inguinal hernia ($N = 53$ with a mean suspension of 48.4 d), appendicitis ($N = 24$ with a mean suspension of 35.8 d), and cholecystitis ($N = 17$ with a mean suspension of 120.1 d). The mean time of suspension was 101.6 ± 231.4 d. Of the 174, 10 pilots did not return to work. Two pilots did not return following appendicitis surgery and one pilot each did not return for the following conditions: aortic aneurysm, concussion, bariatric surgery, following surgery for cholecystitis, following surgery for inguinal hernia, pilonidal sinus, stricture of artery, and following thyroid surgery.

Urology

There was a total of 93 pilots with urological conditions (**Table V**). The mean age was 46.8 ± 10.5 yr. There were 90 men with a mean age of 47.1 ± 10.6 yr and 3 women with a mean age of 37.7 ± 3.1 yr. The most common conditions were kidney stones ($N = 35$ with a mean suspension of 96.6 d) and ureter stones ($N = 26$ with a mean suspension of 99.5 d). The mean time of suspension was 109.4 ± 223.5 d. A total of 10 pilots did not return to work. Five pilots were diagnosed with prostate cancer, two pilots with bladder cancer, one pilot with kidney cancer, one pilot with testicular cancer, and one pilot did not return following ureter stones.

Ophthalmology

There was a total of 68 pilots with ophthalmological conditions (**Table VI**). The mean age was 44.8 ± 13.2 yr. There were 67 men with a mean age of 45.1 ± 13.1 and 1 woman who was 23 yr old. The most common conditions were cataract surgery ($N = 14$ with a mean suspension of 136 d) and retina disorders ($N = 14$ with a mean suspension of 106.6 d). The mean time of suspension was 90.3 ± 128.7 d. Two pilots did not return to work; one following cataract surgery and one who was diagnosed with glaucoma.

Psychiatry

There was a total of 61 pilots with psychiatric conditions (**Table VII**). The mean age was 42.3 ± 11.7 yr. There were 55 men with a mean age of 43.3 ± 11.6 yr and 6 women with a mean age of 32.8 ± 8.6 yr. The most common conditions were anxiety ($N = 29$ with a mean suspension of 276.8 d) and alcohol-related causes ($N = 10$ with a mean suspension of 493.5 d). The mean time of suspension was 385.6 ± 594.3 d. There were 20 pilots who did not return to work. The most common reasons were anxiety ($N = 8$), depression ($N = 4$), and alcohol-related causes ($N = 3$).

Ear Nose and Throat (ENT)

There was a total of 59 pilots with ENT conditions (**Table VIII**). The mean age was 44.1 ± 12.1 yr. There were 56 men with a mean age of 47 ± 12.1 yr and 3 women with a mean age of 34.7 ± 11.5 yr. The most common conditions were sinusitis ($N = 15$ with a mean suspension of 41.8 d) and vertigo ($N = 12$ with a mean suspension of 135.1days). The mean time of suspension was 150.4 ± 285.9 d. One pilot did not return to work; he was diagnosed with an acoustic neuroma.

Obstetrics and Gynecology

There was a total of 30 female pilots with obstetric and gynecological conditions (**Table IX**). The mean age was 36.2 ± 4.9 yr. The most common condition was pregnancy ($N = 27$ with a mean suspension of 356.7 d) The mean time of suspension was 419.4 ± 382.6 d. Four pilots did not return to work; all were pregnant.

Table II. Period of Temporary Incapacitation for Pilots – Musculoskeletal.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Foot and Ankle			
Metatarsal Fracture	13	73.1±50.9	0
Ankle Fracture	12	64.9±54.4	1
Ankle Sprain	4	35.2±13.4	0
Tarsal Fracture	4	73.2±64.1	0
Achilles Tendon Tear	3	215±171.4	0
Syndesmosis Injury	3	22±16.6	0
Calcaneus Fracture	2	34.5±16.3	0
Hallux Valgus	2	219±42.4	0
Bunion Surgery	1	11	0
Foot Contusion	1	444	0
Nailbed Injury	1	40	0
Osteoarthritis Ankle	1	DNR	1
Toe Fracture	1	17	0
Unspecified Foot Injury	1	44	0
Unspecified Sprain	1	43	0
Arm and Elbow			
Proximal Radius Fracture	9	40±23	0
Forearm Fracture	3	417.5±482	0
Humerus Fracture	2	91±21.2	2
Triceps Tendon Tear	2	94±82	
Elbow Dislocation	1	48	0
Olecranon Bursitis	1	65	0
Olecranon Fracture	1	76	0
Pain Elbow	1	3	0
Osteoarthritis Elbow	1	283	0
Hand and Wrist			
Metacarpal Fracture	16	68.1±79.8	0
Distal Radius Fracture	11	54.5±22.8	0
Carpal Bone Fracture	9	180.1±254.2	0
Phalanx Fracture	7	49.1±24.3	0
Phalanx Dislocation	4	94±86.1	0
Crush Injury Finger	3	75±36.6	0
Nail Bed Injury	3	59.6±22	0
Tenosynovitis	3	239±286.9	0
Thumb Fracture	3	20.7±37.6	0
Carpal Dislocation	2	50±14.1	0
Dupuytren Disease	2	26.5±23.3	0
Hand Fracture	2	27±29.7	0
Nonspecified Wrist Injury	2	43.5±4.9	0
Ganglion Wrist	1	24	0
Hand Ligament Tear	1	174	0
Mallett Fracture	1	41	0
Trigger Finger	1	12	0
Wrist Pain	1	21	0
Other			
Removal of Hardware	2	17	1
Osteochondrosis	1	300	0
Other Bone Disorder	1	113	1
Hip			
Osteoarthritis	5	133.8±148.1	0
Total Joint Replacement	3	108±123.1	0
Pelvic Fracture	2	1385	1
Hip Dislocation	1	49	0
Hip Pain	1	93	0
Impingement	1	960	0
Knee			
Meniscus Injury	39	56.8±65	0
Anterior Cruciate Ligament Injury	10	134±92.7	0
Pain	6	174.7±224.3	0
Osteoarthritis	3	232.7±285.5	0
Multiligament Injury	2	81±7.1	0
Osteochondritis Dissecans	2	43	1
Effusion	1	28	0
Joint Pain	1	DNR	1
Patella Disorder	1	100	0
Patella Tendinitis	1	24	0
Posterior Cruciate Ligament	1	191	0
Prepatella Bursitis	1	104	0
Total Joint Replacement	1	33	0
Lower Extremity			
Tibial Shaft Fracture	7	137.6±164.7	0
Tibial Plateau Fracture	6	104.5±43.5	0
Femur Fracture	4	463±267.5	0
Stress Fracture	4	80.2±10.1	0
Muscle Tear	2	14.5±9.2	0
Osteoarthritis	2	82.5±2.1	0
Other Leg Fracture	2	216.5±280.7	0
Surgical Complications	1	147	0
Shoulder			
Impingement	19	121.1±246.2	0
Clavicle Fracture	13	62±64.7	0
Proximal Humerus Fracture	9	59.1±41.7	0
Rotator Cuff Tear	7	296.4±507.2	0
SLAP Lesion	7	68.7±33.3	0
Dislocation	6	121.7±167.6	0
ACJ Dislocation	4	113.5±128.3	0
Calcific Tendinitis	2	219±260.2	0
Bone Cyst Humerus	1	67	0
Other	1	92	0
Scapula Fracture	1	22	0
Spine			
Lumbar Spine Disc Prolapse	23	184.5±239.9	0
Low Back Pain	12	173.2±253.7	1
Cervical Radiculopathy	7	54.7±40.8	0
Cervical Myelopathy	6	179.8±155.8	1
Lumbar Spine Fracture	5	152.5±161.3	1
Cervical Disc Prolapse	2	54±11.3	0
Sciatica	2	22.5±9.2	0
Thoracic Spine Pain	2	705±865.5	0
Ankylosing Spondylitis	1	70	0
Cervical Disk Replacement	1	57	0
Lumbar Spine Radiculopathy	1	47	0
Sacroiliitis	1	25	0
Spondylolisthesis	1	76	0
Torticollis	1	DNR	1
Total	392	--	13

DNR: did not return.

Dermatology

There was a total of 21 pilots with dermatological conditions (**Table X**). The mean age was 46.3 ± 10.6 yr. There were 20 men with a mean age of 47 ± 10.5 and 1 woman who was 34 yr old. The most common conditions were melanoma (N = 10) and psoriasis (N = 2). The mean time of suspension was

Table III. Period of Temporary Incapacitation for Pilots – Medicine.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Cardiology			
Hypertension	60	101.6±222.4	1
Angina	27	217.5±349.9	2
Arrythmia	26	170.6±189.4	1
Syncope	14	232.6±253	2
Myocardial Infarction	4	207.5±61.5	2
Atrial Septal Defect	3	451.5±453.2	1
Intracardiac Thrombosis	3	148±123.2	0
Atrial Fibrillation	2	442.5±458.9	0
Cardiac Stenting	2	516.5±338.7	0
Unstable Angina	2	641.5±649.8	0
Abnormal Cardiovascular Function	1	DNR	1
AV Malformation	1	127	0
Cardiac Valve Disorder	1	DNR	1
Ischemic Heart Disease	1	218	0
Pulmonology			
Sleep Apnea	28	173±428.3	1
Pulmonary Embolus	8	138.2±52.8	2
Covid	7	26.6±33.5	0
Upper Respiratory Infection	3	22.7±11.7	0
Asthma	2	43±7.1	0
Pneumothorax	2	45±7.1	0
Abnormalities of Breathing	1	DNR	1
Cough	1	66	0
Other Lung Disorders	1	415	0
Pleuritis	1	DNR	0
Pneumonia	1	2170	0
Shortness of Breath	1	751	0
Gastroenterology			
Crohn's Disease	5	112.4±65.1	0
Ulcerative Colitis	3	87±54.3	0
Abnormal Liver Function	2	56	1
Acute Pancreatitis	2	9±5.65	0
Gastritis	2	151±188.1	0
Irritable Bowel Syndrome	2	303.5±33.2	0
Reflux	2	159.5±166.2	0
Diarrhea	1	783	0
Nausea/Vomiting	1	DNR	1
Pyloric Stenosis	1	20	0
Neurology			
Dizziness	9	156.1±145.1	1
Migraine	3	164	2
TIA	3	271	2
Cognitive Impairment	2	259	1
Bell's Palsy	1	DNR	1
Brain Disorder Unspecified	1	548	0
Caisson's Disease	1	53	0
Dementia	1	15	0
Headaches	1	DNR	1
Multiple Sclerosis	1	281	0
Parkinson	1	517	0
Pituitary Adenoma	1	334	0
Stroke	1	DNR	1
Trigeminal Neuralgia	1	869	0
Infections			
Amoebiasis	2	16.5±4.11	0
Unclear Fever	2	36±12.7	0
Fever Unknown Origin	1	23	0
Leishmania	1	28	0
Lyme Disease	1	803	0
Malaria	1	1354	1
Mononucleosis	1	46	0
Syphilis	1	1	0
Tuberculosis	1	245	0
Oncology			
Colon Cancer	4	580	3
Lymphoma	3	22±29.7	1
Leukemia	2	614±796.2	0
Benign Myocardial Neoplasm	1	2167	0
Esophagus Cancer	1	DNR	1
Hodgkins Lymphoma	1	DNR	1
Lung Cancer	1	DNR	1
Endocrinology/ Rheumatology			
Diabetes	26	116.9±208.9	1
Thyrotoxicosis	6	122.3±128.8	0
Iron Deficiency	5	83±134.8	0
Gout	3	47.5±26.2	1
Hypothyroidism	3	77±124.7	0
Inflammatory Arthropathy	3	257.7±289.8	0
Rheumatoid Arthritis	2	53.5±45.9	0
Enteropathic Arthropathy	1	830	0
Hashimoto's	1	13	0
Osteoporosis	1	20	0
Vitamin Deficiency	1	281	0
Nephrology			
Kidney Failure	3	191.3±145.8	0
Proteinuria	1	22	0
Other			
Thrombocytopenia	2	79±2.8	0
Deep Vein Thrombosis	1	340	0
Unspecified	1	DNR	1
Total	335	–	37

DNR: did not return.

44.9 ± 39.6 d. Three pilots did not return to work; two were diagnosed with melanoma and one pilot had other causes (not specified in the database).

DISCUSSION

The results of this database study revealed a total of 1133 temporary and 100 permanent license suspensions over a 4-yr period in the United Arab Emirates. This equates to an annual average of 283 temporary and 25 permanent license suspensions. In 2022 approximately 10,000 pilots were employed by the 4 major commercial airlines in the United Arab Emirates. This brings the annual temporary incapacitation rate to 2.8% and the permanent suspension rate to 0.25%. Evans and Radcliffe[8] reported an annual temporary incapacitation rate of 4.3%, which is slightly higher. However, the 1.5% difference is probably not significant and within the normal margin of statistical error. It should be noted that Evans and Radcliffe[8] also included in-flight medical events, which was not captured by our data.

Table IV. Period of Temporary Incapacitation for Pilots – Surgery.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Hernia Inguinal	53	48.4±95.4	1
Appendicitis	24	35.8±77.9	2
Cholecystitis	17	120.1±200.2	1
Hemorrhoids	12	202.7±350.2	0
Hernia Umbilical	12	56.6±95.4	0
Anal Fistula	5	86±83.9	0
Diverticulitis	4	64.5±56.4	0
Pilonidal Sinus	4	35.7±28.3	1
Post-Surgical Procedure	4	24.7±12.9	0
Rib Fracture	4	99.2±112.8	0
Thyroid Surgery	4	734.3±1119.6	1
Head Injury	3	247±189.7	0
Phlebitis	3	52.7±26.4	0
Aspiration for Complication	2	133±63.3	0
Concussion	2	28	1
Anal Cancer	1	26	0
Aortic Aneurysm	1	DNR	1
Bariatric Surgery	1	DNR	1
Breast Hypertrophy	1	8	0
Cellulitis	1	76	0
Complication from Procedure	1	13	0
Disease Intestine	1	55	0
Dog Bite	1	24	0
Hernia Diaphragmatic	1	50	0
Intussusception	1	18	0
Mandible Fracture	1	42	0
Necrotizing Fasciitis	1	1002	0
Neoplasm Aortic Body	1	204	0
Obesity	1	455	0
Occipital Condyle Fracture	1	92	0
Post GIT Surgery	1	574	0
Post Procedure Hypothyroidism	1	41	0
Right Quadrant Pain	1	7	0
Scalp Laceration	1	7	0
Stricture of Artery	1	DNR	1
Varicose Veins	1	4	0
Total	174	–	10

DNR: did not return.

Table V. Period of Temporary Incapacitation for Pilots – Urology.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Kidney Stones	35	96.6±183.7	0
Ureter Stones	26	99.5±216.8	1
Prostate Cancer	7	69±29.7	5
Renal Colic	6	155.7±214.7	0
Bladder Disorder	3	203.7±320.8	0
Bladder Cancer	2	DNR	2
Circumcision	2	18±4.2	0
Haematuria	2	24.5±3.5	0
Prostate Hypertrophy	2	28±29.7	0
Testes Disorder	2	17±4.2	0
Kidney Cancer	1	DNR	1
Other RENAL Disorder	1	1268	0
Scrotal Varices	1	42	0
Testicular Cancer	1	DNR	1
Urethral Stricture	1	70	0
Urine Retention	1	58	0
Total	93	–	10

DNR: did not return.

Accurate planning and flight scheduling is important for any commercial airline and these figures will be helpful to plan and roster pilots and consider temporary license suspensions. Another important factor is cost. We have previously shown that a dedicated musculoskeletal rehabilitation unit results in significant cost savings and earlier return to work.[16] When using the figures from our publication, the calculated cost for each day of temporary grounding is calculated to $1500 per day excluding the costs for medical treatment. These figures will be helpful for financial planning.[16]

Musculoskeletal conditions were the most common reasons for temporary medical license suspension, with a mean period of 115 d. Of the total 392 cases, 83% were related to trauma; 152 cases were related to fractures, and 92 cases to joint dislocations and ligament injuries. Obviously, pilots have to maintain fitness and are engaged in athletic activities that possibly account for the relatively high number of traumatic injuries in this population group. The annual incidence for traumatic injuries for aircrew has previously been reported to be 73–81 per 100,000 population for women and 24–100 per 100.000 population for men.[24] Previously, Hohmann et al. have shown that a dedicated musculoskeletal rehabilitation unit reduced the time to return to flying by 39% from a mean of 188 to 85 d.[16] Applying the findings of Hohmann et al.[16] to this study, it is possible that return to flying for musculoskeletal conditions could be reduced to 70 d, resulting in significant cost savings.

The second most common reason for temporary incapacitation was medical illnesses. However, of the 335 cases, 44% were related to cardiac disease such as arrythmias (29%), angina (24%), and hypertension (41%). The incidence of cardiac related disease is moderately higher than in the normal population. Hemingway et al. reported a 2.03 incidence for men and 1.89 in women per 100 population.[15] Annual medical license examinations in pilots are a possible cause for these discrepancies, as it can be expected that quiet cardiac disease will be detected, resulting in further tests and temporary suspension. The least common reasons were dermatological conditions. Of the 21 cases, 10 were related to melanoma and 2 pilots (20%) did not return to work. This is consistent with the current published literature [27] and the results of this database study confirm a higher risk for pilots. A total of 59 cases were related to ENT conditions; 34% were caused by acute infections such as sinusitis, tonsilitis, and otitis. Evans and Radcliffe have reported annual incapacitation rates in pilots and noted that 6% of all medical incapacitations were associated with ENT conditions.[8] The findings in our study were similar. In our study cohort nearly 5% of temporary suspensions were correlated to ENT conditions.

A total of 174 cases of temporary incapacitation were pertaining to surgical pathologies: 30% were related to inguinal hernia repairs, 14% to appendicitis, and 10% to cholecystitis.

Table VI. Period of Temporary Incapacitation for Pilots – Ophthalmology.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Cataract	14	136±207.5	1
Retina Disorder	14	106.6±151.3	0
Myopia	9	45.7±25.3	0
Visual Disorder	5	96±37.9	0
Keratoconus	4	86.7±19.6	0
Chorioretinopathy	3	135.7±97	0
Refractive Disorder	3	47.6±1.5	0
Conjunctivitis	2	27±26.9	0
Pterygium	2	23±5.6	0
6th Nerve Palsy	1	509	0
Diplopia	1	122	0
Glaucoma	1	DNR	1
Irregular Eye Movement	1	9	0
Keratitis	1	74	0
Lens Implant	1	73	0
Low Vision	1	32	0
Oculomotor Nerve Injury	1	8	0
Orbital Floor Fracture	1	50	0
Panuveitis	1	49	0
Viral Infection	1	63	0
Vitreoretinal Disorder	1	69	0
Total	68	–	2

DNR: did not return.

Inguinal hernia repairs are performed at a rate of 240 episodes per 100,000 population in the United Kingdom[20] and the all ages incidence has been reported to be 13 per 10,000 population.[26] The annual incidence of appendicitis ranges between 7–10%.[9] The incidence of cholecystitis among people with gallstones are unknown, but of patients admitted to hospital for biliary disease, 20% have acute cholecystitis.[10] The findings in this study are in accordance with the published literature and do not suggest an increased prevalence in pilots.

Ninety-three pilots (7.5%) were temporarily suspended for urological conditions. The most common reasons were renal (38%) and ureter stones (28%). Evans et al. reported a slightly lower rate of 4% for genitourinary-related causes.[8] The percentage of urolithiasis in our study cohort was 5.1%. These figures are similar to previously reported data. Hyams et al. demonstrated that 3.7–4.6% of commercial aviation pilots were diagnosed with urolithiasis.[17] Masterson et al. [21] showed that the prevalence in Navy pilots is 2.4% and Lang et al. [18] analyzed data from the Global Burden of Disease database that the incidence of urolithiasis in the normal population was 1.4%. The available data suggests that pilots probably have a higher risk of genitourinary renal and ureter stones. These differences are possibly caused by the low humidity levels in the airplane cabin, resulting in hypohydration.[31] Another contributing factor is that pilots possibly minimize fluid intake during flight to reduce the need for micturition. This may be more prevalent since the introduction of locked flightdeck doors, making it more difficult to easily access the toilet. It will be interesting whether future studies will show an increase in renal disease in pilots.

Sixty-eight pilots were temporarily suspended for ophthalmological conditions. Cataract surgery (20%) and retina disorders (20%) were the most common causes for ophthalmological conditions; a total of 68 cases were recorded. Evans and Radcliffe[8] reported that 2% of temporary medical unfitness was associated with ophthalmological disorders. Temporary medical license suspension for ophthalmological disorders was significantly higher in our sample and reached 5.5% of all cases. The mean age of pilots in this group was 44.8 ± 13.2 yr compared to 47 yr in Evan and Radcliffe's cohort. Risk factors for cataract are age, smoking, long-term use of steroids and other medications, exposure to ultra-violet radiation, diabetes, trauma, hypertension, and radiation therapy.[6] One could safely assume that these risk factors are similarly distributed between Evan and Radcliffe's study cohort and the study group of this research with the exception of exposure to ultra-violet radiation. In the United Kingdom the average hours of annual sunshine are 1400 compared to 3000 h in the United Arab Emirates.[29] The substantial difference between the United Kingdom and United Arab Emirates could possibly explain the higher incidence of cataracts.

Table VII. Period of Temporary Incapacitation for Pilots – Psychiatry.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Anxiety	29	276.8±333.3	8
Alcohol	10	493.5±1108.9	3
Depression	8	832±988.9	4
Stress	6	537±528.9	1
Counseling	5	170.7±90	2
ADHD	1	DNR	1
Bipolar Disorder	1	DNR	1
Strange Behavior	1	296	0
Total	61	–	20

DNR: did not return.

Table VIII. Period of Temporary Incapacitation for Pilots – ENT.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Sinusitis	15	41.8±61.4	0
Vertigo	12	135.1±152.5	0
Eustachian Tube Disorder	4	10.2±3.6	0
Sinus Polyps	4	15.5±9.9	0
Sudden Hearing Loss	4	524.25±814.7	0
Vestibular Neuritis	3	533.7±325.3	0
Acoustic Neuroma	2	276	1
Hypertrophic Nasal Turbinates	2	17.5±6.4	0
Maxillary Sinusitis	2	306±490.7	0
Other Nasal Disorders	2	20±12.6	0
Cholesteatoma	1	46	0
Condition of Glottis	1	486	0
Condition of Hard Palate	1	297	0
Condition of Larynx	1	80	0
Meniere's Disease	1	564	0
Otitis Media	1	2	0
Benign Salivary Gland Tumor	1	16	0
Tonsillitis (Acute)	1	7	0
Tonsillitis (Chronic)	1	7	0
Total	59	–	1

Table IX. Period of Temporary Incapacitation for Pilots – Obstetrics and Gynecology.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Pregnancy	27	356.7±497.2	4
Endometriosis	1	14	0
Salpingitis	1	5	0
Uterus Myoma	1	9	0
Total	30		4

There were 61 pilots who were temporarily suspended for psychiatric and mental health issues. The most common causes were anxiety (47%) and alcohol disease (16%) followed by depression (13%). The mean days of suspension was the highest, with 493 d for alcohol-related disorders and 832 d for depression. In addition, the rate of permanent loss of license in this group was the highest of all subgroups, reaching 33%. Wu et al. performed an anonymous survey and showed that depressive and mental health disorders are higher when compared to the normal population, but similar to those found in other high stress occupations.[30]

Although only 30 cases were associated with obstetric and gynecological conditions, this cohort had the longest mean days for license suspension and the second highest rate of permanent loss of license. However, of the 30 cases, 27 pilots were incapacitated because of pregnancy. It could therefore be concluded that gynecological disease does not play a role in temporary license suspensions in female pilots.

Ascertainment of medical causes for temporary license suspensions is important and highlights medical risks that require the most attention but will also aid in determining possible future changes to medical requirements.[8] Previous studies have reported morbidity among airline pilots. Parker et al. showed that cardiac conditions accounted for 25% and musculoskeletal cases for 11% of disability.[25] Sykes et al. reported that of 595 pilots in New Zealand, kidney disease was observed in 3.3% and melanoma in 1.9%.[28] Nicholas et al. surveyed over 10,000 airline pilots for self-reported disease and established that the most common causes for disease were melanoma, motor neuron disease, and cataracts.[23] Evans and Radcliffe[8] documented the annual incapacitation rate in pilots. In their series of over 700 patients, accidents accounted for 18%, musculoskeletal for 18%, cardiovascular events for 14%, and psychiatric diseases for 10% of the annual rates.[8] The incapacitation rates from these studies are similar to the results from our study, showing that musculoskeletal and cardiac-related conditions account for the majority of temporary medical unfitness in commercial pilots. Pilots reporting sick or unable to return to flying duties can affect the ability of an airline to ensure a manageable roster. Typically, reserve cover and pilots on standby allow adequate coverage for these scenarios. For routine rostering and planning, the incidence of temporary medical incapacitation, knowledge about the expected mean duration of medical unfitness, and subsequent return to work is helpful. The goal of database studies is to provide information for data-driven strategies and the data reported in this study may be valuable for airlines in planning for and including expected sickness rates for pilots. This is in agreement with Evans and Radcliffe, who noted a lack of data when studying commercial pilot incapacitation rates.[8]

Table X. Period of Temporary Incapacitation for Pilots – Dermatology.

	N	MEAN DAYS & SD OF LICENSE SUSPENSION	DID NOT RETURN
Melanoma	10	43±50.6	2
Psoriasis	2	45±8.5	0
Acne	1	106	0
Allergy	1	47	0
Dermatitis	1	35	0
Lipoma	1	72	0
Sebaceous Cyst	1	15	0
Squamous Cell Carcinoma	1	12	0
Vasculitis	1	76	0
Herpes Zoster	1	12	0
Other	1	DNR	1
Total	21		3

DNR: did not return.

This study has limitations. It is limited by the fact that it only included episodes of incapacitation resulting in temporary suspension of both medical and flying license. It is possible that pilots did not report minor injuries and illness and continued with their duty despite a compulsory reporting requirement. As such, the real rate of illness and injury may have been underreported. The period of incapacitation was defined as the time from license suspension by the regulatory authority to the time of license reinstatement. It is possible that operational and other reasons have caused delayed reporting of incapacitation and also a delay in requesting license reinstatement to the regulatory authority, causing inaccurate data. However, this is a limitation of any database study, which may vary in the degree of detail and accuracy.[13] In contrast, database studies are considered to be representative of the population of interest and serve as an inexpensive source of reliable data.[13] The established criteria for return to work and reinstatement of the return to flight privileges was based on the regulations of the local regulatory body[12] and other regulatory authorities[7,12] may have different functional criteria. This limits the external validity of this study. It is possible that the ICD-10 categorization of pathology by the treating physician was incorrect, over- or underinflating certain diagnoses. In addition, it is also possible that we have incorrectly categorized reported ICD-10 codes.

In conclusion, this database study showed that musculoskeletal conditions are the most common reasons for temporary loss of medical license, followed by medical and surgical conditions. The least common reason was dermatological conditions. The longest period of incapacitation was associated with psychiatric conditions followed by medical and ENT conditions. The annual calculated temporary incapacitation rate was 2.8% and the permanent suspension rate was 0.25%. The results of this study may help in understanding the reasons for temporary pilot incapacitations related to medical conditions and possibly aid with rostering and return to work planning.

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Extended Reality Applications for Space Health

Mahdi Ebnali; Phani Paladugu; Christian Miccile; Sandra Hyunsoo Park; Barbara Burian; Steven Yule; Roger D. Dias

INTRODUCTION: Spaceflight has detrimental effects on human health, imposing significant and unique risks to crewmembers due to physiological adaptations, exposure to physical and psychological stressors, and limited capabilities to provide medical care. Previous research has proposed and evaluated several strategies to support and mitigate the risks related to astronauts' health and medical exploration capabilities. Among these, extended reality (XR) technologies, including augmented reality (AR), virtual reality (VR), and mixed reality (MR) have increasingly been adopted for training, real-time clinical, and operational support in both terrestrial and aerospace settings, and only a few studies have reported research results on the applications of XR technologies for improving space health. This study aims to systematically review the scientific literature that has explored the application of XR technologies in the space health field. We also discuss the methodological and design characteristics of the existing studies in this realm, informing future research and development efforts on applying XR technologies to improve space health and enhance crew safety and performance.

KEYWORDS: space health, space medicine, extended reality, augmented reality, virtual reality, mixed reality, immersive technology.

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For over 60 yr of human space exploration, the National Aeronautics and Space Administration (NASA) and other space agencies have shown a growing interest and dedicated tremendous effort to advancing the space exploration field. Keeping astronauts safe and healthy throughout missions has been a major area of focus since the earliest days of space exploration.[29] These goals are even more critical when considering the recent global efforts of governmental agencies and private companies to enable commercial spaceflights for non-astronaut travelers. Understanding the effects of spaceflight on human physiology and developing mitigation strategies to protect space travelers' health is crucial as future missions move beyond low Earth orbit to lunar explorations and into deep space destinations.[19]

The space environment imposes unique physical and psychological challenges for crewmembers, affecting their performance during routine activities in space, and creating unprecedented levels of health-threatening hazards and potential accidents.[11] An extensive body of literature has already shown that long-term exposure to microgravity conditions significantly affects spatial orientation, sensorimotor coordination, and neurophysiological adaptive responses.[7,45] Previous studies have also reported deleterious psychological effects of isolation and confinement during space missions. Furthermore, delays and disruptions in the communication between mission control and the spacecraft can create additional challenges to crewmembers,[26,48] especially during medical events, compromising crew health and capacity and posing a significant risk to mission success.[6,42]

Previous research has proposed and evaluated several strategies to support and mitigate the inherent risks related to space health and medical exploration capabilities. Effective clinical tools and medical training have been identified as critical requirements for space explorations,[21] especially for long-duration missions. The NASA human research roadmap identifies critical gaps in current knowledge in the areas of medical decision-making and crew clinical skills required to enable extended missions and/or autonomous operations.[1,31] Several researchers are investigating different types of interventions, including clinical decision support systems and

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medical training to support astronauts during medical event management.[42] High-fidelity simulation, for example, has emerged as an effective methodology for educating, practicing, and evaluating team performance in aviation, spaceflight, and medicine.[25] However, the physical nature of simulation and associated expertise and equipment required to run real-time training programs limits scalability and portability. More deployable and scalable solutions are required to train and maintain clinical competency in operational settings, particularly in remote and resource-constrained environments such as space.

Extended reality (XR) technologies have increasingly been adopted for training and operational support in both terrestrial[30,33] and space settings,[35,44] and a growing number of studies have shown the potential for space crews to enhance their operational and behavioral skills using these immersive technologies.[24,35,44] XR refers to a wide range of technology that blends the physical and the digital worlds in a reality-virtuality continuum. Experiences in which graphics are overlaid onto video streams of the physical world are defined as augmented reality (AR), and experiences that present a fully digital experience are known as virtual reality (VR). Mixed reality (MR) covers experiences between these two extremes.[2]

Research addressing the use of XR for space health applications is relatively scarce; however, a few promising preliminary findings have been reported in the past decades on the utility and effectiveness of XR technologies for promoting space health. The aim of the present study was to systematically review the scientific literature and describe how XR technologies, including AR, VR, and MR, have been applied to the space health field. Additionally, we will discuss the methodological and design characteristics of the existing studies in this realm, informing future research and development efforts on applying XR technologies to improve space health and enhance crew safety from low Earth orbit, through lunar explorations, to deep space missions such as Mars.

METHODS

This study was carried out according to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines.[38]

Data Source

In May 2021, a literature search was conducted within the following databases for studies published between January 1900 and June 2021: MEDLINE (PubMed), the IEEE Xplore Digital Library, the Association for Computing Machinery (ACM) Digital Library, PsycINFO (Ovid), EMBASE, and the Web of Science Core Collection.

Search Strategy

We developed a comprehensive search strategy to retrieve all studies with a focus on XR technologies in the space health domain. We adapted the Medical Subject Headings (MeSH) terms and keywords from our MEDLINE search strategy to the other databases according to the specific syntax required for each database. No database filters were used and the search query was applied to both title and abstract. To ensure literature saturation, we also hand-searched the reference list of all included articles for other potential inclusions. We used the following search query: (astronauts OR "space flight" OR "space research" OR spacecraft OR "extraterrestrial environment" OR "extravehicular activity" OR hypogravity OR moon OR mars OR astronaut* OR cosmonaut* OR orbit* OR gravity* OR microgravity* OR "space mission" OR "space exploration") AND ("virtual reality" OR "augmented reality" OR "extended reality" OR "mixed reality" OR immersive).

Eligibility Criteria and Selection Process

Only peer-reviewed original studies were included. We excluded studies that were not peer-reviewed original full manuscripts, not space-related, not healthcare-related, not XR-related, and not in English. All studies retrieved by the search strategy were imported into a web-based systematic review management platform (Covidence). Using the Covidence platform and in pairs, four researchers independently screened titles and abstracts based on the eligibility criteria. In case of disagreement, another researcher made the final decision. Subsequently, the same four researchers read and screened full-text articles for inclusion/exclusion, and another researcher solved disagreements. The PRISMA flow diagram showing screening and selection results is shown in **Fig. 1**.

Data Extraction

A data extraction form was designed in the Covidence platform and three independent researchers extracted data, in pairs, from eligible studies. A fourth researcher compared the data extracted from each pair and solved disagreements. If necessary, a fifth researcher was consulted. The Covidence dataset was extracted in CSV format to allow descriptive data analysis. The following fields were extracted from all the studies: title, methods, study design, sex and age of participants, the total number of participants, type of participants, medical specialty, clinical condition, study setting, XR modality, primary purpose, design features, addressed issues and limitations of XR tools, usefulness and usability measures assessment, type of XR device, technology acceptance assessments, objective, and subjective assessment metrics.

Data Synthesis and Quality Assessment

We conducted a qualitative narrative synthesis of all included studies, providing a descriptive analysis based on study design and setting, population, type of medical condition and specialty, type of XR technology, and measurements. Four independent researchers, in pairs, evaluated the methodological quality of all the studies using the validated Medical Education Research Study Quality Instrument (MERSQI),[10] which is a 10-item instrument that assesses 6 domains of research quality (study design, sampling, data type, validity of assessments, data analysis, and outcomes). Each domain

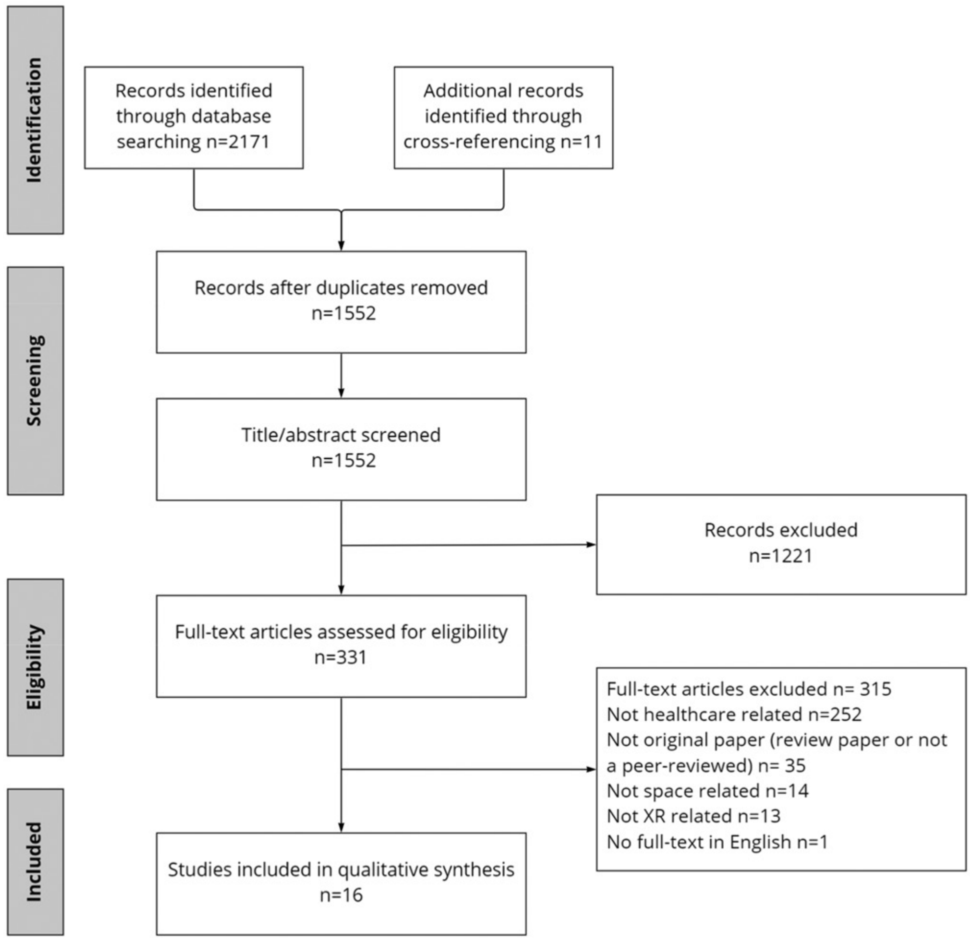

Fig. 1. PRISMA flow diagram.

receives a score from 0 to 3 for a maximum total score of 18. We calculated and reported the mean MERSQI score, based on the two authors' individual ratings, for each included study, as well as the mean and standard deviation MERSQI score among the studies.

RESULTS

A total of 2182 studies were imported for screening and 630 duplicates were removed. We screened 1552 studies based on title and abstract, from which 331 were assessed for eligibility based on the full text. After the full-text screening, 315 studies were excluded and a total of 16 studies were included in the final systematic review. **Fig. 2** shows the distribution of the studies based on the date of publication.

Study Design and Setting

Four studies (25%) were pre/post-test, four (25%) case report or descriptive, three (19%) cohort, two (13%) randomized control trials, one (6%) nonrandomized control trial, one (6%) cross-sectional, and one (6%) qualitative study. All studies (N = 16, 100%) were conducted in simulated settings and no study was conducted in a real space environment. Among the simulation-based studies, 10 studies (62.5%) performed their experiments in an intravehicle setting, 4 studies (25%) explored an extravehicle setting, and 6 studies (37.5%) included microgravity simulations.

Population

While three studies did not mention participants, the remaining 13 studies included in aggregation a total of 777 participants, representing astronauts, clinicians, engineers, and students. More specifically, the participants were: physicians in five studies (31%), engineers in four studies (25%), astronauts in two studies (12.5%), flight surgeons in two studies (12.5%), other healthcare professionals in two studies (12.5%), other healthcare students in two studies (12.5%), and medical students in one study (6.2%). Moreover, most of the studies (N = 11, 68.8%) included other types of participants such as analog astronauts, family members of astronauts, master students, and nonspecified students.

Medical Conditions

Medical specialties were classified into two main groups: surgical and nonsurgical. The majority of studies developed and/or evaluated XR technologies involving nonsurgical specialties (N = 12, 79%) and only 4 studies (25%) evaluated XR

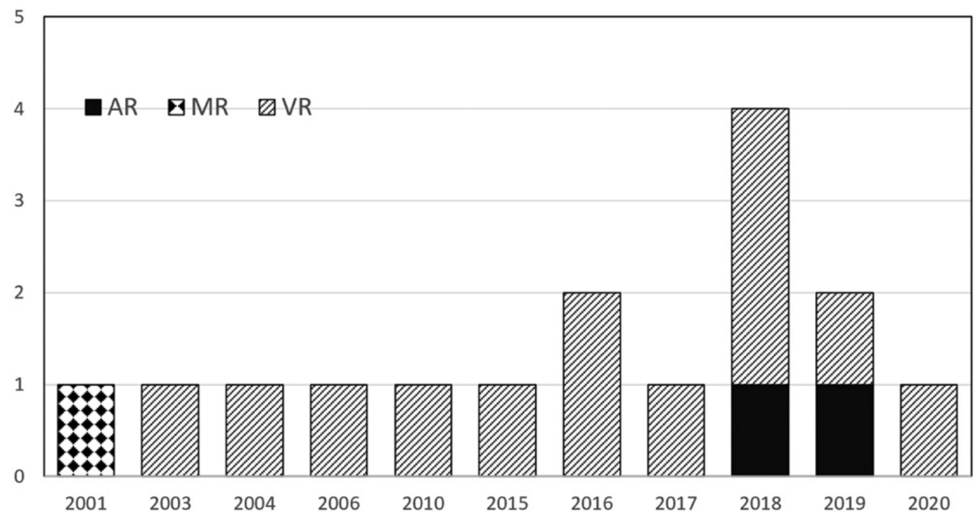

Fig. 2. Number of studies by year of publication, grouped by type of XR tools (VR, AR, and MR).

applications in surgical specialties. The nonsurgical specialties were: three (25%) in Neurology, three (25%) in Rehabilitation Medicine, two (15.6%) in Radiology, two (15.6%) in Emergency Medicine, and two (15.6%) in Psychiatry. **Table I** and **Table II** also show the details of the studies separated based on surgical and nonsurgical applications.

XR Technology

Among all included papers, 13 studies (81.2%) used VR technology, two studies (12.5%) used AR, and one study (6.2%) reported an MR application.

Hardware. Based on the technological embodiment continuum proposed by Flavián et al.,[16] as shown in **Table III**, we categorized XR hardware used in these studies into four groups: stationary external devices (e.g., desktops, fixed displays), portable external devices (e.g., smartphones), wearable devices (e.g., HDM), and implanted devices (e.g., microchips or smart contact lenses).

Table IV also shows the types of XR devices used in the studies. Most studies used either PC/projector tools or custom VR environments. Oculus Rift and Microsoft HoloLens were the only two commercially available tools used in these studies.

Measurements

We extracted the type of measures these studies used to evaluate XR applications. The measures were categorized in the following domains:[5]

1. Self-report: Out of 16 studies, 9 (56.2%) used various types of self-reported tools, including the orientation preference questionnaire,[8,9] system usability score (SUS),[28] simulator sickness questionnaire,[8,47] usability interview,[28] usability structured questionnaire,[29] trainer's rating of instructional design method,[28] NASA Task Load Index (TLX),[15,17] Short Stress State Questionnaire,[15] social connectedness and satisfaction questionnaire,[17,46] and expert scoring questionnaire.[29]
2. Observation-based: Task performance also was measured in two studies[15,34] using observational methods. They focused on performance accuracy and time until completion of a task. In one study also, the reviewers measured the number of VR-based laparoscopic tasks that were successfully completed and the percentage of task attempts.[39]
3. Knowledge tests: Only two studies (12.5%) used knowledge tests as a metric to evaluate the effectiveness of an intervention. Finseth et al. used a written quiz for wayfinding and emergency response abilities of users as a result of a VR-based intervention for spaceflight hazard training during a graduated stress exposure condition.[15] Limbu et al. also evaluated users' knowledge after practicing with a sensor-based AR system designed for aircraft maintenance, medical imaging, and astronaut training.[29]
4. Motion-Kinematic: a wide range of metrics associated with human motion and kinematics was used to evaluate the effectiveness of XR applications or to modify and customize the applications: hand movement,[3,27] waist trajectories,[27] torso alignment and force transducer data,[20] path length,[39] knee extension and joint motion velocity,[47] stride length and step length symmetry,[14] center of pressure, body angle, and orientation.[9] For example, the hands' position and motion were measured using magnetic trackers and sensor gloves to evaluate a surgical simulator developed for astronaut training.[3]
5. Physiological data: In general, only three studies (18.8%) used physiological metrics, including EEG,[27,47] heart rate variability, and blood pressure.[15]
6. System-related data: Although we only included studies that collected data from human participants, a few studies also reported on metrics associated with system performance, which can directly or indirectly affect the human experience in using XR applications. Barnes et al. used software features such as integration accuracy and update rate to discuss the feasibility of implementation of a surgical training system for astronauts.[3] Other studies[12,20] involved measurement of

Table I. Summary of the Studies Included in This Review With a Focus on XR-Based Surgical Applications.

REF (YEAR)	NO. PARTICIPANTS	STUDY DESIGN	XR TECHNOLOGY	MEDICAL SPECIALTY	CLINICAL CONDITION	SETTING	ASSESSMENT METRICS	MERSQI	PRIMARY PURPOSE
Ross[43] (2001)	Not reported	Case report—descriptive	MR/PC-Monitor	Surgical	Elective/Chronic	Spacecraft	Not reported	9.5	Telemedicine
Barnes et al.[3] (2003)	Not reported	Case report—descriptive	VR/PC-Monitor	Surgical	Elective/Chronic	Other	Kinematics/Others	6.6	Clinical training/telemedicine
Harnett et al.[20] (2004)	20	Case report—descriptive	VR/VR laparoscopy simulator	Surgical	Not specified	Microgravity	Observation based/Kinematics/Others	8	Clinical training/telemedicine
Panait et al.[39] (2008)	14	Pre-test/post-test	VR/VR laparoscopy simulator	Surgical	Elective/Chronic	Microgravity	Observation-based/Kinematics/Others	10.75	Usability/human factors

system execution time (surgery time), video streaming rate, video recording time, and system latency to evaluate an XR-based data collection system for human performance.

Primary Purpose of Space Health XR Applications

1. Usability: The primary purpose of most of the studies ($N = 10$, 62.5%) was usability evaluation of XR applications in which they tested usability aspects of nine VR interventions and one AR intervention.
2. Virtual diagnosis/therapeutics: Seven studies (43.8%) also evaluated XR applications with a focus on virtual diagnosis/therapeutic aspects such as motion sickness and physiological adaptations to microgravity[9,12,14] and stress/isolation management.[15,17,46] All of the virtual diagnosis/therapeutic applications were evaluated in VR setups.
3. Medical training: Six studies (37.5%) performed research on evaluating XR applications as clinical training tools using VR[3,20,37] and AR.[9,12,29]
4. Telemedicine: Telemedicine was the main purpose of four studies (25%); one of these studies used MR[43] and three studies used VR[3,17,37] in their experiments.

Methodological Quality

The mean (SD) total MERSQI score of the studies was 9.36 (2.7) out of 18, ranging from 3.5 to 13.2. The average MERSQI scores for individual studies are listed in Table I and Table II.

DISCUSSION

This study provides a systematic review of the literature regarding the application of XR-based space health technologies, distilling evidence from a wide range of interventions, type of XR technology, medical conditions, application purposes, experimental setups, and assessment metrics. We identified 16 articles reporting the use of XR technologies in space-health applications which were all conducted in simulated scenarios. Practical methodological limitations were found in the studies which relied on small sample size and weak study designs, adversely influencing the consistency and quality of the studies' conclusions. Additionally, the low MERSQI scores across all studies demonstrate the overall poor quality of the evaluation methods used. In the following sections, we discuss the main findings, strengths, and limitations of the studies and outline suggested directions for future research and development of XR applications for space health.

Participants

Various types of participants, including physicians, engineers, astronauts, flight surgeons, and students, were recruited in the studies. However, only two studies included astronauts as research subjects. The findings from these studies are still useful since more non-astronaut travelers are expected to participate in space explorations. Future studies should investigate how design considerations of space health XR applications need to be tailored for specific types of space travelers.

Table II. Summary of the Studies Included in This Review With a Focus on XR-Based Nonsurgical Applications.

REF (YEAR)	NO. PARTICIPANTS	STUDY DESIGN	XR TECHNOLOGY	MEDICAL SPECIALTY	CLINICAL CONDITION	SETTING	ASSESSMENT METRICS	MERSQI SCORE	PRIMARY PURPOSE
Yoshimitsu[47] (2010)	9	Pre-test/ post-test	VR/Not reported	Rehabilitation	Other	Microgravity	Physiological/Kinematics	12	Usability/human factors
Chen et al.[8] (2015)	32	Pre-test/ post-test	VR/PC-Monitor	Neurology	Emergency/ Acute	Other	Self-report/Kinematics	9	Usability/human factors
Wu et al.[46] (2016)	53	Cross sectional	VR/Custom VR	Psychology	Elective/ Chronic	Other	Self-report	8	Usability/human factors
Eikema et al.[14] (2016)	20	Non-RCT	VR/Custom VR	Rehabilitation	Other	Other	Kinematics	11.5	Usability/human factors
Chen et al.[9] (2017)	34	RCT	VR/Oculus Rift	Neurology	Elective/ Chronic	Other	Self-report/Kinematics	11	Usability/human factors
Limbu et al.[28] (2018)	142	Cohort	AR/HoloLens	Radiology	Elective/Chronic	Spacecraft	Self-report	9.5	Clinical Training/Telemedicine
Galunder et al.[17] (2018)	12	Cohort	VR/Not reported	Psychology	Emergency/Acute	Other	Self-report/Others	9.25	Stress Management
Finseth et al.[15] (2018)	20	RCT	VR/Custom VR	Emergency Medicine	Elective/Chronic	Microgravity	Self-report/Knowledge/ Observation/Physiological	13.2	Usability/human factors
Del Mastro et al.[12] (2018)	3	Case report	VR/Oculus Rift	Rehabilitation	Elective/Chronic	Other	Self-report/Others	4.5	Clinical Training/Telemedicine
Limbu et al.[29] (2019)	398	Cohort study	AR/HoloLens	Radiology	Elective/Chronic	Spacecraft	Self-report/Knowledge Tests	12	Clinical Training/Telemedicine
Li et al.[27] (2019)	20	Pre-test/ post-test	VR/PC-Monitor	Neurology	Emergency/Acute	Other	Self-report/Physiological/ Kinematics	11.5	Usability/human factors
Nasser et al.[37] (2020)	Not Reported	Qualitative	VR/Custom VR	Emergency Medicine	Emergency/Acute	Spacecraft	Others	3.5	Clinical Training/Telemedicine

Study Designs

The majority of the studies lack rigor in the design. More than 80% of the studies did not include control groups and only two studies (13%)[9,15] used randomized controlled experiments. Furthermore, no study followed up participants to measure outcomes longitudinally and none of the training research assessed long-term knowledge and/or skills retention.

Most of the XR tools (75%) used in the studies were non-immersive (2D displays and nonwearable devices). Therefore, it can be difficult to generalize findings from these studies regarding the actual effectiveness of immersive XR technologies in space health. Moreover, as no full validation strategies were outlined, it is unclear whether the proposed XR applications published to date are of true value in improving astronauts' health and space mission safety. Particularly for studies focused on training aspects of XR applications in space health, it is critical to investigate the transfer of learning into real-life settings and the progression of knowledge and skills over time through proper longitudinal studies. Future investigations of XR-based educational applications for astronauts' training in medical event management could result in significant advances in our understanding of the suitability of this technology for supporting medical learning and clinical practice in space.

Primary Purpose of XR Applications

The majority of the studies aimed to investigate the usability of XR applications for space health, where virtual therapeutic techniques, clinical training, and telemedicine were the three main focuses of these applications. Surprisingly, XR-based decision support and procedural clinical guidance was not investigated in any of the studies. XR technologies, particularly AR, have been widely used as a clinical support/guidance tool for terrestrial applications.[4,22,40] Due to minimal interaction with ground controllers, communication limitations, and prolonged nature of the mission, just-in-time (JIT) training and real-time clinical guidance systems are critical for long deep-space missions. NASA and the Translational Research Institute for Space Health (TRISH) have highlighted the importance of the development of augmented clinical tools (ACTs) to support astronauts by providing planned composite medical education and real-time care delivery guidance systems during spaceflights.[34] XR could be used to seamlessly deliver ACTs, helping astronauts to effectively manage medical events in space. The Augmented Reality Coach (AR-Coach) is an example of a clinical guidance application in which a virtual coach system guides the crew in real time on how to perform point-of-care ultrasound during medical emergencies in space.[32]

Medical Specialty

Most of the studies focused on nonsurgical conditions. Although the frequency of nonsurgical medical conditions is higher than surgical events in space travel, surgical care should be an essential component of space health solutions for developing effective and comprehensive medical exploration capabilities to ensure the health and safety of space travelers. Although the feasibility of performing certain surgical

Table III. Group of XR Hardware Used in the Studies (Based on Human Technological Embodiment Continuum[37]).

XR HARDWARE GROUPS	NUMBER OF STUDIES (%)
Stationary external devices[3,8,14,15,17,20,27,39,43,46,47]	11 (68.8)
Wearable devices[9,12,15,28,29]	5 (31.2)
Portable external devices[37]	1 (6.2)
Implantable devices	0

procedures in space has already been determined,[13] only a few relevant investigations have taken place due to challenges associated with the availability of clinical expertise and both diagnostic and operational resources during space missions. Considering the promising application of XR technologies in surgery in terrestrial settings,[40] it is critical to investigate potential opportunities and challenges of immersive technologies to ensure safe and effective surgical care in space. For instance, AR can be used to provide real-time or near-real-time support to flight surgeons from Earth or other space stations, enhancing collaboration in telesurgery. Providing a unified view of the surgical field by superimposing digital information onto AR glasses helps flight surgeons and the medical expert on Earth or another space station effectively communicate in managing medical emergencies. AR information also reduces looking back and forth between different sources of information. Virtual projections of subsurface anatomy allow flight surgeons to identify, anticipate, and avoid critical structures before they are exposed. Future studies need to establish baseline concepts of functionalities and design features of XR applications that could provide surgical support during spaceflight, from the preoperative to the postoperative period. Surgical support can be provided as a real-time guide or surgical training program which prepares space travelers for various surgical procedures.

XR-Based Medical Training

Most of the studies did not clearly describe the learning theories they used to guide the design or application of XR in space health. Generalizability is not only reduced by the difference in XR settings, it has also been affected by divergent underlying learning theories. To date, it is unclear if the use of XR technology in training astronauts is likely to contribute to astronauts' safety and mission success. Although ground-based evidence supports that as training tools and content become more engaging and reliable, more learning outcomes may be expected, and patients will ultimately benefit,[36] there is still a lack of comprehensive theoretical guidance for developing XR-based medical training curricula. Most of the investigations on Earth or in space related to XR medical training have been focused on the acquisition of technical skills. However, it is crucial to incorporate nontechnical skills into XR-based medical training curricula, particularly for space applications where errors can pose a significant risk to mission success. For instance, training situational awareness in high-risk environments is reported as a critical component of operation safety, but is lacking in XR-based medical educational curricula for space.[4]

There is not enough evidence to inform the design of suitable learning activities with XR systems, where knowledge and skill development could be integrated into the astronauts' capabilities during space missions. Therefore, further research should illuminate minimum requirements of XR systems' and models' designs, features, and functionalities, as well as how to effectively use them for healthcare education.

Table IV. Type of XR Devices Used in the Studies.

XR DEVICE	NUMBER OF STUDIES (%)
Oculus Rift[9,12]	2 (12.5)
HoloLens[28,29]	2 (12.5)
Custom VR environments[14,15,37]	4 (25)
PC/monitor or projector[3,8,27,43]	4 (25)
VR laparoscopy simulators[20,39]	2 (12.5)
Not reported[17,47]	2 (12.5)

XR Hardware, Devices, and Modalities

A high variability was observed in XR tools used in the studies; however, most of them did not use portable or wearable tools such as head-mounted displays. Considering the publication year of the papers, it is not surprising that only four studies used HMDs available in the market. Wearable VR devices emerged with the introduction of the PC-connected Oculus Rift prototype in 2010 and progressed rapidly over the course of the last decade. The cost of VR headsets has dropped dramatically and computer hardware capable of running these headsets is virtually mainstream. XR systems are now part of affordable standalone AR and VR headsets, which are expected to be cheaper and lighter in upcoming years. Future studies need to investigate XR applications deployed in these new hardware technologies.

Evaluation Measures

Alongside the poor methodological quality of the studies included in this review, there was a large variability in assessment metrics, which compromises the generalizability and reliability of results obtained from these studies. Methodological quality assessed by the MERSQI score was low for most studies, indicating that several aspects of research in this field can be improved. Although some studies employed validated tools for assessing the effectiveness of XR applications, most did not follow a systematic evaluation approach. Further studies to strengthen the existing evidence would require assessing behavioral and patient-related outcomes through more rigorous and systematic approaches. Future studies should include larger sample sizes and standard validated measurement methods.

In addition to space, the findings from this systematic review can be used to support the design and development of XR applications for terrestrial settings such as telemedicine, medical training, and clinical decision support in remote and austere environments. The paradigm of health care delivery has shifted dramatically from hospital-based to homecare and telehealth. XR technology in these contexts has the potential to provide useful resources. This study may also help researchers and developers to gain a better understanding of the challenges in developing XR-based solutions for improving patient care, particularly in low-resource environments.

Limitations

Several limitations should be considered when interpreting the results of this systematic review. Given the rapid growth of XR technology in recent years, it is likely that research involving certain XR applications in space health has not yet been published or is under patent/copyright restrictions, precluding their inclusion in this review. Clinical utility and validity of XR applications included in this review were limited by high variability in sample size, design of the study, medical conditions, and type of XR tools. Included studies also covered a wide range of main purposes, which may limit the specific scope of findings considering high variability in XR applications' primary purposes. Future review studies should target a narrower concentration of main purposes for XR applications. This relatively new research field must build on more validated metrics to investigate the impacts of XR tools on astronauts' health and performance. In addition, further research should include the analysis of other moderating variables in order to provide a better understanding of the impact of XR on space health.

One of the other major drawbacks of most of the included papers is that they were not clear about the design and prototyping stage of the XR systems and how they incorporated astronauts' needs and feedback into the design process of the XR applications. Human-centered design has emerged as a promising and versatile approach to engage users in the design and adaptation of healthcare digital systems to better meet clinicians' and patients' needs, resulting in fewer usability issues and human errors, plus a higher adoption rate of technologies.[18,41] In terrestrial medicine, for example, unsatisfactory clinicians' perceptions of a system's content and design are associated with less successful technology implementations.[23]

Conclusion

To our knowledge, this is the first study that systematically reviews the existing literature on XR applications for space health. We reviewed applications of XR technologies that focused on space health and encompassed a broad range of experimental design, XR tools, medical specialties, clinical conditions, space-related experiment setups, and assessment metrics. The limited number of the studies and wide variation in the design of the studies, medical conditions being studied, and primary purpose of the XR applications pose substantial challenges to reporting compelling evidence in support of successful implementations of XR in space health. There was a lack of consistently positive outcomes and high-quality studies for all XR modalities.

XR technology is in the early stages of application within space health, but it has enormous potential for supporting astronauts and non-astronaut space travelers during medical event management. Real-world applications of XR in space health not only require designing pertinent functionality and features, but also identifying appropriate clinical guidelines and training methodologies to better address the needs of astronauts and other space travelers during medical event management in space.

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A Regional Approach to Aviation Accident Analysis in Hawaii

Alexander J. de Voogt; Jason Brause

BACKGROUND: The geographical circumstances, such as mountains and ocean, and specific aviation operations, especially sightseeing, make the state of Hawaii stand out in aviation. These conditions support a regional approach to aviation accident analysis.

METHODS: Accident reports of aviation accidents collected from the online National Transportation Safety Board database were used to study a 10-yr time period between 2008 and 2017.

RESULTS: There was a significantly higher proportion of fatal accidents during night, dawn, and dusk (6 out of 13) than during daytime (13 out of 74). In addition, a significantly higher proportion of accidents occurred in diminished light conditions among fixed wing airplanes (11 out of 48) as opposed to other aircraft (2 out of 39), and among twin-engine aircraft (6 out of 12) as opposed to single-engine aircraft (7 out of 74). Out of seven weight-shift control aviation accidents, four were reported to be fatal; the latter all took place during instruction.

DISCUSSION: Light conditions are the main environmental concern in Hawaiian aviation that particularly affect twin-engine fixed wing aircraft and warrant specific attention in advanced training exercises. Helicopter operations have not exhibited a diminished safety record since the 1990s, showing a lasting effect of a previous safety intervention. A relatively high number of fatal weight-shift control aircraft accidents requires further research in other parts of the United States.

KEYWORDS: general aviation, aviation accident, twin-engine aircraft, helicopter, light conditions.

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Aviation safety, specifically accident prevalence, varies according to geography for both air carriers, air taxi, and general aviation.[5,8] Subsequent studies have concentrated on Alaska as a geographic area of concern.[2,10] Regional differences within the United States may point to favorable weather conditions for aviation, such as the states of California and Florida, or unfavorable conditions creating particularly challenging operations, such as those in Alaska.

Other than Alaska, the state of Hawaii is one of few regions that received separate attention with regards to aviation accidents. The state of Hawaii stands out due to its environment of mountainous islands as well as its type of operations, which include a high percentage of both helicopter and fixed wing sightseeing operations. In 1994 the high rate of helicopter accidents involved in sightseeing made the Federal Aviation Administration address aviation safety with new regulations, which proved successful according to a subsequent helicopter accident analysis study.[6]

The following study compares previous research on Hawaii with more recent years but also includes other aircraft. It contrasts causes and contributing factors of helicopters with other aircraft as well as providing a general overview of aviation accidents of this island state. The results aim to assist state-specific regulations or interventions to optimize aviation safety.

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Table I. Comparison of Type of Aircraft in Hawaii Aviation Accidents.

AIRCRAFT	TOTAL	FATAL	SERIOUS INJURY	DESTROYED	SUBSTANTIAL DAMAGE	TURBINE	PISTON	NO ENGINE
Fixed-wing	48	10	8	6	40	9	39	0
Helicopter	28	4	4	2	25	17	11	0
Weight-shift control	7	4	1	0	7	0	7	0
Glider	4	1	1	1	3	0	3	1

METHODS

We extracted case reports from the Case Analysis and Reporting Online database made available by the National Transportation Safety Board (NTSB).[9] All aviation accidents occurring between 1 January 2008 and 31 December 2017 in the state of Hawaii were extracted and completed reports were selected for further analysis.

Each accident has a factual report and a probable cause statement that summarizes the findings of the NTSB investigator with a narrative, a set of findings that determines and codes the cause and contributing factors of the accident, as well as categorical data on the pilot, aircraft, airfield, and meteorological conditions. Findings in the accident reports were analyzed using the terminology and coding presented by the NTSB investigators.

Significant differences between expected and actual values within the dataset of categorical data was determined using Pearson's Chi-squared analysis using one degree of freedom, a 0.05 significance level, and a Fisher's exact test when cell counts fell below 5.

RESULTS

Between 1 January 2008 and 31 December 2017, 88 accidents were reported in the state of Hawaii. An accident with incomplete information was removed, leaving a total of 87 accidents for our analysis, which is 0.55% of the total number of accidents in the United States in that time period. The type of aircraft included gliders ($N = 4$), weight-shift control aircraft ($N = 7$), helicopters ($N = 28$), and fixed wing airplanes. The total number of weight-shift control aircraft accidents in the same period in the United States is 138, which means that an above average proportion of 5.07% of these accidents occurred in Hawaii. Lack of denominator data prevents further analysis of the risk of weight-shift control flights in Hawaii. There was a total of 44 fatalities among the 87 accidents, with an average of 2.3 fatalities per fatal accident. The distributions of damage and injury between the different aircraft is shown in **Table I**.

There was an average of 8.7 accidents per year, with 2016 having the most accidents ($N = 13$) and 2010, 2011, and 2015 having the fewest accidents ($N = 6$). Accidents happened under Part 91 ($N = 65$) in 74.7% of the cases, with a further 19.5% happening under Part 135 ($N = 17$). Furthermore, 29.9% of accidents were instructional flights ($N = 26$), of which 5 were fatal, a proportion of fatal accidents that was not significantly different from other operations ($P > 0.05$). Out of the five instructional fatal accidents, four pertained to weight-shift aircraft and one to a helicopter.

Pilots' ages ranged from 20 yr old to 84 yr old, with an average age of 47.8 yr, and 85.1% of pilots that were men. No significant differences could be determined between the type of accident for male and female pilots.

Pilot's total flight time ranged from 0 to 28,500 h, with a median of 2154.3 h, with one unreported case. Out of 26 pilots operating aircraft with turbine engines, 12 had more than 5000 total flight hours, which is a significantly higher proportion than 13 out of 60 accidents in which the pilots operated nonturbine engine aircraft ($\chi^2 = 5.27, P < 0.05$).

The majority of aircraft were single-engine ($N = 74$), with the remaining either twin-engine ($N = 12$) or unpowered ($N = 1$). Of the 86 powered aircraft, 69.8% had reciprocating engines ($N = 60$) and 30.2% had turbine engines ($N = 26$).

Out of 12 accidents with twin-engine aircraft, 6 were in nondaylight conditions, which is a significantly higher proportion than the 7 nondaylight accidents out of 74 with single-engine aircraft ($\chi^2 = 13.23$, $P < 0.05$). This result remains significant when only looking at fixed-wing twin-engine airplanes, of which 6 accidents out of 11 occurred in nondaylight while 5 out of 32 single-engine airplanes occurred in nondaylight ($\chi^2 = 8.08$, $P < 0.05$), but not for helicopters ($P > 0.05$). **Table II** shows a complete overview of the number of accidents per aircraft type with the light conditions in which the accidents took place.

Table II. Number of Accidents in Hawaii According to Light Conditions and Aircraft Type.

	DAYLIGHT	NON-DAYLIGHT
Total all aircraft	74	13
Airplane total	37	11
All single engine airplanes	32	5
Single engine reciprocating	29	4
Single engine turbo prop	3	1
All twin-engine airplanes	5	6
Twin engine reciprocating	3	3
Twin engine turbo fan	1	1
Twin engine turbo jet	1	0
Twin engine turbo prop	0	2
Glider	4	0
Helicopter total	26	2
All single engine helicopters	25	2
Single engine reciprocating	10	1
Single engine turbo shaft	15	1
Twin engine turbo shaft	1	0
Weight-shift	7	0

Table III. Comparative Data Between Time Periods.

	TIME PERIOD			
	1981–1994	**1995–2008**	**2008–2017**	**2008–2017**
Aircraft type	Helicopters	Helicopters	Helicopters	All aircraft
Total # accidents	37	22	28	87
Malfunctions % of total	51% (N = 19)	68% (N = 15)	25% (N = 7)	20.7% (N = 18)
VFR-IMC % of total	5% (N = 2)	32% (N = 7)	3.6% (N = 1)	4.6% (N = 4)
Ocean % of total	22% (N = 8)	5% (N = 1)	7.1% (N = 2)	16.1% (N = 14)
Fatal accidents % of total	21.6% (N = 8)	36% (N = 8)	14.3% (N = 4)	21.8% (N = 19)
# Passengers/flight	4.3	4.7	3	5.64

VFR: visual flight rules; IMC: instrument meteorological conditions.

Accidents occurred during the day in 85.1% (N = 74) of the cases, 4.6% occurred during dusk (N = 4), and 10.3% occurred during night or dark conditions (N = 9). Accidents occurred in visual meteorological conditions in 94.3% (N = 82) of all cases, with one accident not reporting the meteorological condition at the accident site. Hawaii has only two seasons. The winter season from November to April had 45 accidents, and the summer season from May to October had a similar number of 42.

There was a significantly higher proportion of fatal accidents during night, dawn, and dusk (6 out of 13) than during the day (13 out of 74) ($\chi^2 = 5.29$, $P < 0.05$). In addition, there was a significantly higher proportion of accidents that occurred in diminished light conditions among fixed wing airplanes (11 out of 48) as opposed to other aircraft (2 out of 39) ($P < 0.05$).

Of the 87 accidents, 71.3% were found to have issues related to the functioning of the aircraft (N = 62), 72.4% had personnel issues (N = 63), and 50.6% reported environmental issues (N = 44) according to the classification by the NTSB investigators. The accidents that were found to have been associated in part with environmental issues can be broken down into four categories: contribution to the outcome (N = 14), effect on crew (N = 12), effect on operations (N = 15), and effect on the equipment (N = 7).

Accidents involving environmental causes with an effect on the crew had 6 out of 12 accidents as fatal while all other causes combined had a significantly smaller proportion, with 13 fatal out of 43 accidents ($\chi^2 = 6.47$, $P < 0.05$). However, causes merely identified as environmental were not significantly more likely to involve a fatality.

DISCUSSION

The Hawaiian data confirm previous research that highlights the dangers of nondaylight conditions as well as the particular dangers for twin-engine airplanes.[1,3] Environmental issues that affected the crew of the aircraft, as specified by the NTSB investigators, were found to be more often fatal compared to other causes. In general, environmental conditions were expected to play a role in Hawaiian aviation, but this appeared to be mostly the case for light conditions.

It is also shown that Hawaii has a relatively high number of accidents that relate to weight-shift operated aircraft, which also have a disproportionate number of fatalities, especially during instruction. The study of weight-shift accidents may find a useful starting point in the state of Hawaii, particularly in comparison with other states.

The data collected for the time period between 2008 and 2017 is markedly different from that reported in a previous study on Hawaiian helicopter accidents as shown in **Table III**, although the time periods are not equal and no denominator data were available. However, the percentage of accidents in each category appears markedly different and the proportionate number of fatal accidents shows relevant differences in the absence of denominator data.[7] Environmental conditions remained significant, but not just for helicopters. The main finding did not pertain to visual flight rule flights into instrument meteorological conditions as in previous years, but instead to flights in diminished light conditions at night, dawn, or dusk. This result was more apparent in fixed wing aircraft, especially twin-engine fixed wing aircraft, which confirms previous accident analysis on twin-engine noncommercial general aviation aircraft.[1] As expected, twin-engine pilots have a higher number of flight hours compared to nonturbine engine aircraft, which suggest that the type of training and not the amount of training itself is important in preventing accidents with twin-engine fixed wing aircraft. In contrast with fixed wing aircraft, a recent study showed that twin-engine helicopters show a lower risk of accidents compared to single-engine helicopters both in Hawaii and Alaska.[4]

It is concluded that state-specific accident analysis is an insightful line of research but should include all types of aircraft. The focus of attention in Hawaii in both initial training and professional checks of pilots should remain on the environment and emphasize light conditions. In addition, the main concerns in Hawaii at the present time relate to twin-engine fixed wing aircraft and weight-shift operations, as opposed to helicopter operations, for which an intervention in the 1990s has shown a lasting effect.[6]

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Lingering Altitude Effects During Piloting and Navigation in a Synthetic Cockpit

Jeremy Beer; Bria Morse; Todd Dart; Samantha Adler; Paul Sherman

INTRODUCTION: A study was performed to evaluate a cockpit flight simulation suite for measuring moderate altitude effects in a limited subject group. Objectives were to determine whether the apparatus can detect subtle deterioration, record physiological processes throughout hypobaric exposure, and assess recovery.

METHODS: Eight subjects trained to perform precision instrument control (PICT) flight and unusual attitude recovery (UAR) and completed chamber flights dedicated to the PICT and UAR, respectively. Each flight comprised five epochs, including ground level pressure (GLP), ascent through altitude plateaus at 10,000, 14,000, and 17,500 ft (3050, 4270, and 5338 m), then postexposure recovery. PICT performance was assessed using control error (FSE) and time-out-of-bounds (TOOB) when pilots exited the flight corridor. UARs were assessed using response times needed to initiate correction and to achieve wings-level attitude. Physiological indices included S_pO_2, heart rate (HR), end tidal O_2 and CO_2 pressures, and respiration metrics.

RESULTS: Seven subjects completed both flights. PICT performance deteriorated at altitude: FSE increased 33% at 17,513 ft and 21% in Recovery vs. GLP. Mean TOOB increased from 11 s at GLP to 60 s in Recovery. UAR effects were less clear, with some evidence of accelerated responses during and after ascent.

CONCLUSIONS: The test paradigm was shown to be effective; piloting impairment was detected during and after exposure. Physiological channels recorded a combination of hypoxia, elevated ventilation, and hypocapnia during ascent, followed by respiratory slowing in recovery. Findings indicate precision piloting and respiration are subject to changes during moderate altitude exposure and may remain altered after S_pO_2 recovers, and changes may be linked to hypocapnia.

KEYWORDS: hypoxia, physiological episodes, precision piloting, respiration rate, hyperventilation.

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Moderate hypoxia presents a particular challenge in aviation safety since its effects are not necessarily conspicuous or related to self-observed symptoms:[12] if subtle hypoxia—perhaps below the threshold where the pilot recognizes it—increases control error only slightly, impairment could be dangerous precisely because of this subtlety, as in Type I spatial disorientation. This challenge is amplified by the variety of cognitive components in aviation. Whereas hypobaric and normobaric (ground-level) hypoxia reliably induce physiological effects, including increased heart rate (HR), decreased oxygen saturation (S_pO_2), and changes to cerebral oxygen delivery,[1,15,20] the range of reported cognitive manifestations has been varied. Declines in executive and auditory processing, speeded arithmetic, and vigilance have been reported,[3,4] whereas certain other components, including simulated aviation control metrics, can remain relatively unscathed during mild or moderate exposure (up to 13,999 ft/4267 m).[5] In the realm of normobaric exposure, breathing mixtures at more severe hypoxia levels ranging from 18,000–25,000 ft (5486–7620 m) equivalent altitude increased control error in simulated flight,[13,16] and in a multiple-exposure paradigm,

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initial exposure to 25,000 ft (7620 m) equivalent hypoxia reportedly caused piloting impairment during subsequent mild exposure.[14]

Additional concern arises from reports that pilots are vulnerable to a "hypoxia hangover" comprising lingering impairment during posthypoxia recovery.[18] In this hypothesis, returning the pilot to pre-exposure oxygen levels—either O_2 breathing concentrations or peripheral S_pO_2—might not restore proficiency immediately. To date, studies have employed diverse tasks (simulated sorties,[14] synthetic workstation,[3] psychomotor vigilance,[4] and simple and choice reaction tasks[6]) to examine the persistence of impairment following hypoxia, with some identifying continuing impairment and others reporting none or only equivocal hangover effects.[6,17] This divergence indicates a need for further investigation to characterize the prevalence, duration, and nature of postexposure impairment.

Because of the potential danger of creeping control raggedness, the need to detect subtle impairment using flight-relevant tasks, and the additional hazard if posthypoxia effects emerge, we saw a need to develop an affordable platform to assess piloting during and after exposure to moderate altitude conditions. This exploratory study was performed to verify the effectiveness of a synthetic environment and test concept incorporating a model cockpit, a visual simulator, physiological monitoring, and hypobaric exposure. The test paradigm was designed to employ control and navigation tasks relevant to aviation during progressive ascent through moderate hypobaric plateaus. Since aviation takes place in a pressure-varying environment and the physiological and phenomenal effects of normobaric vs. hypobaric exposure are not necessarily identical,[1,19] the cockpit was situated in a hypobaric chamber. A physiological monitoring suite including oximetry, respiration, and gas analysis was employed, and testing included a recovery period against which baseline performance was compared.

The study's primary objective was to determine whether this apparatus could identify moderate altitude effects in a small group of volunteers who were not career aviators but would train to proficiency on tasks with manifest face validity. These tasks were employed to test whether exposure would render the pilots susceptible to ragged control or impaired directional corrections as physiological metrics were recorded. The first, precision instrument control (PICT) task, resembled tasks in earlier studies[13,14,16] wherein subjects maintained altitude, airspeed, and heading while countering simulated disturbances. A second task presented unusual attitude recoveries (UAR): pilots must level the aircraft after being placed in a scenario depicting unpredictable bank and pitch states. Subjects completed two identical hypobaric ascents (hereinafter called "flights"): one for PICT and one for UAR. Both flights progressed through five 10-min epochs: baseline ground-level pressure (GLP) equivalent to 659 ft (201 m) above sea level, then equivalent pressure altitudes of 10,000 ft (3050 m), 14,000 ft (4270 m), and 17,500 ft (5338 m), and finally a Recovery epoch following return to GLP.

Two hypotheses were tested to validate the sensitivity of the apparatus and paradigm for assessing piloting at altitude, and to determine effect sizes to inform future studies examining moderate exposure. The first null hypothesis was that altitude exposure would not affect performance, measured using PICT control error and UAR response times and with emphasis on the comparison between baseline GLP and 17,500 ft (5338 m). The second null hypothesis was that no difference would emerge between performance recorded during Recovery vs. GLP.

METHODS

Subjects

The study protocol was approved by the AFRL 711th HPW Institutional Review Board. A total of eight nonsmoking, U.S. Air Force active-duty volunteers ages 33–40 (seven men, one woman) enrolled with written informed consent. Subjects were screened to a 20/20 distance vision criterion, with two participating wearing vision correction. All were encouraged to forego participation if they were not well rested or had consumed alcohol or excessive caffeine in the day before testing. Subjects completed three training sessions. After introducing the subject to flight controls and PICT in session 1, sessions 2 and 3 presented instruction on both PICT and UAR. During UAR training, subjects were encouraged to correct bank before pitch and apply throttle to facilitate recovery. Subjects then completed two flights at least 44 h apart: one each for PICT and UAR. Flight presentation order was counterbalanced across subjects to the extent possible; three subjects completed the PICT flight first and four completed UAR first. One subject, scheduled to complete PICT first, experienced physiological difficulties, including discomfort from a poor mask fit in both flights, and was removed.

Flights

In the PICT flight, subjects performed the task for 10 min at GLP and then the chamber executed controlled decompressions, ascending to three successive 10-min altitude plateaus at 10,000, 14,000, and 17,500 ft (3050, 4270, and 5338 m). The chamber then returned to GLP and a 10-min Recovery epoch ensued. Chamber pressure ascents and descents were executed at 5000 ft (1524 m) $\cdot$ min^{-1} unless the subject experienced ear or sinus pain upon descent, in which case descent rate was reduced. Subjects breathed air (21% O_2) throughout all five epochs.

The same five-epoch profile was executed in the other flight; in this case, each epoch contained one block of eight UAR trials. After completing each block, the subject was instructed to return to the straight-and-level indicated state of 15,000-ft (4572-m) altitude, 350-kn airspeed, and 090° heading for the remainder of the epoch.

Equipment and Tasks

A cockpit mockup (Sage Cheshire, Inc., Lancaster, CA, USA) was situated in Hypobaric Chamber E of the Brooks Aerospace Environment Protection Laboratory. The cockpit, which duplicates the interior dimensions of a U-2, incorporates a Hyundai

P224W LED monitor (1680 × 1050 pixels; 52 × 41°) for the piloting display and Thrustmaster® Warthog flight controls.

During flights, subjects wore an HGU-55/P helmet and breathed through an MBU-20/P mask and CRU-60 connector. A CRU-73 regulator was used to deliver filtered air at demand (not safety) pressure continuously. A Fleisch pneumotachograph, standardized daily against a calibrated flowmeter, was interposed between regulator and mask. Mask gases and pressure were sampled using tap lines connecting the mask to an Extrel MAX300-LG mass spectrophotometer (Process Insights, Houston, TX, USA) and Validyne (Northridge, CA, USA) pressure transducer. Spectrophotometer and pressure transducer were calibrated daily against high-purity sample gases and independently calibrated instruments, respectively.

Respiration and gas data channels (mask inflow, pressure, $\%O_2$, $\%CO_2$, chamber altitude) were recorded at 100 Hz via LabVIEW script. S_pO_2 and HR were recorded at 1 Hz using a Nonin (Plymouth, MN, USA) Wrist-Ox® 3150 oximeter with 8000R sensor on the left temple. Peripheral S_pO_2 and HR were also monitored for safety via displays outside the chamber, using a Masimo (Irvine, CA, USA) SET® Rainbow oximeter on the left hand or an Athena GTX® (Johnston, IA, USA) HSPro on the left arm. Data recording devices were synchronized before each flight.

The PICT was presented using a laptop running an F/A-18F aircraft model in X-Plane V11 (Laminar Research, Columbia, SC, USA). Presentation was controlled using a LabVIEW script to set conditions and record data. The visual simulation depicted overcast instrument conditions and a head-up display (HUD) incorporating a horizon, climb-dive ladder, altitude (feet), airspeed (knots), and heading indicators. Below this, a synthetic panel displayed head-down instruments and engine settings. In the PICT, the subject was instructed to maintain a straight flight path at altitude 15,000 ft (4572 m), 350 kn indicated airspeed, and heading 090°. Performance was assessed in part by recording how continuously subjects could maintain corridor values between 14,800–15,200 ft (4511–4633 m), 340–360 kn, and 088–092°, respectively. Task difficulty was added by incorporating a time-varying disturbance in the aerodynamic model: a prevailing 10-kn wind was added to the surrounding airmass in a vector whose direction changed continuously at 4°/s. As a result, maintaining target airspeed required continual throttle modulation, with attendant effects (via nonconstant lift and drag) on altitude and heading. Aircraft states and flight control settings were recorded in LabVIEW at a sampling rate of approximately 39 Hz. Tracking performance was calculated across the last 7 min of each epoch to allow subjects time at the start to establish straight-and-level flight. Altitude, airspeed, and heading tracking were assessed using root-mean-square (RMS) error:

$$RMS = \sqrt{\frac{\sum_{1}^{n}\left(x_i - \bar{x}\right)^2}{n}}$$

where $\left(x_i - \bar{x}\right)$ is the deviation from each parameter's target value and n is the number of samples in the epoch. Each component RMS error value was normalized by dividing by the target value: altitude 15,000, airspeed 350, heading 090. The mean of the three normalized RMS values was then calculated to represent overall piloting error within each epoch. This overall performance metric is named flight-sim error (FSE).[14] PICT performance was also assessed using a time-out-of-bounds (TOOB) metric comprising the cumulative time during which the subject permitted any of the three flight parameters to deviate from the corridor boundaries. TOOB was recorded across the last 7 min of each epoch.

The UAR was also presented via LabVIEW script using XPlane. This task assessed subjects' ability to perceive and correct an unusual attitude state as might occur during situational distraction. UAR presented eight far-from-level attitude states in random order, comprising all possible combinations of upward and downward 30° pitch with left and right bank states of 45° and 135°. In each trial, the script reset XPlane to display a dark screen and then restored the display with the aircraft placed in one of the above states. The subject was instructed to use the flight controls and HUD indicators to correct bank and then pitch to regain straight-and-level flight. UAR performance was assessed using three metrics: total response time (RTT) from trial start until the subject stabilized attitude for 2 s continuously, keeping pitch within ±10° of the horizon and bank within ±5° from level; initial response time (RTI) recorded from trial start until the subject's first joystick deflection beyond 10% in the bank dimension; and correct response time (RTC) from trial start until the subject's first joystick deflection beyond 10% in the correct direction (e.g., leftward when the trial presents a right-banked attitude).

Statistical Analysis

FSE and TOOB were analyzed using one-way repeated measures ANOVA (SPSS Version 19, IBM, Armonk, NY, USA) including one independent variable called Epoch with five periods: GLP, 10,000 ft (3050 m), 14,000 ft (4270 m), 17,500 ft (5338 m), and Recovery. Datasets were screened for normality using Kolmogorov-Smirnov tests. Where Mauchly's test identified departures from sphericity, Greenhouse-Geisser (G-G) correction was applied to degrees of freedom. Least significant difference contrasts (equivalent to two-tailed *t*-tests; $\alpha = 0.05$) were used to detect differences between 5338 m vs. GLP and Recovery vs. GLP epochs. To increase sensitivity with this small sample, contrasts did not employ multiple-comparison correction, which slightly increased the chance of Type I error. UAR RTT, RTI, and RTC ANOVAs employed additional parameters, Bank and Pitch, to identify effects of aircraft state on attitude recovery, yielding a three-way, 5 × 2 × 2 repeated measures design.

Mean values for S_pO_2 and HR were calculated across each epoch and averaged across flights. Respiration metrics were calculated in postprocessing using temporal analysis of flow and spectrophotometric data. Time boundaries for each breath were assigned at the minima of recorded flow into the mask. Each breath was assigned a time stamp at the time of maximum inhalation flow. Respiration rate (f) was calculated in breaths/min using time elapsed between successive breaths.

Table I. PICT and UAR Piloting Metrics.

	GLP	3050 m	4270 m	5338 m	RECOVERY	*F*(WITHIN DF, ERROR DF)	SIG.	GLP vs. 5338 m	GLP vs. RECOVERY
PICT Metrics									
Flight simulator error (FSE; normalized metric)	0.024 (0.002)	0.025 (0.003)	0.031 (0.004)	0.032 (0.004)	0.029 (0.003)	*F*(4, 24) = 4.0	0.013	x d = 0.97	x d = 1.13
Time out of bounds (TOOB; seconds)	10.81 (6.6)	23.12 (12.1)	53.89 (21.9)	73.44 (32.4)	60.06 (13.9)	*F*(4, 24) = 4.6	0.007	[0.057] d = 0.89	x d = 1.63
UAR Metrics									
Total Response Time (RTT; seconds) by epoch:	10.17 (0.553)	9.94 (0.554)	10.07 (0.650)	9.62 (0.457)	9.86 (0.534)	*F*(4, 24) = 2.0	NS	x d = −1.90	
	L/R 45°	**L/R 135°**	***F*(WITHIN DF, ERROR DF)**	**SIG.**					
RTT in seconds, by bank	9.80 (0.521)	10.06 (0.560)	*F*(1, 6) = 4.5	[0.078]					
	PITCH UP	**PITCH DOWN**	***F*(WITHIN DF, ERROR DF)**						
RTT in seconds, by pitch	10.73 (0.398)	9.13 (0.702)	*F*(1, 6) = 17.0	0.006					
	GLP	**3050 m**	**4270 m**	**5338 m**	**RECOVERY**				
Initial response time (RTI; seconds) by epoch:	1.035 (0.046)	0.969 (0.045)	0.901 (0.036)	0.940 (0.057)	0.898 (0.034)	*F*(4, 24) = 5.8	0.002		x d = −1.28
	L/R 45°	**L/R 135°**	***F*(WITHIN DF, ERROR DF)**	**SIG.**					
RTI in seconds, by bank:	0.956 (0.056)	0.940 (0.031)	*F*(1, 6) = 5.8	NS					
	PITCH UP	**PITCH DOWN**							
RTI in seconds, by pitch:	0.910 (0.031)	0.986 (0.048)	*F*(1, 6) = 10.2	0.019					
	GLP	**3050 m**	**4270 m**	**5338 m**	**RECOVERY**				
Initial correct RT (RTC in seconds) by epoch:	1.053 (0.050)	1.000 (0.036)	0.938 (0.043)	0.979 (0.054)	1.039 (0.118)	*F*(1.3, 7.6 (G-G)) = 313.8	NS		
	L/R 45°	**L/R 135°**	***F*(WITHIN DF, ERROR Df)**	**SIG.**					
RTC in seconds, by bank:	1.029 (0.068)	0.975 (0.034)	*F*(1, 6) = 0.503	NS					
	PITCH UP	**PITCH DOWN**	***F*(WITHIN DF, ERROR DF)**	**SIG.**					
RTC in seconds, by pitch:	0.925 (0.034)	1.079 (0.057)	*F*(1, 6) = 7.3	0.035					
	CONTRAST OF INTEREST	**COHEN'S d**	**REQUIRED *N***						
FSE	GLP vs. 4270 m	0.87	13						
TOOB	GLP vs. 4270 m	0.97	11						
TOOB	GLP vs. 5338 m	0.89	12						
RTT	GLP vs. 5338 m	−1.90	5						
RTI	GLP vs. Recovery	−1.28	7						

Marginal means are listed followed by standard errors of the mean in parentheses "()". Right two columns list two-tailed contrast; "x" indicates *t* significance at $\alpha = 0.05$. Cohen's d indicates effect size. Brackets "[]" indicate trends approaching significance ($0.05 < \alpha < 0.1$). Bottom rows indicate comparisons of potential interest in future studies including milder, 4270-m exposure, with projected sample sizes.
PICT: precision instrument control; UAR: unusual attitude recovery; DF: degrees of freedom; GLP: ground level pressure; SIG.: significance; NS: not significant; L/R: left/right.

Inhalation tidal volume (V_T) was recorded in L/breath by integrating mask flow across breath duration. Ventilation $(\dot{V}_E)$ in $L \cdot min^{-1}$ comprised the product of f and V_T. A peak-finding algorithm was applied to the spectrophotometric mask data to identify end-tidal minimum O_2 and maximum CO_2 concentrations within each breath. These were entered in a conversion equation, which accounts for water vapor pressure (not registered by the spectrometer) using an assumed value of 47 mmHg to calculate end-tidal partial pressures ($P_{ET}O_2$ and $P_{ET}CO_2$). (Note that assuming this fixed vapor pressure introduces some imprecision to $P_{ET}O_2$ and $P_{ET}CO_2$ calculations.) Mean f, V_T, $\dot{V}_E$, $P_{ET}O_2$, and $P_{ET}CO_2$ values were calculated across breaths within each epoch and averaged across flights.

RESULTS

Pilot performance metrics are shown in **Table I**. Among PICT metrics, Epoch influenced FSE [$F(4, 24) = 4.0$, $P < 0.02$], with contrasts identifying greater normalized piloting error during 17,500 ft (5338 m) and Recovery than GLP. TOOB varied with Epoch [$F(4, 24) = 4.6$, $P < 0.01$], with subjects exceeding corridor boundaries longer during 5338 m and Recovery than GLP, though the former difference missed significance ($P = 0.057$). **Fig. 1** illustrates FSE and TOOB means by Epoch.

Among UAR metrics, RTT varied with Pitch [$F(1, 6) = 17.0$, $P < 0.01$], but not Bank [$F(1, 6) = 4.5$, $P = 0.078$] or Epoch [$F(4, 24) = 2.0$, $P = 0.121$], though a contrast identified shorter RTT at 17,500 ft (5338 m) vs. GLP; a Bank*Pitch interaction was identified [$F(1, 6) = 13.8$, $P < 0.02$] whereby the gain from starting pitch-down was greater with shallower bank. The nondirectional RTI metric varied with Epoch [$F(4, 24) = 5.8$, $P < 0.003$] and Pitch [$F(1, 6) = 10.2$, $P < 0.02$], with faster initial responses recorded during Recovery vs. GLP, and no interaction. With correct response direction considered in the RTC metric, only the Pitch effect remained [$F(1, 6) = 7.3$, $P < 0.05$]; subjects responded sooner in pitch-up attitudes, with no interactions or Epoch effect identified. We note that while analyses of variance are typically robust against nonnormality, the Kolmogorov-Smirnov test detected some departure from normality in the UAR metrics.

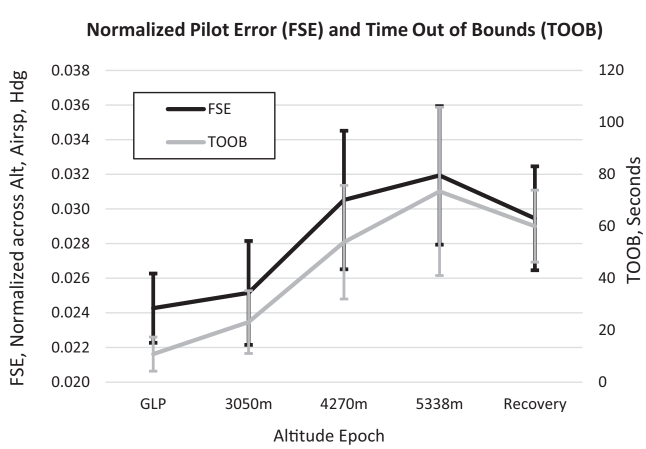

Fig. 1. Mean precision piloting error metrics recorded across five altitude epochs. FSE represents RMS error across altitude, airspeed, and heading parameters (metric is normalized and dimensionless). TOOB represents total duration of all data intervals in which a subject permitted any of the parameters to exit the corridor boundaries. Bars represent the standard error of the mean in each epoch.

Physiology metrics also exhibited nonnormality, but nevertheless showed striking variation among altitude conditions (**Table II**). S_pO_2 varied with Epoch, with lower values at 17,500 ft (5338 m) than GLP. HR varied with Epoch, with higher values at 17,500 ft (5338 m) than GLP and lower values during Recovery. Mean respiration rate remained largely uniform from GLP throughout exposure, but decreased during Recovery (see **Fig. 2**, which also illustrates S_pO_2). V_T and $\dot{V}_E$ varied across Epoch, with subjects inspiring more L/breath and more L/min at 17,500 ft (5338 m) vs. GLP. $P_{ET}O_2$ decreased at altitude vs. GLP. $P_{ET}CO_2$ also decreased at altitude, with lower means at 17,500 ft (5338 m) and in Recovery.

DISCUSSION

The primary study objective was accomplished: the apparatus was shown to be effective for measuring moderate hypoxia effects. While the study's limited scope marks findings as preliminary, the paradigm proved sufficiently sensitive to detect performance changes, associated mainly with piloting precision, in a hypoxia regime where measured effects are typically subtle,[5,16] while continuously monitoring a meaningful group of physiological metrics. In PICT, the normalized FSE and temporal TOOB metrics both indicated effects of progressive hypoxia, whereby piloting error increased with altitude and remained elevated relative to baseline levels. Observed findings extended from psychophysical to physiological domains and included both direct and indirect hypoxia markers. Hypobaria elicited a classic altitude response in which subtle piloting impairment was accompanied by indicators of hypoxia (decreased S_pO_2 and $P_{ET}O_2$, elevated HR), hyperventilation (elevated V_T and $\dot{V}_E$), and hypocapnia (decreased $P_{ET}CO_2$).

UAR findings were more complex; while the task offers a promising instrument, no coherent configuration of effects emerged, and our observations suggest that subjects required more training and were distinguished by individual performance differences. In RTT, attaining stability from pitch-up probably took longer because controls responded sluggishly on a slowing aircraft model. Conversely, faster initial RTI and RTC responses in pitch-up trials could be explained perceptually: since pitch-up HUD symbology is solid, it might be processed faster than the dashed pitch-down indicators. The effect of Epoch on UAR was ambiguous; responses were not slowed during exposure and contrasts indicated accelerated responses at altitude in RTT and during recovery in the nondirectional RTI response. It is possible that subjects continued to learn throughout UAR testing, accelerating responses in later epochs. Alternatively, these contrasts resemble an earlier observation of decreased RT in executive tasks during

Table II. Physiological Metrics: Means by Epoch.

METRICS	GLP	3050 m	4270 m	5338 m	RECOVERY
O_2 saturation (S_pO_2; %)	97.9 (0.5)	92.1 (0.7)	85.7 (1.2)	79.5 (1.6)	97.7 (0.4)
Heart rate (HR; bpm)	79.1 (5.0)	83.9 (5.1)	88.1 (5.2)	93.0 (5.3)	76.2 (4.9)
Respiration rate (f; breaths/min)	14.9 (0.6)	14.8 (0.6)	15.1 (0.5)	14.9 (0.7)	12.2 (0.9)
Tidal volume (V_T; L/breath)	0.699 (0.027)	0.742 (0.029)	0.806 (0.037)	0.929 (0.059)	0.859 (0.091)
Ventilation ($\dot{V}_E$; L/min)	10.4 (0.3)	11.0 (0.3)	12.1 (0.5)	13.7 (0.6)	10.3 (1.1)
End-tidal O_2 (PP $P_{ET}O_2$; mm)	108.0 (5.0)	65.8 (4.3)	53.5 (3.9)	45.0 (3.5)	104.2 (6.5)
End-Tidal CO_2 (PP $P_{ET}CO_2$; mm)	32.5 (4.4)	30.4 (4.0)	28.3 (3.7)	25.9 (3.4)	29.0 (4.1)

Marginal means are listed followed by standard errors of the mean in parentheses.

hypoxia,[2] which could be explained as a speed-accuracy trade-off. This could be tested in future studies incorporating more training and larger sample sizes to determine whether subjects recovering from altitude execute corrections sooner and with less inhibition.

The persistent elevation in PICT error metrics bears comparison to various findings of post-hypoxic impairment, which have been referred to as "hypoxia hangover." Lingering impairment has been reported in paradigms where S_pO_2 recovered rapidly, suggesting that S_pO_2 might not be the only predictor of postexposure performance and that other, slower-recovering factors such as cortical perfusion, inflammation, or axonal potentiation be considered.[4,14] Here, metrics of precision piloting error remained elevated after exposure even as S_pO_2 recovered swiftly. Seeking to explain this, we observe that $\dot{V}_E$ increased with altitude as $P_{ET}CO_2$ decreased, embodying a combination of hyperventilation (a hypoxia sequela) with hypocapnia (depressed CO_2), which can induce respiratory alkalosis,[11] cognitive deficits,[7,8] and attendant chemoreceptor responses that could require 45–100 min for recovery.[9,10]

To account for effects during recovery, the most parsimonious explanation is that hypobaria, combined with progressive hypoxia-induced hyperventilation of considerable duration—at least 33 min above 10,000 ft (3050 m)—resulted in respiratory alkalosis that recovered more slowly than S_pO_2. Consistent with this, persistently ragged piloting could be an indicator of incomplete neurocognitive recovery while compensatory respiratory inhibition engaged to counter the effects of hypocapnia. Future studies should investigate with greater temporal resolution indicators of delayed psychomotor recovery, including elevated FSE, and physiological indicators, including $P_{ET}CO_2$ and respiration rate.

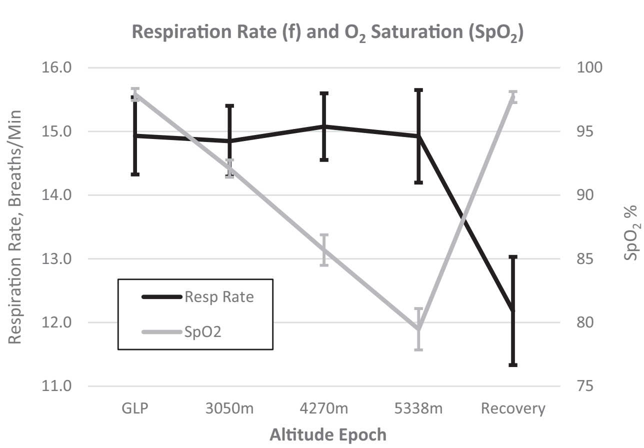

Fig. 2. Mean respiration rate (f) and percentage of oxygenated hemoglobin (S_pO_2) recorded across five altitude epochs. Bars represent the standard error of the mean in each epoch.

The primary limitation of this exploratory study is its modest statistical power. In recognition of this, these findings justify a robust subsequent effort to refine this paradigm for measuring piloting impairment and recovery. Future studies can incorporate larger samples (Table I recommends sample sizes to guide specific comparisons) and counterbalanced presentation. Future UAR applications should also include more training.

Existing findings regarding hypoxia and hypocapnia etiology and recovery indicate that moderate altitude exposure induces changes in executive processing, early perception, and auditory performance which may persist after blood O_2 saturation has recovered but CO_2 concentration may not have. This study demonstrates a hypobaric test paradigm to characterize altitude-related changes in a broad range of additional constructs, including precision piloting and respiration.

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MARCH 1998

CO_2 in the space environment (DLR-Institute of Aerospace Medicine, Linder Höhe, Köln, Germany): "For the operation of manned spacecraft, the removal of CO_2 from the cabin atmosphere, produced by its inhabitants, is essential. This is accomplished by chemical absorption in a gas processing unit, a process which requires energy and consumables. Therefore, in terms of resource management, the CO_2-level should be kept as high as possible. Otherwise, considering crew health and performance and also the interference with life science experiments, the CO_2 load should be as on Earth, close to zero. In order to obtain more information about the permissible CO_2 level for future space missions and also to clarify Space Station design criteria, NASA-ESA-DARA have initiated a ground-based simulation study with two different CO_2 levels: 0.7% (first campaign) and 1.2% CO_2 (second campaign). For this study the deep diving facility of DLR was used to provide atmospheric control and long-term habitation for the test subjects in studying the effect of increased CO_2 on physiological and psychological functions. A number of experiments were implemented, which tested selected effects of raised CO_2 on humans. Four male subjects stayed in the chamber for 26 d in each campaign, in order to perform the different tests in repeated trials, with the aim of evaluating possible long-term effects. CO_2 was controlled by absorption with soda lime, flushing with fresh air and the addition of CO_2, if necessary. Essentially, the CO_2 produced by the subjects was used to maintain the level at 0.7 and 1.2%, respectively. Basic control of CO_2 was carried out in the soda lime container of the Life Support System. In order to maintain the required level, the amount of gas flowing through the soda lime could be adjusted by a remote controlled bypass. With this set-up it was possible to keep CO_2 at an average level between 0.67 and 0.73% in the first campaign and between 1.17 and 1.23% in the second campaign. The results of the experiments support the current CO_2 limits for space operations, insofar as values around 1% do not impose any severe restrictions to human habitation for at least several weeks, whereas life sciences experiments especially sensitive to CO_2 influences have to be carefully evaluated for possible interferences."[3]

MARCH 1973

Combined effects of noise and vibration (Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, OH): "In our laboratory vibration has been shown to be the primary cause of performance impairment in studies of the combined effects of noise and vibration on human tracking performance. Noise has had little consistent effect when presented alone, and has added little or not at all to the impairment produced by vibration. In two studies with heat included as a third stressor, vibration presented alone had a slightly more adverse effect on tracking performance than combined heat, noise and vibration. In the present experiment, 12 subjects were exposed to lower noise and vibration levels for a longer period of time than used previously. Subjects were tested under the following conditions: (1) no vibration–60 dB (dB re 20 $\mu N/m^2$) noise; (2) no vibration–100 dB noise; (3) 6 Hz vibration at 0.10 g_z (peak)–60 dB noise; and (4) 6 Hz vibration at 0.10 g_z–100 dB noise. Noise had no significant effects on tracking performance, while vibration adversely affected both dimensions of the tracking task. On both horizontal and vertical tracking, vibration combined with 60 dB noise produced greater impairment than vibration combined with 100 dB noise. These results parallel previous findings from studies of combined noise, heat, and vibration, and give support to a subtractive interaction interpretation of the combined effects of noise and vibration on human tracking performance."[2]

MARCH 1948

Safety of air evacuation (U.S. Army Air Forces): "During the past five years, the Army Air Forces moved approximately 1,360,000 patients by air. This figure includes those patients who were evacuated from forward medical installations, those who were evacuated from the theaters of war to the Zone of the Interior, and those moved from one hospital in the United States to another for more specialized treatment…

"Forty-six deaths [occurred during this period]…"

"In conclusion, it may be stated that almost any patient suitable for evacuation by any means may safely be transported by air. Precautions to prevent deaths or ill results from air evacuation must include, first, the presence of a physician trained in air evacuation at the point of origin in order to turn down nonacceptable cases, and second, the attendance in flight by a well-trained and well-equipped medical team consisting of a flight nurse and a medical technician. In accepting patients for air evacuation, as in all aspects of medicine, the importance of accurate diagnosis cannot be overemphasized. The case reports at least in part confirm the soundness of the criteria for acceptance of patients for air evacuation."[1]

Civil aviation medicine research (presented at the 18th annual meeting of the Aero Medical Association, Atlantic City, NJ, 1947): "Civilian aviation medicine research has for many years lagged seriously behind the military and has lived a catch-as-catch-can existence. It can no longer afford to do so if the United States is to maintain its aviation superiority. The greatest lesson to be learned from attempting to apply military research to civilian aviation is the necessity for a tremendous increase in civilian aviation medicine research."[4]

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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 from Mira LibrarySmart via https://submissions.miracd.com/asmaarchive/Login.aspx.

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Welcome Stella, the Blue Journal's New Editorial Assistant

With Pam Day's retirement and Rachel Trigg becoming the Managing Editor, a new assistant was needed. Stella Reneke (pronounced ruh-NEEK) was hired at the end of 2022 and started in mid-January 2023. AsMA welcomes our new Editorial Assistant for *Aerospace Medicine and Human Performance*. Here is her introduction in her own words.

Hi everyone,

It is good to be here! I am excited to get to know all of you, so let me begin by offering a bit of background about myself.

I have Bachelor of Arts degrees in both Journalism (specializing in Photo/Video) and Philosophy, plus a minor in Cognitive Science, from the University of North Carolina at Chapel Hill. During my studies, I worked as a columnist and photographer for *The Daily Tar Heel* and volunteered as an Adult GED and ESOL tutor with the Orange Literacy Council. I also became an active member of the Carolina Neuroscience Club and was recruited for a multidisciplinary research colloquium created by the Department of Psychology and Neuroscience. Simultaneously, I spent 3 years as a copyeditor for the Department of Allied Health Sciences. I even enjoyed a summer studying Nonprofit Management in India through the University of Florida and started the following summer as a Communications Intern for a child welfare nonprofit, both of which reaffirmed my passion for serving others through the dissemination of information.

After graduation, I returned to my hometown of Gainesville, FL, and dabbled in library work. I also volunteered as the Director of Communications for a budding legal empowerment nonprofit, helping them develop and standardize a mission statement, values, and other company rhetoric. Then in the summer of 2020, I moved to Pensacola, FL, and began teaching English Language Arts at a Title I public middle school. I taught there until I earned this position and made the move up to Alexandria, Virginia.

Currently, I am pursuing a Publishing Master of Professional Studies degree from George Washington University. On a more personal note, I am also (very) excited to announce that after April of this year, you will have to re-learn my name. I am marrying my fiancé, Adam Sanchez, shortly before our Annual Scientific Meeting this spring, so please forgive me if I stumble a bit when we meet in person. I will still be getting used to introducing myself as Stella "Sanchez!"

After my first week as your new Editorial Assistant, I can only say that I am sincerely grateful to have joined such a wonderful team of people, whose kindness has already made me feel at home. I look forward to spending the next big chapter of my life with the Aerospace Medical Association and continuing to grow alongside all of you, both personally and professionally.

Warmest wishes,
Stella Reneke

Ever Upward

For the latest, please read our newsletter online: http://www.asma.org/news-events/asma-news-archive/newsletters.

Winners of the 2022 AsMA Fellows Scholarship

The AsMA Fellows Scholarship Committee is pleased to announce their selection of the 2022 scholarship winners. The 1st Place Winner was Bonnie Posselt for her presentation and published manuscript on "Human Performance Using Stereo Symbology in a Helmet Mounted Display & Association with Individual Stereoacuity." The 2nd Place Winner was Thomas Abitante for his presentation and manuscript on "Peak Hip Reaction Forces During Neuromuscular Electrical Stimulation of the Thigh Muscles".

Bonnie Posselt

Thomas Abitante

The AsMA Fellows Scholarship is funded by the AsMA Foundation and is presented annually to two AsMA members who are students in an aerospace medicine residency program, graduate program in aerospace medicine (Master or Ph.D.), medical certificate or aerospace diploma course, or in a full time education/training program in the allied fields of nursing, physiology, human factors, psychology, ergonomics, and engineering. Selection criteria include delivering a slide or poster presentation as a first author at the AsMA Annual Scientific Meeting and then submitting a manuscript as first author for publication in AsMA's *Aerospace Medicine and Human Performance* (AMHP) Journal based on the same topic and/or material covered in the slide or poster presentation. The 1st and 2nd Place Winners are selected by the AsMA Fellows Scholarship Committee based on the highest scientific value, originality, quality and relevance of the applicant's presentation and AMHP manuscript related to the field of aerospace medicine (including allied scientific disciplines). Special consideration is given to those applicants who are at an early stage in their career development. The scholarship monetary awards are used for the purpose of underwriting, in whole or in part, the cost of registration fees, transportation, hotel accommodations, or any other valid fees or expenses incurred by the winners in relation to their attendance at one or more scholarly meetings on topics related to aerospace medicine.

Twelve candidates delivered presentations at the 2022 AsMA meeting in Reno, Nevada (first eligibility requirement). Six candidates submitted manuscripts that were approved for publication in the AMHP journal (second eligibility requirement). These six candidates were considered the final eligible candidates for the 2022 scholarship.

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Member News

Serena Aunon-Chancellor, M.D., M.P.H., Associate Fellow of the Aerospace Medical Association (AsMA), and Aerospace Medicine Residency Program Director for the University of Texas Medical Branch (UTMB), was recently featured on an NEJM podcast. The January 3rd edition of NEJM's Resident 360 Curbside Consultants podcast welcomed her and **Dr. Michael Barratt**, a Fellow of AsMA, to discuss aerospace medicine, space tourism, space constraints, and more. To listen, please visit https://resident360.nejm.org/curbside-consults/space-medicine-with-drs-serena-aunon-chancellor-and-michael-barratt.

FAA News

De-Icing Pads at Memphis International Airport

Federal, state, local and business leaders marked the completion of 3.3 million-square-foot de-icing pads at Memphis International Airport, home to FedEx's largest air cargo sorting facility. The pads are large enough to de-ice 12 wide-body cargo aircraft simultaneously, which will help get goods where they need to go quicker and more efficiently this holiday season. The FAA invested $174 million to help make this project a reality. With these innovative de-icing pads at Memphis International Airport, message boards eliminate the need for audio communication with pilots, taxiway lead-in lights eliminate the need for follow-me vehicles or marshallers, and infrared cameras help position airplanes in the de-icing bays. These pads offer more environmentally friendly de-icing procedures with wider safety margins. De-icing planes at a central pad instead of the gate allows an aircraft to depart sooner, reducing the need to de-ice an aircraft again. The new pads have a segregated drainage system and large-volume containers to collect de-icing fluid. The fluid's release is metered into the sanitary sewer system, where it breaks down and helps sanitize city wastewater. The complete press release about this can be found at https://www.faa.gov/newsroom/new-de-icing-pads-will-keep-packages-moving-key-cargo-airport-holiday-season.

Use of Program to Detect, Mitigate Risks Early

The U.S. Department of Transportation's Federal Aviation Administration (FAA) proposed a rule that requires charter, commuter and air tour operators, and aircraft manufacturers to implement a critical safety approach that has helped create the safest era in aviation history. The program, Safety Management System (SMS), is a set of policies and procedures where companies identify, monitor, and address potential operational hazards early on, before they become serious problems. The rule would support the FAA's preventive approach that detects and corrects potential safety issues before they result in accidents or incidents. The FAA has strongly encouraged aviation industry members other than scheduled airlines to voluntarily implement SMS. The proposed rule goes beyond the requirements of the Aircraft Certification, Safety and Accountability Act of 2020, which directed the FAA to mandate SMS only for aircraft manufacturers. The rule also addresses recommendations from the National Transportation Safety Board and independent review panels. Compliance times would vary between one and two years after the rule took effect, depending on the operation. For the full press release, visit https://www.faa.gov/newsroom/faa-proposes-rule-mandating-use-program-detect-mitigate-risks-early.

Jet Companion Becomes a Corporate Member

Jet Companion is a Canadian company that offers medical personnel to travel on a plane with those who need extra care during the trip. Their founder was a flight paramedic who served onboard air ambulances and commercial flights and heard the stories of those who wanted to travel but were frustrated at having to depend on someone else. This became a dedication to assisting people to be able to travel regardless of age or illness. The company now has a mix of nurses, paramedics, and doctors who can serve as travel companions. They also offer an air ambulance service that can handle a variety of medical transport requests as well as a child travel program, repatriation assistance, and other similar services.

—For more information on Jet Companion, please visit their website at https://www.jet-companion.com/.

Future AsMA Annual Meetings

May 21 – 25, 2023
Sheraton New Orleans Hotel, New Orleans, LA

May 5 – 9, 2024
Hyatt Regency Chicago, Chicago, IL

June 1 – 6, 2025
Hyatt Regency Atlanta, Atlanta, GA

May 17-21, 2026
Sheraton Denver Downtown, Denver, CO

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MEETINGS CALENDAR

Please check the websites of meetings listed to see updates.

Calls for Papers—Ongoing: IAF's Global Networking Forum Space Conversations Series, online. For more info, please visit https://www.iafastro.org/events/ iaf-gnf-space- conversations-series/.

HFACS Workshops: Workshops on the The Human Factors Analysis and Classification System (HFACS) are available online and in-person. For more info, please visit https://www.enrole.com/erau/jsp/course.jsp?categoryId=&courseId=HFAC for in-person & https://www.enrole.com/erau/jsp/course.jsp?categoryId=558570F8&courseId=OHFA for online.

March 20-23, 2023; Preventive Medicine 2023; New Orleans, LA. For more information or to register, please visit https://pm2023.acpm.org/.

Upcoming FAA AME Seminars

Dates	Location	Seminar Type
March 20-24, 2023	Oklahoma City, OK	Basic
May 23-26, 2023	New Orleans, LA	AsMA
June 12-16, 2023	Oklahoma City, OK	Basic

For more, visit: http://www.faa.gov/other_visit/aviation_industry/designees_delegations/designee_types/ame/seminar_schedule/.

Aerospace Medicine and Human Performance
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The five types of articles specified below should be submitted through the web site and will undergo peer review. Other submissions 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 layed out below, an exception may be granted. Please contact the Editoiral Office to discuss your submission.*

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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 Introduction 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.

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