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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.

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A Call to Service

Joseph Dervay, M.D., M.P.H., MMS, FACEP, FAsMA, FUHM

It is a distinct honor to serve as the Aerospace Medical Association (AsMA) President for the upcoming 2023–2024 year. I wish to thank Dr. Susan Northrup for her stewardship and leadership of AsMA this past year as President. Her professionalism, friendship, and wonderful demeaner has always been appreciated.

I joined AsMA in 1985 as a new Navy Flight Surgeon. The initial years of involvement were primarily attending Annual Scientific Meetings, balancing scheduling challenges during military deployments and subsequent residency training. A mentor during my early years with AsMA was Dr. Russell Rayman, COL, USAF (Ret.) and former AsMA Executive Director. Dr. Rayman shared with me that "the volunteer effort you put into the unique nature of AsMA will be paid back many-fold in personal satisfaction and integration with a truly wonderful community". How true his words rang! By serving over the years in a host of roles on various committees and leadership positions within AsMA and Constituent groups, I have been privileged to develop tremendous friendships and a litany of professional colleagues within the United States and internationally. Compared to several other organizations in medicine to which I belong, AsMA is truly a home and family, and an organization that will hopefully always be part of the fabric of my life.

Thank you to the Past Presidents who have previously led AsMA. Serving with many of you directly on Council and EXCOM, I have observed your passion and efforts and have learned something from each of you that I hope can be incorporated into my current role. Your advice and counsel will continue to be appreciated.

The Home Office, led by our Executive Director Jeff Sventek, is truly the rudder which keeps AsMA on a steady course. Weathering the challenges and impacts of the COVID-19 Pandemic has been a collective endeavor of the Home Office and AsMA volunteer leadership in maintaining financial resilience and ongoing educational opportunities. How wonderful it has been to see our members returning to in-person meetings and professional exchange.

It is truly inspiring to see the enthusiasm and increased membership in AsMA through the Aerospace Medicine Student Resident Organization (AMSRO). AMSRO member participation in activities throughout AsMA continues to grow to higher levels and is a testament to the importance of mentoring and guiding these wonderful young colleagues.

With upcoming additions of the President's Page, I will be sharing initiatives and goals of our organization that many of you are actively engaged in supporting, and new areas that will be addressed. I urge each of you to consider potential service to AsMA as well as our numerous Constituent and Affiliate organizations. From being a member on various committees, to higher future leadership roles, each of you has a contribution to make, and a perspective to share, that will make AsMA stronger and enrich your sense of belonging to a truly wonderful international community of professionals.

All the best.

Keep 'em flying…and Full Steam Ahead!

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Pilots' Spatial Visualization Ability Assessment Based on Virtual Reality

Mengdi Zhang; Meng Wang; Huimin Feng; Xunyuan Liu; Lihong Zhai; Xianrong Xu; Zhanguo Jin

BACKGROUND: The aim of this study was to investigate the effectiveness of the mental rotation test (MRT) based on virtual reality (VR) in predicting pilots' spatial visualization ability (SVA).

METHODS: Based on VR, 118 healthy pilots' SVA were evaluated by MRT. The pilot flight ability evaluation scale was used as the criterion of test validity. According to the scale score, pilots were divided into high, middle, or low spatial ability groups pursuant to the 27% allocation principle. Differences in reaction time (RT), correct rate (CR), and correct number per second (CNPS) of MRT between groups were compared. Correlations between scale scores and MRT scores were analyzed. RT, CR, and CNPS of MRT among different age groups and between genders were also compared.

RESULTS: The RT of the high spatial ability group was remarkably slower than that of the low spatial ability group (363.4 ± 140.2 s, 458.1 ± 151.7 s). The CNPS of the high spatial ability group was dramatically higher than that of the low spatial ability group (0.111 ± 0.045 s, 0.086 ± 0.001 s). There were no significant differences in RT, CR, and CNPS between different genders. Pilots in the 29–35 yr old age group had considerably slower RT than those in the 22–28 yr old age group (330.8 ± 140.3 s, 417.2 ± 132.7 s). Pilots in the 29–35 yr old age group had conspicuously higher CNPS than pilots in the 22–28 yr old age group (0.119 ± 0.040 s, 0.096 ± 0.036 s). All pilots' scale scores were positively correlated with CNPS ($r = 0.254$) and negatively correlated with RT ($r = -0.234$).

DISCUSSION: MRT based on VR has a good discrimination efficacy for SVA of pilots and is a good indicator for the SVA component measurement.

KEYWORDS: visual reality, pilot, visualization, mental rotation, spatial ability.

Zhang M, Wang M, Feng H, Liu X, Zhai L, Xu X, Jin Z. *Pilots' spatial visualization ability assessment based on virtual reality*. Aerosp Med Hum Perform. 2023; 94(6):422–428.

Spatial ability is the individual ability to understand and remember spatial relationships among objects. It is one of the most widely investigated domains of cognitive ability, which is a key element in determining how individuals perceive and interact with their surroundings. Spatial ability enables us to locate targets in space, perceive objects visually, and understand the two-dimensional (2D) and three-dimensional (3D) spatial relationships among objects and the environment.[7] In the course of flight, pilots first need to observe the changes of landmarks through vision, listen to the sound of the engine, and feel the change of acceleration through hearing and proprioception, and then receive, process, integrate, decide, and judge the spatial information to form the perception of the aircraft status. It is of great practical importance to study the basic theory and experimental methods of spatial ability, especially how to predict and train spatial cognitive ability.[11,16] In recent years, one of the key development directions of aviation medicine is how to apply the scientific and technological progress and research achievements of medicine, psychology, and other disciplines to the field of aviation medicine, so as to realize the best model of "human-machine-environment". Some major breakthroughs in the field of cognitive psychology will be applied to pilot selection, training, and medical assessment.

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The study of spatial ability originated in the late 19th century from Western scholars' research on human intelligence, dating back to the experimental investigation of imagination by Galton's. Since then, scholars have defined spatial abilities from multiple perspectives and developed a great variety of measures of spatial ability. So far, research on human cognitive abilities has proposed several kinds of spatial abilities, with partially overlapping distinctions and no complete agreement. Scholars generally believe that spatial orientation and spatial visualization are the stable elements of spatial ability.[14] Spatial visualization describes a variety of complex mental operations on spatial information, such as imagining the rotation of objects, the folding or unfolding of flat patterns, and the ability to change the relative positions of objects, which was one of the important components of spatial ability. Among the traditional measures of spatial ability, the mental rotation test is regarded as the most representative test content for estimating spatial visualization.[10]

With the rapid development of information technology, exploring spatial ability tests with ecology, simulation, and immersion has become an increasing research hotspot for scholars.[1,2,9] The advancement of VR has solved the shortcomings of inferior experience in traditional tests, fewer data analysis indicators, relatively single dimension, and poor visualization, providing a technical feasibility for cognitive psychological science research based on virtual environments.[6,20,25] In this study, based on the Shepard-Metzler Mental Rotation,[21] a spatial ability testing system with an immersive experience was developed by using 3D visualization modeling software and HTC Vive as an interactive experience platform. By comparing the test scores of pilot groups with different spatial abilities, we explored the differences in the mental rotation ability between pilot groups, the differences in spatial ability between different genders and among different age groups of pilots, and the effects of pilots' age and flight time on spatial ability. The results of the present exploratory study show the interest of taking into consideration different spatial abilities, different ages, and different genders in pilots to study the RT, CR, and CNPS based on a VR mental rotation task. In particular, this provides new theories and approaches for predicting pilots' spatial ability, improving the efficiency of pilot selection and training and the quality of medical assessment.

METHODS

Subjects

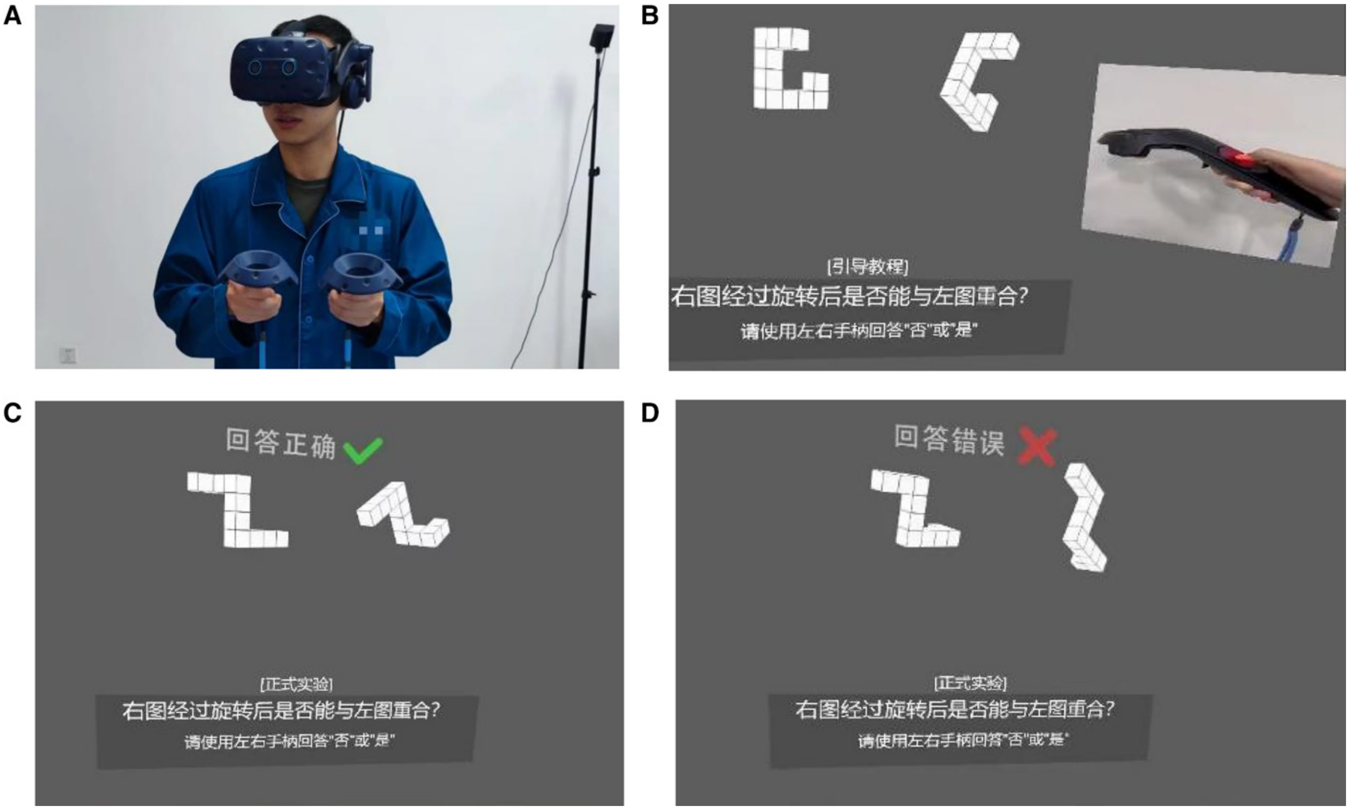
The project was approved by the Ethics Committee of the Air Force Special Medical Center (KT2022-16-SL02), and informed consent was obtained from each subject. The participants were 118 healthy pilots, 22–47 (28.91 ± 7.061) yr of age, with flight time of 260–4500 (1218.69 ± 1060.78) h, including 106 men and 12 women. All participants possessed a bachelor's degree, were right-handed, and had normal vision. All of them could operate the handle skillfully and had no dizziness when wearing the helmet.

Measures

Apparatus. This task was the modification of the original task by Shepard and Metzler.[21] This study used 3D visualization modeling software (3DMAX) to create 3D mental rotation stimuli consisting of 10 cubes, while using the HTC Vive as the interactive experience platform, combined with the Lighthouse base station and Unity3D, to complete the participants' immersive experience in the virtual scene (Air Force Special Medical Center, China) (**Fig. 1**). For subjects' comfort, we used adjustable headbands to fit the head-mounted display during the testing. A pair of operating handles were used to rotate the stimuli and answer a question during the testing as well. By using the handle and head-mounted display, participants could observe and operate the cubes as a first-person viewer. The VR testing was administered on a desktop workstation running Microsoft Windows 10 and equipped with a high-end graphics card. The testing was observed by a researcher through a 24-in light-emitting diode flat monitor, which showed the progress of the program.

Each group of stimuli consisted of eight original stimuli. A total of 96 different morphological stimuli were produced by its original or mirror-reversed version, which was rotated around the Z-axis respectively (30°, 60°, 90°, 120°, 150°, and 180°) clockwise or counter-clockwise from its vertical upright position (**Fig. 2**). One stimulus was randomly selected from the eight original stimuli via the Application Program Interface (API). The original mental rotation stimulus was placed on the left side of the virtual scene space, and the test stimulus was placed on the right side. First, if the right stimulus was the same as the left stimulus (just rotated at different angles), then they were identical. And if the subject could determine that the pair of cubes were identical, the response was correct. If the subject thought the pair of cubes were a mirror image, the response was incorrect. Second, if the right stimulus was formed by the mirror image of the left stimulus, then they were different. And if the subject could judge that the pair of cubes had a mirror-reversed relationship, the response was correct. If the subject thought the pair of cubes were the same (just rotated at different angles), the response was incorrect. There was a total of 48 questions in a test (composed of 24 identical versions and 24 mirror-reversed versions rotated around the Z-axis, respectively). Participants were required to judge, as quickly and accurately as possible, whether a pair of cubes had a mirror-reversed relationship or were identical (just rotated at different angles). The method was to press the VR handle trigger key with the right hand (indicating a "yes" answer, namely coincidence), or press the VR handle trigger key with the left hand (indicating a "no" answer, namely mirror-reversed relationship).

The principle of the questioning adhered to the following logic: four identical versions and four mirror-reversed versions were randomly selected from six angles (30°, 60°, 90°, 120°, 150°, and 180°) to ask questions. Of those questions, 24 contained a cube pair with an identical relationship and 24 contained a pair with a mirror-reversed relationship. Both the order of angles and the order of identical versions or mirror-reversed versions were random.



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右图经过旋转后是否能与左图重合?
请使用左右手柄回答"否"或"是"

回答错误
[正式实验]
右图经过旋转后是否能与左图重合?
请使用左右手柄回答"否"或"是"

Fig. 1. Practical demonstration of the mental rotation test. A) An example of using handle and head-mounted display for testing. B) Screenshot of the tutorial for mental rotation tasks. C) An example of a correct answer (as shown, the two test stimuli are mirrored, and if the subject makes a correct judgement, the answer is correct). D) An example of an incorrect answer (as shown, the two test stimuli coincide, and if the subject cannot make a correct judgement, the answer is incorrect).

VR-based mental rotation test. The subjects were tested individually in a quiet room. Before the experimental session, the participants were informed about the aim of the study, the procedure, their rights, and the possibility of stopping the experiment at any time they chose. Afterward, the participants signed a written informed consent form.

The basic process included four stages: 1) Preparation Stage: firstly, the notes related to this experiment were introduced,

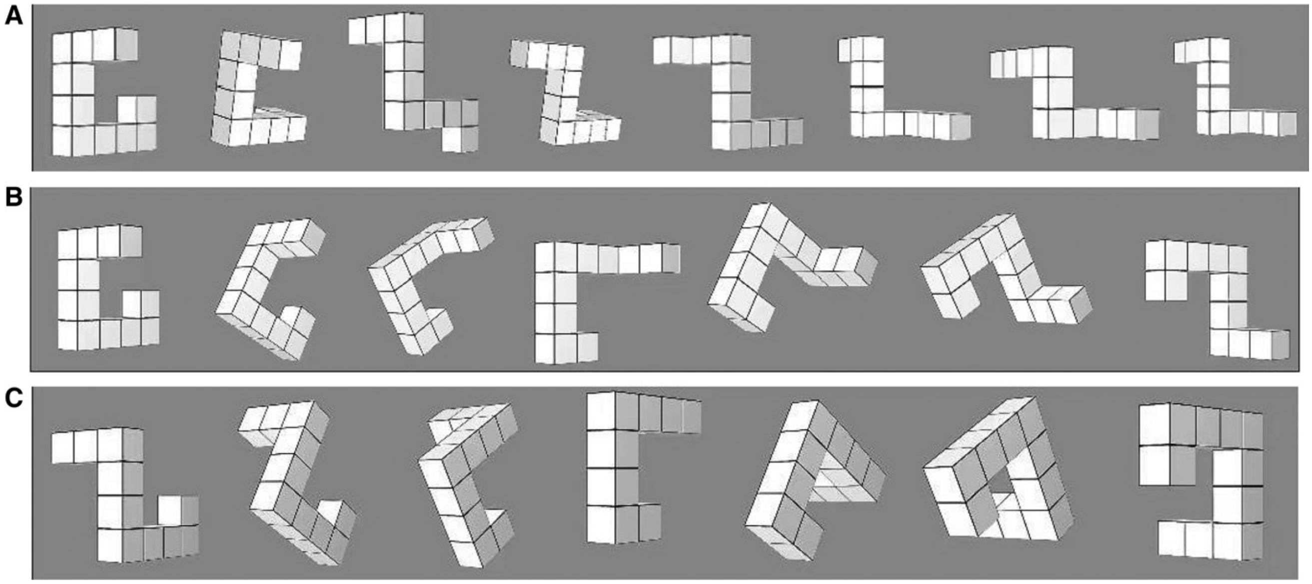

Fig. 2. Presentation of the stimulus of mental rotation test. A) Eight original stimuli. B) One of the eight original stimuli with different rotation angles (0°, 30°, 60°, 90°, 120°, 150°, and 180°). C) Mirroring the stimulus of Fig. 2B with different rotation angles (0°, 30°, 60°, 90°, 120°, 150°, and 180°).

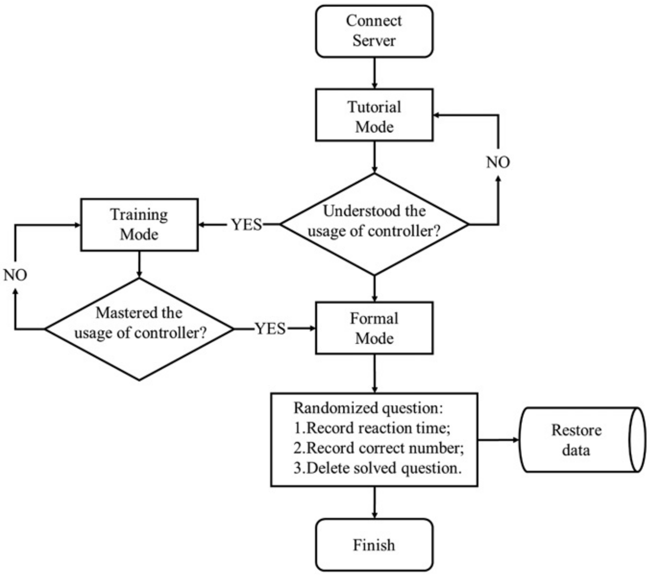

Fig. 3. Flow chart of the experiment.

then the participants read the paper instructions to clarify the task of this experiment; 2) Learning Stage: participants wore VR helmets to watch the guide tutorials, followed the instructions to complete the corresponding keystroke operations, and chose to enter the next stage or learned the guide tutorial stage again by operating the handle; 3) Practice Stage: after completing 10 exercises and thinking that they had mastered the operation keys, the participants entered the formal experiment; 4) Formal Experiment Stage: there were 48 questions, which required participants to respond as quickly and accurately as possible to judge whether the pair of cubes had a mirror-reversed relationship or were identical (just rotated at different angles). The reaction time and the correct number were stored in the local database simultaneously (**Fig. 3**).

Criterion test. The pilot flight ability evaluation scale was used (**Table I**),[12] and, according to the scale scores, the participants were divided into groups based on a 27% allocation principle. The upper and lower 27% rule was commonly used in item analysis based on Kelley's derivation.[8] He stated that 27% should be selected at each extreme to yield upper and lower groups that were most indubitably different with respect to the trait in question. First, the total scale scores were calculated and ranked; then, the first 27% of the total scores ranked from highest to lowest were used as the high spatial ability group (32 cases), the last 27% as the low spatial ability group (32 cases), and the rest as the middle spatial ability group (54 cases).

Statistical Analysis

Data analyses were done with Statistical Package for the Social Sciences (SPSS) 23 package software. Data with a normal distribution were presented as mean ±SD, whereas the data with a nonnormal distribution were described with median, upper, and lower quartiles. The Freeman-Halton Test was used to analyze the categorical variables. One-way ANOVA was used when a quantitative data followed a normal distribution. The Mann-Whitney *U*-test and Kruskal-Wallis test were used when the quantitative data followed nonnormal distribution. The Spearman test was used for the correlation analysis. The criterion for significance was set at 0.05.

TABLE I. Pilot Flight Ability Evaluation Scale.

NO.	QUESTIONNAIRE OPTION
Q1:	How satisfied are you with the subjects you have completed during your actual flight training?
Q2:	How accurate do you think you are in judging various situations during the actual flight?
Q3:	In general, what is the speed and quality when you deal with in-air events?
Q4:	Basically, how well do you think you have accomplished for the flight subjects in all weather?
Q5:	How well do you think you did for your performance in completing the complex, advanced, and special flight subjects?
Q6:	What do you think about your flight training performance in a long time?
Q7:	How do you evaluate your overall reaction ability and reaction speed to the several instruments' information when compared to other pilots in terms of the relevant flight subjects?
Q8:	How well do you think about your ability to control the conditions of the aircraft while completing various flying subjects?
Q9:	How well do you orient the aircraft status by instrument in complex weather conditions?
Q10:	How do you think about your performance on the landing?
Q11:	How often have you experienced the flight illusion?
Q12:	Based on all the factors and your flying performance, what level do you think your flying skills are within the whole regiment?
Q13:	How well do you handle problems in complex situations?
Q14:	How well can you adapt to low altitude and high-speed flight conditions?
Q15:	How well are you able to overcome the illusion of flight once it has occurred?
Q16:	What is your emotion when completing difficult technical movements?
Q17:	How do you think about your speed of refitting and adaption when flying new types of aircraft compared to other pilots?
Q18:	Do you think you are suitable for flying in higher performance aircraft at your current skill level?
Q19:	Do you perform well in aerial target shooting compared to other colleagues?
Q20:	How do you feel about your comprehension skills compared to other colleagues when learning a new flying discipline or maneuver?
Q21:	How do you perform in imitating the new flight maneuvers?

RESULTS

Among the 118 pilots, 32 cases were in the high spatial ability group, 54 cases in the middle spatial ability group, and 32 cases in the low spatial ability group. There were no significant differences in age, gender, or flight time among the three groups [$F(2, 115) = 2.894$, $P = 0.059$; $\chi^2 = 1.553$, $P = 0.535$; $F(2, 115) = 1.950$, $P = 0.147$].

There were significant differences in reaction time (RT) and correct number per second (CNPS) among the high, middle, and low spatial ability groups [458.1 ± 151.7,

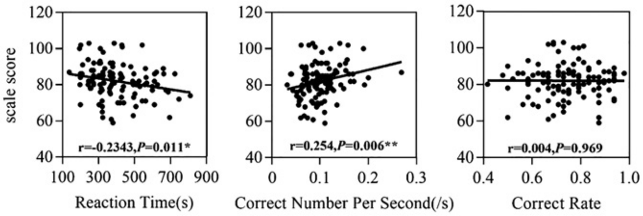

Fig. 4. Correlation analysis of the result of the mental rotation test and calibration test; ** $P < 0.01$; *$P < 0.05$.

386.2 ± 125.6, 363.4 ± 140.2, P = 0.029; 0.086 ± 0.028, 0.102 ± 0.034, 0.111 ± 0.045, P = 0.028, respectively; Kruskal-Wallis test]. RT of the high spatial ability group was remarkably slower than that of the low spatial ability group [363.4 ± 140.2 and 458.1 ± 151.7, respectively; Kruskal-Wallis test, P = 0.030]. CNPS of the high spatial ability group was notably higher than that of the low spatial ability group [0.111 ± 0.045 and 0.086 ± 0.028, Kruskal-Wallis test, P = 0.042].

In this study, there were 106 male pilots and 12 female pilots. There was no distinguishable difference in RT, CR, or CNPS between male and female pilots [394.8 ± 141.0 and 441.7 ± 137.5, P = 0.183; 0.748 ± 0.116 and 0.736 ± 0.161, P = 0.989; 0.102 ± 0.037 and 0.088 ± 0.032, P = 0.247; respectively; Mann-Whitney test].

Remarkable differences in RT and CNPS existed between pilots of different age groups [417.2 ± 132.7, 330.8 ± 140.3, 397.3 ± 151.5, P = 0.017 and 0.096 ± 0.036, 0.119 ± 0.049, 0.100 ± 0.036, P = 0.048, respectively; Kruskal-Wallis test]. Pilots in the age group of 29–35 yr had considerably slower RT than those in the age group of 22–28 yr [330.8 ± 140.3 and 417.2 ± 132.7, respectively; Kruskal-Wallis test, P = 0.013]. Pilots in the age group of 29–35 yr had a dramatically higher CNPS than pilots in the age group of 22–28 yr [0.119 ± 0.397 and 0.096 ± 0.035, respectively; Kruskal-Wallis test, P = 0.042].

Correlation analysis between the scale scores and mental rotation test scores showed that the flight ability of 118 pilots in this study was positively correlated with CNPS (r = 0.254, P = 0.006) and negatively correlated with RT (r = -0.234, P = 0.011) (**Fig. 4**).

DISCUSSION

In the study, using flight skills of pilots in flight practice as a validator, we examined the predictiveness of spatial visualization ability on flight skills with a newly developed immersive spatial mental rotation test and the possible effects of age and gender on test results in this population. The validity scale is closely related to the actual working practice and operating environment, and we found the flight skill level of pilots was significantly positively correlated with CNPS in the virtual mental rotation test, and negatively correlated with RT, which indicates that the spatial visualization test with virtual reality can offer good differentiation and prediction for individuals with different flight abilities. Many researchers have shown that there is a close relationship between operational tasks and cognitive abilities.[3,17] Especially in the aerospace field, strong spatial ability is the basis to ensure the correct flight status and spatial orientation of the pilots.[5] A pilot's workload requires him or her to react to spatial information and process it accurately in as short a time as possible. Therefore, a superior pilot must have excellent spatial ability. It has been demonstrated that a pilot's spatial ability has some predictive value for their flight ability.[4] Superb pilots are more capable in perceptual quick conversion, as well as verbal and graphic memory, and they have superior mental rotation, efficient thinking, and excellent short-term working memory.

In the present study, three groups of pilots with different spatial abilities were required to judge, as quickly and accurately as possible, whether the two stimulus models in the virtual scenario coincided. The results showed significant differences in RT, CR, and CNPS among the high, middle, and low spatial ability groups. The results revealed that the pilots in the high spatial ability group had remarkably slower RT and higher CNPS compared to the pilots in the low spatial ability group. The significant gap between groups illustrated the correlation between pilots' spatial ability and mental rotation ability. This was consistent with the results of previous studies. In a recent study, Roach et al.[15] used a timed mental rotation test to explore differences in the performance of individuals in different spatial ability groups when solving mental rotation tasks, and they found that individuals with high spatial ability showed a strong advantage over individuals with low spatial ability in terms of the time required to complete the test and the accuracy of their answers. Many studies have identified that when the speed of visuospatial tasks is accelerated, the burden on working memory increases and the speed of mental processing becomes a key factor in performance.[26] Thus, the number of incorrect answers may not be directly attributable to a deficiency in ability or the lack of knowledge tested, but instead to their ability to process information with great speed. Too much emphasis on answer speed may mask the ability of individuals with low spatial ability to perform on tests requiring spatial reasoning, and the RT may directly affect concentration during problem-solving and reduce the ability to accurately perform MRTs.

Researchers have demonstrated that adults' cognitive abilities decline gradually with age after reaching optimal levels. Salthouse et al.[18] compared the spatial visualization ability of male subjects in two age groups and found that there was a decreasing trend in spatial visualization test scores with increasing age. Using seven paper-and-pencil tests reflecting basic cognitive ability, Wu et al.[27] explored the differences in the cognitive test scores and the flight ability of pilots in different age groups, and they discovered that the optimal ages of basic cognitive abilities for pilots were between ≥26 and <29 yr of age, with a decline trend after 29 yr. In another study, they also revealed that the short-term memory ability of pilots decreased significantly after 35 yr of age, and the acceleration algorithm and dual operation ability of pilots decreased specifically after 29 yr.[28] This has similarity with the outcomes of our study. There were significant differences in RT and CNPS on the MRT among pilots in various age groups in our study. The pilots in the age group of 29–35 yr had the fastest RT and the highest CNPS in the mental rotation test. In addition, adult cognitive ability generally tends to decline after reaching optimal levels; however, on the MRT in this study, pilots over 35 yr had the higher CNPS, the higher CR, and the slower RT than the younger pilots (<28 yr). There are a few possible reasons. Firstly, mental rotation ability reflects the basic ability to encode and transform spatial graphics. More experienced pilots, who have accepted a greater amount of highly intelligent and informative training, manifest superior spatial cognitive ability and are able to construct mental images of objects in their minds more speedily after rotation. Secondly, it is closely related to the actual working practice and operating environment of pilots. As young pilots have shorter flight time, insufficient flight working experience, and smaller spatial working memory capacity, they fail to adapt to the need to search, process, integrate, and decide on various information decisively and correctly in a shorter period of time, and therefore they have longer reaction latency and reaction time than senior pilots in mental rotation tasks. As a matter of fact, our findings showed a significant difference in the flight time of pilots in different age groups [388.0 ± 125.4, 1682.0 ± 455.2, 2564.8 ± 636.9, $F(2115)=373.1$, $P = 0.000$]. The flight time of the older group was significantly longer than the other two groups. This may be a verification of our assumption. However, we did not investigate the effect of subjects' gaming or VR experience on the experiential criteria of this test, and future studies are needed to explore the impact of prior gaming or VR experience on testing.

A large amount of literature also reports a relationship between space performance and gender.[24] Earlier studies indicated that females lagged in performance in tasks with spatial factors, and the variance between males and females increased with age. However, it has also been indicated that gender difference may be limited and even absent, depending on the stimuli and tasks.[22] Some studies have also pointed out that gender has less effects on cognitive spatial processing speed in the pilots with aviation experience.[13] Gender effects may be associated with lower spatial cognitive abilities, whereas in pilots who are considered to have higher spatial cognitive abilities, there may be an experience factor that leads to no gender differences.[23] In our study, the male and female pilots in our study did not exhibit any noticeable differences in RT, CR, or CNPS in the MRT. Schnable et al.[19] pointed out that the ability to get immediate feedback by interacting with objects in a 3D virtual environment contributed to a better understanding of spatial issues, whereas display effects and technical drawings presented in 2D form generally made it difficult for subjects to intuitively understand space. The VR environment used in our study can realistically simulate the structure of the stimulus after rotation, which can reduce the cognitive load, thus helping to observe and evaluate spatial information more intuitively, improving the processing of spatial perceptual information and compensating for the stress of weaker spatial abilities in females. Besides, our findings showed insignificant differences in RT, CR, and CNPS in consideration of gender in different ages and flight times ($P = 0.454$, $P = 0.207$ and $P = 0.468$). However, a limitation of this study was that there were less female pilot subjects, and possibly different consequences may emerge with subsequent expansion of the sample size.

With the development of VR, it is believed that the experimental research of spatial visualization ability will focus more on the aspect of ecological scenarios, the spatial ability test based on VR will be combined with comprehensive dynamic flight actual tasks, and the test scene will be closer to real flight scenarios, providing a new technical tool for the prediction and training of pilots' spatial cognitive ability.

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Accuracy and Similarity of Team Situation Awareness in Simulated Air Combat

Heikki Mansikka; Don Harris; Kai Virtanen

BACKGROUND: Fighter pilots' Team Situation Awareness (TSA) has been studied from the perspective of TSA accuracy, which represents how closely the pilots' collective knowledge is aligned with the real world. When TSA accuracy is low, the pilots can have similarly or dissimilarly inaccurate SA. The concept of TSA similarity represents the similarity of team members' collective knowledge. This paper investigates how TSA accuracy and similarity of F/A-18 pilots are associated with performance.

METHOD: Data were extracted from simulated air combat missions. Performance and TSA were investigated in 58 engagements. The accuracy and similarity of pilots' SA were elicited and performance was evaluated. TSA accuracy and similarity were analyzed with respect to the flights' performance, and the independent variables were events in which the flights initiated engagements with enemy aircraft versus events in which the flights were engaged by enemy aircraft.

RESULTS: With the mentioned events as the main effect, there were statistically significant differences at all levels of TSA accuracy and similarity. With performance as the main effect, there were also significant differences at all levels of TSA accuracy and similarity. TSA accuracy and similarity were superior in offensive engagements and when engagements were successful.

DISCUSSION: The main contribution of this paper is the extension of the concept of TSA similarity to air combat: both TSA similarity and accuracy were higher when the flight was engaging the enemy aircraft, compared to situations when the flight itself was being engaged. The results also suggest that low TSA accuracy and similarity have a statistically significantly negative impact on the flights' performance.

KEYWORDS: air combat; team performance output; team situation awareness accuracy; team situation awareness similarity.

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In air combat, pilots must repeatedly make tactical decisions. Ideally, the pilots would possess all available knowledge regarding friendly and enemy entities engaged in air combat. In addition, they would have the time and capacity to scrutinize the potential outcome of each decision alternative before making their final decision. Decisions in air combat, however, must be made with incomplete knowledge and there is seldom time to evaluate completely the expected outcomes of even a few alternatives. While pilots may occasionally reach an acceptable outcome simply by chance, the likelihood of being successful increases if the pilots' decisions are based on adequate situation awareness (SA). The dominant theory of SA describes it as a hierarchical construct with three levels.[8] According to Endsley, SA is the perception of relevant elements in the environment (SA level 1), comprehension of their meaning (SA level 2), and a projection of their status in the near future (SA level 3).

For pilots to make good decisions, they do not need to have knowledge about everything around them. In fact, trying to obtain all knowledge about the entities involved in a fast-paced air combat engagement would be extremely slow and thus counterproductive for SA and decision-making. A person's knowledge is organized in a form of mental representations[30] and stored in and transferred between a long term memory (LTM) and a working memory (WM).[1] When the mental

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representations held in LTM are activated (i.e., transferred to WM) and updated with observations, they enable a person to comprehend the situation they are interacting with[17] and to generate descriptions of the situation's observed and predicted states.[25] While the knowledge held in LTM is static and often context-independent, the knowledge in WM is dynamic and context-dependent. These situated and dynamically updated mental representations are referred to as situation models[9] or, more commonly, as SA.[8]

SA is an essential precursor to rational decision-making and response selection, which eventually result in performance outputs.[7] As the outputs modify the environment that a decision-maker is interacting with, the decision-making process essentially forms a reciprocal, cyclical interaction between a decision-maker and the environment.[23] In air combat, both the friendly and enemy pilots have their own decision cycles, often contextualized as Orient, Observe, Decide, Act (OODA) loops.[3] One of the objectives in air combat training is to manipulate the pace of the cognitive and action processes within these loops such that a dominant operational tempo can be achieved.[29]

To gain and maintain a satisfactory SA for timely tactical decision-making, the pilots must allocate their attention and the capacity of their working memory only to the most relevant factors in their tactical environment. An attribute is the smallest relevant unit of which the pilots can have SA; a functional collection of attributes is a concept.[16] For example, a nonfriendly aircraft is a concept whose attributes include position, type, and offensive capabilities, among others.

While there are many different techniques to evaluate pilots' SA, they all essentially attempt to elicit their internal representation of important SA attributes' current and future states. The accuracy of SA is determined by comparing pilots' internally depicted states of the attributes to their states in objective reality, often referred to as "ground truth."[15] The better the pilots' internal representation of the attributes is aligned with the ground truth, the better their SA.

Pilots typically engage in air combat in teams of four (i.e., flights). A flight consists of a flight leader, a two-ship leader, and their wingmen. The flight leader is usually referred to as #1, the two-ship leader as #3, and their wingmen as #2 and #4, respectively. While each pilot has their own internal representation of the flight's task, the flight's tactical environment, and the flight itself,[4] the flight also possesses a shared and organized knowledge regarding these attributes.[19] Terms such as "team mental model," "shared cognition," and "shared knowledge"[12] all essentially refer to this type of common cognitive ground of the flight, each with a slightly different perspective and emphasis. In this paper, the term "Team SA (TSA)" is used to describe the flight members' collective SA.

The relationship between a flight's performance output and TSA is a complex one. For example, a recent study has shown that the relationship is curvilinear, not linear as was previously assumed.[16] In addition, in a highly complex task environment like air combat, the flight's success is not only dependent on the flight's ability to gain and maintain TSA, but also other factors like chance. As a result, equally successful flights can be either good or simply fortunate, and unsuccessful ones can be either unlucky or simply poor. In general, good TSA is an essential contributor to effective decision-making and satisfactory performance output. Therefore, there is a practical need to evaluate flights' TSA in air combat to separate the unfortunate teams from the poor ones.

The flight's TSA has previously been studied almost completely from the perspective of TSA accuracy (TSA ACC).[21] TSA ACC represents how closely the flight's collective knowledge is aligned with the ground truth. For most purposes, the evaluation of TSA ACC is adequate. However, TSA ACC does not draw a complete picture of the nature of the shared knowledge possessed by the flight. For example, the widely used Situation Awareness Global Assessment Technique (SAGAT)[6] estimates TSA based on the overlap of team members' correct responses to SA probes, thus totally ignoring the information about the SA of those team members whose responses are incorrect. If TSA ACC is high, the flight members' SA is closely matched with the ground truth. In such a situation, SA of each flight member is also very similar. If, however, TSA ACC is low, the pilots can have similarly or dissimilarly inaccurate SA. While the idea of TSA similarity (TSA SIM) is not new,[27] two important issues about the flight's collective knowledge in air combat settings are still to be answered. Firstly, previous formal efforts have not investigated how the similarity or dissimilarity of the flight's collective knowledge are associated with its performance output. Secondly, it remains unclear whether team members' similarly or dissimilarly inaccurate SA is better for the flight's performance output. This paper bridges these remaining gaps between TSA as a theoretical construct and air combat as a real-life team activity.

In air combat, the flight's taskwork is what it does, whereas teamwork is about how the flight does it[20] (see the work of Ohlander et al.[22] and Tsifetakis and Kontogianni[28] for more information about teamwork and a recent article by Mansikka et al.[15] about taskwork in an air combat context). Team performance considers the flight's performance output in a given task, whereas team effectiveness takes a more holistic view and takes into account how it achieved it.[11] Both teamwork and taskwork are needed for a flight to be effective[13] as teamwork processes have a mediating role in transforming team members' efforts into the performance output.[18] Finding and intercepting an enemy aircraft are examples of taskwork, whereas teamwork consists of team activities such as closed loop communication, leadership, and development of shared mental models.[26] TSA itself is a product of teamwork.[2] It is an emergent state, which impacts other team- and taskwork processes.[18] This paper concentrates on two critical events related to flights' taskwork: events where the flight engages the enemy aircraft and events where the flight is engaged by the enemy aircraft. An engagement refers to an activity where an aircraft attempts to achieve a weapon firing position against an opposing aircraft, while simultaneously attempting to prevent the opposing aircraft from achieving such a position. This paper explores the mediating role of teamwork in flight's team performance in air combat. More specifically, this paper investigates how TSA ACC and TSA SIM of F/A-18 flights are associated with the flights' success or failure in the events where the flight is either being engaged by the enemy aircraft or vice versa.

METHOD

Subjects

The data were collected during training that the subjects would have undertaken had no experiment existed. In Finland, an ethical review of nonmedical research involving human subjects is based on a set of guidelines drawn up by the Finnish National Board on Research Integrity, TENK. According to the guidelines of TENK, the research configuration of this paper was such that it did not require an ethical review statement from a human sciences ethics committee.

The study was attended by 16 combat-ready F/A-18 pilots. All subjects were men. Their mean flying experience on the F/A-18 was 432 flight hours (SD = 231). All subjects had passed an aeromedical examination within the last 12 mo and were fit to fly. The subjects manned eight simulators to form two friendly flights, each comprising four simulators. The pilots in each flight had flown with each other before the study. A fighter controller was assigned for both flights.

The flight leaders' mean air combat training experience with the F/A-18 was 352 flight hours (SD = 65) whereas the average of the two-ship leaders was 356 flight hours (SD = 183). The mean F/A-18 air combat training experience of the wingmen was 209 flight hours (SD = 150). The F/A-18 air combat training experience of flights varied from 265 to 323 flight hours (SD = 20). The friendly force is hereafter referred to as "Blue" and the enemy force is referred to as "Red".

Equipment

Two types of flight simulators were used in the study: those with manually operated physical controls and others incorporating digital touch screen controls. Both simulators were routinely used in fighter pilot training. Simulators were linked to each other and to the fighter controllers' simulated command and control position via Distributed Interactive Simulation (DIS) connection. Subjects were able to transfer information with each other via datalink and via radio. The systems of both Blue and Red were simulated. The weapon systems were parametrized using probability parameters in order to account for various uncertainties affecting engagements, including probability of detection, probability of guidance, and probability of kill. As in real life, the subjects had to consider these probabilities when making tactical decisions.

Procedure

Data for this study were extracted from air combat missions flown as part of a larger distributed simulator exercise. The exercise included 28 prepared scenarios. Two Blue flights flew in each scenario. Each scenario was repeated twice. Between scenarios, the pilots of the Blue flights were changed such that all 16 subjects were eventually exposed to the same scenarios. As a result, the Blue flights flew a total of 112 missions during the exercise.

Before each scenario, the subjects entered the simulators and the scenario was loaded. The task of Blue varied from scenario to scenario, whereas the task of the computer-generated Red was always to engage Blue. In each scenario, the Blue flights used their standard tactics to complete their tasks, while Red was programmed to replicate threat behavior and tactics briefed for the scenario. The fighter controllers had access to the simulated radar picture of the fighters' operating area. With the help of this radar picture, the fighter controllers assisted their flights with information about the Red entities and other Blue units. Once the simulation was initiated, the scenario was allowed to evolve freely until the training objectives were achieved. The duration of each mission was approximately 40 min.

After each mission, the pilots attended a standard debrief. In the debrief, the pilots had access to their cockpit videos and audio. A computer-animated reconstruction of the mission with all Blue and Red simulation entities was generated to support the mission review. Red Engaged and Blue Engaged events were identified during the debriefs. The Red Engaged event refers to a situation where Blue has launched a weapon against Red. In contrast, the Blue Engaged event refers to a situation where Red has launched a weapon against Blue.

When a Red Engaged or Blue Engaged event was identified, the mission reconstruction and cockpit videos were paused. While paused, the flight identified an SA concept and its attribute which mostly influenced that event's occurrence. These were selected from a list of platform independent concepts and attributes designed for beyond-visual air combat described by Mansikka et al.[16] Once the attribute was identified, the cockpit videos and the mission animation were rewound for 60 s and played again to the point where the engagement occurred. During the replay, the pilots evaluated their SA during that 60-s time period regarding the recognized attribute. The pilots were allowed to pause the replay and zoom the animation in or out while making these evaluations. It was emphasized to the pilots that they should assess their SA as it was during the mission, not as it was during the debrief. It should be emphasized that asking the pilots to evaluate their SA during a previously flown mission with the ground truth simultaneously visible is a standard protocol in air combat debriefs.

Once the replay reached the Red Engaged or Blue Engaged event, the debrief was again paused. During this pause, the pilots first scored their SA accuracy regarding the attribute in question. SA accuracy was scored against SA levels 1, 2, and 3 following the protocol described in Mansikka et al.[16] Scoring was conducted by asking the pilots a question related to each SA level. They selected the most appropriate answer for each question from the list of answers. Each answer alternative was associated with a corresponding SA accuracy score ranging from 1 (most inaccurate) to 3 (most accurate). Use of a simple three-point scale enhanced the reliability of SA accuracy and similarity assessments during the debriefs.[14] The SA accuracy questions, answer options, and SA scores are summarized in **Table I**.

Table I. SA Accuracy Questions, Answer Options, and SA Accuracy Scores.

		ANSWER OPTION AND THEIR CORRESPONDING SA ACCURACY SCORES		
SA LEVEL	SA ACCURACY QUESTION	SCORE 1	SCORE 2	SCORE 3
1	How was your perception regarding the attribute?	Inaccurate. The inaccuracies had a significant negative impact on my tactical decision-making.	Inaccurate. The inaccuracies had no significant negative impact on my tactical decision-making.	Accurate or almost accurate. Possible slight inaccuracies had no significant negative impact whatsoever on my tactical decision-making.
2	How was your understanding regarding the attribute's tactical meaning?			
3	How was your anticipation regarding the attribute's state in the near future?			

The pilots tend to assess the accuracy of their SA against the impact it has on their decision-making. The verbal descriptions of the SA accuracy scores in Table I were worded to support this tendency such that they differentiate the significant negative impact, no significant negative impact, and no negative impact options.

After the SA accuracy scores were acquired, the pilots evaluated the similarity of their SA to that of other flight members. The scoring of similarity was conducted such that first #1 was encouraged to elicit his level 1 SA. The SA elicitation was assisted with the SA elicitation questions presented in **Table II**. Once #1 had verbalized his level 1 SA, #2, #3, and #4 compared their level 1 SA to the verbally expressed SA of #1 and selected the most fitting option from SA similarity alternatives provided in Table II. Each option for similarity was associated with an SA similarity score, which ranged from 1 (most dissimilar) to 3 (most similar). Similar to the scoring of accuracy, the verbal descriptions of the SA similarity scores in Table II were worded such that they would differentiate the significant negative impact, no significant negative impact, and no negative impact options. Secondly, #2 expressed his level 1 SA, while #3 and #4 compared the similarity of their SA to that of #2 in the same fashion as was done in the first step. Thirdly, #3 stated his level 1 SA and #4 evaluated the similarity of his SA compared to that of #3. This procedure was repeated for all SA levels such that the SA similarity of all dyads was obtained.

Once all pilots' individual SA accuracy and similarity scores were obtained, the performance output of the event was determined either as Failure or Success. The Red Engaged event, i.e., a situation where Blue had launched a weapon against Red, can result in two possible performance outputs: the enemy aircraft can either be hit or it can survive. From the flight's perspective, the former is considered Success and the latter is Failure. In comparison, the Blue Engaged event, i.e., a situation where Red had launched a weapon against Blue, has opposite goals and success criteria. In terms of the performance output, a flight member being hit is Failure, and the flight being able to evade is considered Success.

When the individual SA accuracy and SA similarity had been scored and the flight's performance output in the event had been logged, the debrief was continued until the next Blue Engaged or Red Engaged event was identified. At that point, the previously described SA accuracy and similarity scoring as well as the determination of the flight's output performance in the event of interest were repeated. SA accuracy and similarity scoring as well as performance evaluation were limited to critical events, which occurred before the first Blue flight member was killed. The rationale was that after that point, the flight was no longer complete and would have different dynamics than that of a flight of four pilots. In sorties where none of the Blue flight members were killed during the mission, the procedure was repeated until the first Red aircraft was killed. Based on this logic, 58 critical events were included in the analysis: 29 Blue Engaged events and 29 Red Engaged events.

After the debrief, the flight's SA level 1-3 TSA ACC scores for an event were determined by calculating the average of flight members' individual SA accuracy scores in respective SA levels. SA level 1-3 TSA SIM scores were determined in the same fashion by calculating the average of dyads' SA level 1-3 similarity scores for an event. As a result, the flights' TSA SIM and TSA ACC scores ranged from 1 to 3.

RESULTS

TSA ACC and TSA SIM scores were analyzed with respect to flights' performance (i.e., Failure/Success in critical events) and Red/Blue Engaged as independent variables. The unit of analysis was at flight level, not for each individual pilot.

To minimize the family-wise probability of a type I error, SA level 1-3 TSA ACC and TSA SIM data as dependent variables were subject to a single Multivariate Analysis of Variance

Table II. SA Elicitation Questions, SA Similarity Alternatives, and SA Similarity Scores.

		SA SIMILARITY ALTERNATIVES AND THEIR SA SIMILARITY SCORES		
SA LEVEL	SA ELICITATION QUESTION	SCORE 1	SCORE 2	SCORE 3
1	Briefly describe how was your perception regarding the attribute?	Dissimilar. The dissimilarity had a significant negative impact on the flight's tactical decision making.	Dissimilar. The dissimilarity had no significant negative impact on the flight's tactical decision making.	Similar or almost similar. Possible slight dissimilarity had no significant negative impact whatsoever on the flight's tactical decision making.
2	Briefly describe how did you comprehend the tactical meaning of the attribute?			
3	Briefly describe how did you expect the attribute's short term status to change?			

(MANOVA) with main effects of Blue Engaged/Red Engaged events and Success/Failure performance outputs. This also removed the effects of any intercorrelation between the dependent variables on the main effects. All estimates of observed power are based upon an alpha level of 0.05.

Both main effects were statistically significant. There was an overall difference in TSA accuracy and TSA similarity for the Blue Engaged and Red Engaged events (Wilks' Lambda = 0.407; $F_{(6,49)} = 11.918$; $P < 0.001$; partial eta^2 = 0.593; observed power = 1.000) and for the Success and Failure performance outputs (Wilks' Lambda = 0.717; $F_{(6,49)} = 3.231$; $P < 0.01$; partial eta^2 = 0.283; observed power = 0.893). The interaction term was nonsignificant (Wilks' Lambda = 0.812; $F_{(6,49)} = 1.886$; $P > 0.05$; partial eta^2 = 0.188). To aid the interpretation of the multivariate results, the significant main effects were further analyzed using univariate factorial analyses of variance (ANOVA) with each TSA accuracy and similarity level as a dependent variable.

With the Blue Engaged and Red Engaged events as the main effect, there were statistically significant differences at all three SA levels of TSA ACC. At SA level 1 TSA ACC, $F_{(1,54)} = 58.749$, $P = 0.000$, partial eta^2 = 0.520, and observed power = 1.000. At SA level 2 TSA ACC, $F_{(1,54)} = 44.606$, $P < 0.001$, partial eta^2 = 0.452, and observed power = 1.000. At SA level 3 TSA ACC, $F_{(1,54)} = 37.534$, $P < 0.001$, partial eta^2 = 0.410, and observed power = 1.000. In all cases, TSA ACC was significantly superior when friendly forces were engaging the enemy (i.e., in Red Engaged events) than when the friendly forces were being attacked (see **Table III**). With TSA SIM as the dependent variable, again, all three univariate ANOVAs were significant. At SA level 1 TSA SIM, $F_{(1,54)} = 43.301$, $P < 0.001$, partial eta^2 = 0.445, and observed power = 1.000. At SA level 2 TSA SIM, $F_{(1,54)} = 39.604$, $P = <0.001$, partial eta^2 = 0.423, and observed power = 1.000. At SA level 3 TSA SIM, $F_{(1,54)} = 33.987$, $P < 0.001$, partial eta^2 = 0.386, and observed power = 1.000. TSA SIM at all three SA levels was better when Blue was engaging Red than when Red was engaging Blue (see Table III).

With the Success and Failure performance outputs as the main effect, there were also statistically significant differences at all three SA levels of TSA ACC. At SA level 1 TSA ACC, $F_{(1,54)} = 8.647$, $P < 0.01$, partial eta^2 = 0.138, and observed power = 0.823. At SA level 2 TSA ACC, $F_{(1,54)} = 5.340$, $P < 0.05$, partial eta^2 = 0.090, and observed power = 0.622. At SA level 3 TSA ACC, $F_{(1,54)} = 14.684$, $P < 0.001$, partial eta^2 = 0.214, and observed power = 0.964. In all cases, TSA ACC was significantly superior when the performance was Success compared to Failure (see Table III). With TSA SIM as the dependent variables, again, all three univariate ANOVAs were statistically significant (SA level 1 TSA SIM: $F_{(1,54)} = 4.869$, $P < 0.05$, partial eta^2 = 0.083, observed power = 0.582; SA level 2 TSA SIM: $F_{(1,54)} = 4.717$, $P < 0.05$, partial eta^2 = 0.080, observed power = 0.569; SA level 3 TSA SIM: $F_{(1,54)} = 10.564$, $P < 0.01$, partial eta^2 = 0.164, observed power = 0.891). TSA SIM was always better when the performance output of a flight was Success rather than Failure.

DISCUSSION

TSA is a product of teamwork and an essential contributor for the flights' decision-making and performance output in air combat. Previous studies of TSA have mainly concentrated on TSA ACC[21] and to the authors' knowledge SA SIM has not been investigated in air combat context before now. In this paper, both TSA ACC and TSA SIM were analyzed. When TSA ACC is low, the team members' SA could be either similarly or dissimilarly inaccurate. It is reasonable to assume that when the team members' SA ACC is low, as often is the case in complex and dynamic environments, it is quite likely that their SA is at least to some extent dissimilar. Therefore, to better understand

Table III. Means (M), Standard Deviations (SD), and Sample Sizes (*N*) Of SA Level 1-3 TSA ACC and TSA SIM Scores for the Blue Engaged and Red Engaged Events and the Performance Outputs, i.e., Failure and Success of those Events.

		BLUE ENGAGED			RED ENGAGED			TOTAL		
		M	**SD**	***N***	**M**	**SD**	***N***	**M**	**SD**	***N***
SA level 1 TSA ACC	Failure	1.40	0.48	15	2.73	0.58	14	2.04	0.85	29
	Success	2.04	0.85	14	2.97	0.13	15	2.52	0.75	29
	Total	1.71	0.74	29	2.85	0.42	29	2.28	0.83	58
SA level 1 TSA SIM	Failure	1.53	0.68	15	2.62	0.61	14	2.06	0.84	29
	Success	1.92	0.79	14	2.94	0.22	15	2.45	0.77	29
	Total	1.72	0.75	29	2.79	0.48	29	2.25	0.82	58
SA level 2 TSA ACC	Failure	1.53	0.65	15	2.73	0.58	14	2.11	0.86	29
	Success	2.04	0.85	14	2.97	0.13	15	2.52	0.75	29
	Total	1.78	0.78	29	2.85	0.42	29	2.31	0.83	58
SA level 2 TSA SIM	Failure	1.56	0.72	15	2.61	0.61	14	2.06	0.85	29
	Success	1.93	0.80	14	2.94	0.22	15	2.46	0.76	29
	Total	1.74	0.77	29	2.78	0.47	29	2.26	0.82	58
SA level 3 TSA ACC	Failure	1.40	0.57	15	2.39	0.60	14	1.88	0.77	29
	Success	2.04	0.85	14	2.95	0.14	15	2.51	0.75	29
	Total	1.71	0.78	29	2.68	0.51	29	2.19	0.82	58
SA level 3 TSA SIM	Failure	1.44	0.69	15	2.33	0.60	14	1.87	0.78	29
	Success	1.92	0.79	14	2.91	0.24	15	2.43	0.76	29
	Total	1.67	0.77	29	2.63	0.53	29	2.15	0.81	58

the shared knowledge possessed by a flight, it is necessary to measure its SA SIM together with SA ACC.

While high TSA ACC and TSA SIM are not necessarily the flights' primary objectives or end-states, these emergent states have a role in the flights' success.[18] High TSA ACC and TSA SIM contribute to the flights' performance output by enabling effective coordination of the flight members' activities. Coordination can be either explicit or implicit.[10] With high TSA ACC and TSA SIM, the flight members are able to anticipate each other's actions and information needs without having to communicate the activities regarding decision-making.[24] As such, implicit coordination enables the team to rapidly synchronize its members' activities. If TSA SIM is low, the flight has to rely on communication to explicitly coordinate its work. Situations where both TSA ACC and TSA SIM are low can be highly confusing to the team and may require excessive communication to enable coordinated action. Situations where TSA ACC is low and TSA SIM is high can cause different issues as the team may not even recognize the need for explicit coordination. In both cases, the teams' performance output is likely to fall short of its full potential. Communication as a means of coordination in air combat is slow and vulnerable to deception and jamming. In summary, high TSA ACC and TSA SIM have an essential mediating role in enabling a flight's critical coordination functions and eventually leading to a team's success in air combat (see Table III).

The tasks of engaging an aircraft and being engaged by aircraft have fundamentally conflicting objectives and involve different piloting activities. However, purely from the perspective of pilots' technical and mental demands, the difference between these tasks is unclear. To the authors' knowledge, the existing literature does not present evidence of one type of task being more demanding than the other one. The results of this study clearly indicate that both TSA ACC and TSA SIM were higher when the flight was engaging the Red aircraft, compared to situations when the flight itself was being engaged. It can be rationalized that high accuracy and similarity enabled the flights to grasp the initiative and reach such a tactical advantage that they were able to engage Red. However, not even the highest TSA ACC and TSA SIM can guarantee success in every Red Engaged situation. For example, after Blue had released its weapon at desired launch parameters, Red sometimes performed aggressive evasive maneuvers which resulted in Blue Failure—or Red Success, depending on the perspective. Weapons such as modern air-to-air missiles are technical systems which hit their target with a certain probability affected by several factors. Pilots can manage those probabilities only to a certain extent. In contrast, it is likely that the combination of low TSA ACC and low TSA SIM created coordination problems within the flight which eventually resulted in a flight member being engaged. Even then, reasonable accuracy and similarity enabled the flight to recover from the adverse situation. As the results indicate, in the Blue Engaged situations which resulted in Failure, TSA ACC and TSA SIM were lowest compared to situations which led to Success. The results support an argument that as the flights had reached a tactical advantage, they were in a better position to control the situation and it was relatively easy for them to maintain control once they gained high TSA. In comparison, when the flights had already lost the advantage, there was an increased risk of them becoming reactive. Once that happened, regaining lost TSA became difficult, effective decision-making suffered, and the flights' performance output deteriorated.

The results of the individual univariate ANOVAs decomposing the main effects show that when Red/Blue Engaged was the independent variable, TSA ACC and SIM at level 1 accounted for the most variance, followed by TSA ACC and SIM at levels 2 and 3. This complements the results observed by Mansikka et al.,[16] which suggested that the relationship between TSA and performance was curvilinear. When engagement Success/Failure was the main effect, though, TSA ACC and SIM at level 1 still accounted for more variance than level 2, but the greatest variance in a successful engagement was TSA ACC and SIM at level 3, i.e., the ability to project ahead.[8]

All statistically significant results suggested a substantial size of effect, with the vast majority of them having partial eta-squared values of well in excess of 0.14, which is considered to be large.[5] The significant main effects accounted for 28–59% of the experimental variance, suggesting that the results had substantial functional differences. The variance accounted for in TSA ACC and SIM at each level of TSA was substantially smaller, accounting for 8–16%. However, the majority of significant results had an observed power greater than 0.8, suggesting a type II error probability of below 0.2 in most cases.[5]

While the concept of TSA SIM has been discussed in theory and investigated in several domains, it has not, until now, been applied to air combat. While it is logical that low TSA SIM can only appear together with low TSA ACC, the results of this study clearly indicate that low TSA SIM has a statistically significantly negative impact on the flights' performance output (see Table III). The situation becomes more complex if low or high TSA SIM are accompanied by low TSA ACC. Answering these questions opens interesting possibilities for future research.

The overall approach and findings of this paper should be useful for those responsible for the administration of air combat training curricula. If low TSA ACC and TSA SIM repeatedly occur in a certain training situation among pilots undergoing a similar training program, the observation can be used to detect latent issues in the training curriculum. In addition, if the pilots frequently face training situations where both TSA ACC and TSA SIM are low, the finding should motivate the training organization to look for fundamental errors of omission in the contents of the pilots' training curriculum. Also, situations resulting repetitively in low TSA ACC and high TSA SIM can reveal training items accidently left out of the training curriculum. It should be noted, however, that like any retrospective elicitation technique, the one introduced in this paper is subject to pilots' recall bias. The possibility of pilots untruthfully reporting a high SA cannot be ruled out either. While common access to the ground truth and a healthy organizational culture are likely to reduce such biases, the technique presented in this paper is only as good as the pilots' ability to recall and willingness to verbalize their cognitive processes and statuses during the mission that is being debriefed. Despite the potential challenges, even an attempt to apply the technique in air combat training is valuable as it focuses the flight's attention to events and activities relevant to TSA, thereby adding value simply by promoting reflection and constructive debate.

Most SA measuring techniques suitable for an operational air combat training context are somewhat time-consuming and labor-heavy. Further studies are needed to explore ways to minimize the time and effort it takes to elicit or otherwise disclose pilots' SA. In addition, further studies are needed to investigate if the findings of this paper can be generalized to other aviation domains besides air combat. For the time being, the question of whether team members' similarly or dissimilarly inaccurate SA is better for the teams' performance output in domains other than air combat remains unanswered.

The flight leaders are generally more experienced than two-ship leaders and wingmen are usually less experienced than two-ship leaders. In training setups, such as in missions used for this study, the pattern may not always be as clear. For example, a two-ship leader may be an experienced flight leader supervising a novice flight leader still under training. The pilots' abilities to gain and maintain SA are likely to reflect their experience differences. As the objective of this study was to examine TSA SIM and TSA ACC in a natural setting, no attempt was made to minimize the pilots' experience differences within the flights. Also, the approach to the assessment of TSA SIM and ACC was not intended to direct the training per se. Instead, it was purposed to highlight the importance of the assessment of both TSA SIM and TSA ACC when evaluating the effectiveness of training. The process by which both forms of TSA were calculated involved averaging the scores across the flight. This may diminish the effect of individual SA differences of pilots. Furthermore, not all members of the flight may contribute equally to TSA. The contribution of the flight leader may be disproportionate to TSA and hence also to performance. This should be further investigated in future studies. This paper, however, provides a sound starting point for such explorations.

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Canadian Ultralight Accidents in Water (1990 to 2020)

Conor MacDonald; Christopher Brooks; Ross McGowan; Ari Rosberg

INTRODUCTION: Recently, an analysis of Canadian seaplane accidents terminating in water (1995–2019) was conducted, but ultralight water accidents were excluded due to differences from general aviation operations. This is the first literature that reports a series of ultralight accidents that occurred in water. The purpose of this paper is to identify the circumstances surrounding ultralight water accidents in Canada and to identify actions with the potential to improve survival.

METHODS: Ultralight water accidents that were reported to the Transportation Safety Board of Canada between 1990 and 2020 were reviewed.

RESULTS: Of the 1021 accidents that involved ultralights, 114 terminated in water, involving 155 occupants and 8 fatalities, yielding an occupant mortality rate of 5%. Of the accidents, 52% occurred during landing. There was less than 15 s warning in 78% of cases, which included five (63%) fatalities. The aircraft inverted in 40% of the accidents and, in 21%, it sank immediately. Loss of control was the terminal cause of the accident in 43% of cases, while adverse environmental conditions were reported in 38% of accidents. Little or no details were included on lifejacket or restraint harness use, status of emergency exits, water temperature, or occupant diving experience or underwater escape training.

CONCLUSIONS: The mortality rate in ultralight aircraft water accidents was less than half that of helicopter and seaplane ditchings, but the lack of warning time was similar. All pilots and passengers need to have a well-practiced survival schema before strapping in and can benefit from underwater escape training.

KEYWORDS: ultralight, seaplane, ditching, warning time, escape, crash.

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In 2021, at the request of Transport Canada, survival from Canadian seaplane water accidents between 1995 and 2019 were reported.[9] There were 487 accidents involving 1144 occupants (487 pilots, 657 passengers). The mortality rate was 13% and the principal cause of death was drowning from being trapped within the cabin. There was less than 15 s warning of the impending accident in 86% of cases. A warning time of around 15 s or less is considered an accident characteristic that adversely affects survivability. Over 50% of the seaplanes inverted and 10% floated briefly then sank. Inversion and rapid sinking were both found to be particularly deadly outcomes in this type of accident. While not identical, these factors were in general agreement with those identified for fixed-wing fighter aircraft[5] and what the Transportation Safety Board of Canada (TSB) has published on seaplane accidents[13] and with the findings in ditched helicopter survival reports.[1–3] Ultralight accidents were not included in the 2021 review on seaplanes[9] because ultralights are operated differently from general aviation (GA) seaplanes and are categorized differently by Transport Canada.[4] Ultralight aircraft in Canada are distinguished from GA aircraft by their light weight, low speed, and limited occupancy (a maximum of two people). The Canadian Aviation Regulations divide ultralights into advanced and basic categories. Advanced ultralights must comply with standards for design, construction, performance, modification, and maintenance, whereas basic ultralights do not have such compliance requirements. Further, some ultralights have been assembled by their owners from factory-supplied kits.

Using the classification system of the U.S. Federal Aviation Regulations, advanced ultralights—which accounted for approximately half of the accidents reported in this study—would

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be classified as light sport aircraft. The remainder—basic ultralights—would be classified as ultralights.[7]

Like seaplane accident reports, reports of ultralight accidents on land or water are rarely published in the scientific literature.[6,8,10] Therefore, only comparison to the percentage of fatal or serious injuries can be made. Furthermore, accident rates based on flights or flying hours cannot be determined because Canada does not require aircraft usage to be reported. The purpose of this paper is to identify the circumstances surrounding ultralight water accidents in Canada, compare these to seaplane and helicopter accidents to assess if similar human factors considerations apply, and to identify actions with the potential to improve survival.

METHODS

The authors were interested in all ultralight accidents in water, irrespective of whether the aircraft was fitted with floats or not. After an extensive search of available databases, it was determined that the only reliable data available was the information reported to, or gathered by, the TSB. This data was accessible either digitally on the public website (tsb.gc.ca) or in paper copy physically located in the TSB archives. For this latter data source, a Senior Statistical Analyst from TSB provided assistance. He and a team member searched for additional data in paper files that had not been entered into the electronic TSB database. The narratives and quantitative data from both these sources were extracted and loaded on Microsoft Excel®, reviewed by all four investigators, and transformed as required to support descriptive analysis. For example, when assessing environmental factors, the TSB narrative data was searched for a description of the wind and water conditions, and the accident environmental conditions were recorded in accordance with our classification system.

Similar to the seaplane study,[9] a survival event tree was created involving the pilot and passenger (if carried) from flight planning through embarking, taxiing, takeoff, flight, and landing to the safe return of the ultralight alongside the dock or airfield. The factors examined were: 1) preflight details; 2) factors at the point of impact; 3) post-impact factors; and 4) post-escape factors. Factors associated specifically with the occupants and other aspects of survivability were also investigated and included: pilot experience; evidence of underwater escape training and diving experience; water temperature; status of emergency exits; use of restraint harnesses and life jackets; and the contribution of environmental conditions.

Occurrences where the ultralight landed long and ended up on the beach, or where, after some minor incident, the pilot managed to taxi to the dock and safely disembark the passenger (if carried), were excluded from the analysis. These types of occurrences were not evaluated due to the fact that there were few threats to occupant survival and virtually no injuries or fatalities.

For the majority of human or survivability factors reported, no specified classification system existed. Based on the authors' experience in classifying water ditching,[3,9] the authors created classifications where they were not specified by the TSB, such as warning time.

In previous studies of helicopter and seaplane accidents,[3,9,11] an adequate warning time to take a deep breath, check the seat harness and survival suit, and adopt the crash position prior to sudden water entry were found to be critical to survival. In the current ultralight study, all four authors reviewed the accident reports and available video evidence and estimated whether or not there was less than 15 s warning. Maritime survival educators have historically used this crude but practical number to emphasize advice to crew and passengers that they must be aware of the potential for ditching at any time during the critical phases of flight and, should an event occur, there would be little to no warning, as indicated by the designation of less than 15 s. The assignment of 15 s warning to accidents following this process is consistent with the methods presented in previous publications.[3,9]

When appropriate, a two-tailed Fisher's exact test was used to identify potential differences in categorical variables of sustaining a fatal or serious injury. Fisher's exact was chosen over Chi-squared analysis given the lack of data in the majority of instances, where more than 20% of cells had an expected frequency of less than five. A value of $P < 0.05$ was used as the indicator of statistical significance and all such analyses were performed using SPSS 28.0 (IBM Corp., Armonk, NY, USA). In instances where data was not normally distributed, the median and interquartile range were used to describe the dispersion of the data.

RESULTS

General

A total of 1021 ultralight accidents from 1990 through 2020 were reviewed for the mention of "lake", "river", "sea", or "water" in the narrative. Of these accidents, 114 (11%) terminated in water. There were 155 occupants involved in these accidents (1.4 occupants per accident), including 114 pilots and 41 passengers (6 of whom were student pilots). There were 8 fatalities, 8 serious injuries, and 25 minor injuries which occurred across 31 accidents. In 13 of the accidents at least 1 occupant sustained a fatal or serious injury, while at least 1 occupant in the remaining 18 accidents sustained only a minor injury. There were 39 different models of aircraft involved, of which 88 (77%) were equipped with floats, 16 had wheeled landing gear, and 8 were "flying boat" designs. For two aircraft there was not enough detail in the accident data to determine the landing gear configuration. The cabin configurations of the ultralights, ranked from most to least common, were enclosed [$N = 42$ (37%)], convertible [$N = 41$ (36%)], open [$N = 21$ (18%)], partially enclosed [$N = 6$ (5%)], and unknown [$N = 4$ (4%)].

The number of accidents per year ranged from 0 (2011) to 13 (1997), with a median of 3 and an interquartile range of 3. **Fig. 1** shows the count of accidents per 5-yr span during this

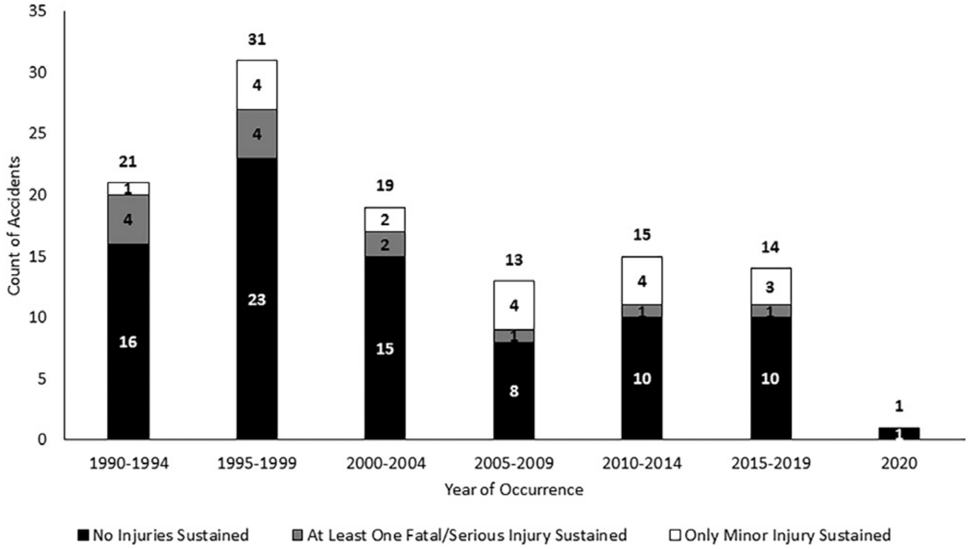

Fig. 1. Count of ultralight accidents terminating in water annually.

time, stratified by the number of accidents in which at least one fatal/serious injury or only minor injury had occurred.

Accidents occurred across nine provinces and territories, while one accident of a Canadian registered ultralight with a planned route over southern Ontario, Canada, occurred in the St. Lawrence River in northern New York in the United States, near the Canadian border. The majority of accidents occurred in Ontario [*N* = 44 (39%)], Quebec [*N* = 33 (29%)], and British Columbia [*N* = 19 (17%)]. The majority of fatalities (*N* = 6) occurred in Quebec. All the accidents occurred during daylight hours between April and November, inclusive. No water temperatures were recorded. When considering the number of accidents per year within each province and territory, the maximum number of accidents in a single province or territory in a single year was five, which occurred three times across Ontario (1993 and 1997) and Quebec (1996).

Preflight Details

In the 11 accidents where pilot flight hours were recorded, no pilot had more than 720 flying hours. In the three accidents where a fatality occurred and flight hours were recorded, the pilots were the sole occupants and had 720, 200, and 53 total flying hours, respectively. A total of 10 accidents involved training of a novice pilot, accounting for 2 fatalities and 4 serious injuries.

The existence of previous underwater escape training (UET) was only documented in one case. There were no reports of pilot or passenger swimming ability or diving experience, or the existence of a preflight briefing (if carrying a passenger).

Factors at the Point of Impact

The primary cause of each accident—the event determined to have set in motion the accident sequence—was attributable to human [*N* = 80 (70%)] or mechanical [*N* = 27 (24%)] factors in most accidents. When human factors were found to have contributed to the accident, there were nine accidents in which at least one fatal or serious injury occurred. Fisher's exact test found no significant association between the primary cause of human factors and sustaining a fatal or serious injury ($P = 0.196$).

Most accidents occurred during landing [*N* = 59 (52%)], while the remainder occurred during takeoff [*N* = 30 (26%)], cruise [*N* = 11 (10%)], taxiing [*N* = 6 (5%)], and while attempting a touch and go [*N* = 6 (5%)]. When considering the primary cause of the accident by phase of flight, most accidents occurred when human factors contributed to the accident during the landing phase [*N* = 46 (40%)]. In this condition there were five accidents which resulted in at least one fatal or serious injury (**Table I**).

There were less than 15 s of warning time in 89 (78%) accidents. Of these, 18 caused harm to the occupants, where 5 fatal injuries, 8 serious injuries, and 14 minor injuries were sustained.

The terminal cause of most accidents was a loss of control [*N* = 49 (43%)], followed by emergency landings [*N* = 17 (15%)] and mechanical failures [*N* = 10 (9%)]. Loss of control was the main terminal cause during the landing [*N* = 30 (26%)] and takeoff [*N* = 15 (13%)] phases of flight, and included a combined 8 accidents in which at least one fatal or serious injury was sustained (**Table II**). Fisher's exact test found that there was a statistically significant association between the accident occurring during the landing or takeoff (combined) phases of flight and the occupants sustaining fatal or serious injury ($P = 0.005$).

Regarding environmental factors, strong and/or gusty winds were determined to have played a role in 19 accidents, 3 of which involved fatal or serious injuries. No environmental conditions are known to have contributed to 63 (55%) accidents; these resulted in 3 fatalities and 6 serious injuries (**Table III**). Fisher's exact test found that there was no significant association between the contribution of environmental conditions to the accident and sustaining a fatal or serious injury ($P = 0.945$).

Table I. Number of Accidents by Primary Cause and Phase of Flight.

PRIMARY CAUSE BY PHASE OF FLIGHT	ACCIDENTS [*N* (%)]	ACCIDENTS W/ FATAL / SERIOUS INJURY [*N* (%)]	# FATAL INJURIES [*N* (%)]	# SERIOUS INJURIES [*N* (%)]	# MINOR INJURIES [*N* (%)]
Human					
Total	80 (70%)	9 (69%)	6 (75%)	6 (75%)	16 (64%)
Landing	46	5	4	2	8
Takeoff	21	1	0	1	5
Cruise	5	2	2	1	3
Taxiing	4	0	0	0	0
Touch and go	4	1	0	2	0
Mechanical					
Total	27 (24%)	2 (15%)	0 (0%)	2 (25%)	8 (32%)
Landing	9	1	0	1	4
Takeoff	8	1	0	1	4
Cruise	6	0	0	0	0
Taxiing	2	0	0	0	0
Touch and go	2	0	0	0	0
Unknown					
Total	7 (6%)	2 (15%)	2 (25%)	0 (0%)	1 (4%)
Landing	4	0	0	0	1
Unknown	2	2	2	0	0
Takeoff	1	0	0	0	0
Grand Total	114	13	8	8	25

Percentage values may not equal 100%, due to rounding error.

Postimpact and Postescape Factors

After impact with the water, 19 ultralights nosed-over during the accident sequence before coming to rest, resulting in 2 fatalities. Once at rest, 55 (48%) floated on the surface and 24 (21%) sank immediately, while 3 others (3%) sank after floating for some time. In 44 (39%) cases the aircraft fuselage inverted immediately, while in 24 (21%) cases the aircraft remained upright (**Table IV**). In the 27 (24%) accidents where both aspects of the final position were unknown, 3 fatalities and 7 serious injuries occurred and no more than a single fatal injury occurred within any of the other 87 (76%) known conditions presented in Table IV.

The use of the restraint harness was not reported in 103 (90%) cases, which included 6 fatalities. In the 11 cases where the use of the restraint harness was known, it was reported to have been worn correctly in 9 cases (1 fatality), incorrectly in 1 case, and not to have been worn in the 11th case (1 fatality).

Similarly, the use of a life jacket was not reported in 104 (91%) cases, which included 6 fatalities. In the 10 cases where the use of a lifejacket was known, it was reported to have been worn correctly in 8 cases (1 fatality), available but not worn in 1 case, and not to have been available in the other (1 fatality).

Information on cause of death was available for only two fatalities. One case was head injury; the other was drowning. In 60 (53%) cases, there was no information about occupant egress or post-accident survival activities; in 73 (64%) cases, there was no information about post-accident rescue activity; and in 46 (40%) cases, there was no information about either occupant egress and survival or post-accident rescue.

Where egress, survival, and rescue were referenced in the data, the most common scenario was for the occupants to have egressed unassisted, sat on or clung to the floating wreckage, and been rescued by local boaters without extensive delay. There were reports of injured or unconscious occupants being assisted from the cabin by other occupants and also reports of occupants self-rescuing by swimming to shore.

Egress difficulty was reported or apparent in six cases, while in eight other cases it was reported or apparent that the occupants had no difficulty with egress. For the remaining 101 (89%) cases, there was no data or discussion of egress difficulty.

DISCUSSION

Canada is the second-largest country in the world by total area and is 9% covered by lakes and rivers. It has had an active and growing civil aviation sector since the dawn of powered flight. The ultralight sector of GA has grown consistently since its origins in the mid-1970 s. These aircraft are attractive to pilot owners because of their low cost, handling qualities, and, for some, the opportunity to complete the assembly of their aircraft. Those equipped with floats or hulls can be operated from the lakes and rivers that adjoin some owners' remote properties. Due to their increasing popularity, the number of ultralight accidents is expected to increase as well.

In Canada, accident reporting is mandatory regardless of the classification of the aircraft. For that reason, the current dataset contains most of the occurrences that involved death or serious injury, or where the aircraft sustained significant damage. Ultralight accidents that do not incur a fatality or significant airframe damage are not required to be reported to the TSB. If there has been damage to property, but no deaths, serious injuries, or major damage to the aircraft, the accident may be investigated by local authorities. There is no central registry to record these minor occurrences that are not reportable to TSB.

Table II. Number of Accidents by Phase of Flight & Terminal Cause.

PHASE OF FLIGHT BY TERMINAL CAUSE	ACCIDENTS [*N* (%)]	ACCIDENTS W/ FATAL / SERIOUS INJURY [*N* (%)]	# FATAL INJURIES [*N* (%)]	# SERIOUS INJURIES [*N* (%)]	# MINOR INJURIES [*N* (%)]
Landing					
Total	59 (52%)	6 (46%)	4 (50%)	3 (38%)	13 (52%)
Loss of Control	30	2	2	0	5
Amphibious Floats Wheels Down	6	1	1	0	2
Stall on Approach	6	2	1	2	2
Emergency Landing	5	1	0	1	1
Obstruction in Water	5	0	0	0	0
Mechanical Failure	3	0	0	0	2
N/A	2	0	0	0	1
Environmental: Wind	2	0	0	0	0
Takeoff					
Total	30 (26%)	2 (15%)	0 (0%)	2 (25%)	9 (36%)
Loss of Control	15	0	0	0	2
Emergency Landing	7	1	0	1	4
Stall on Departure	5	1	0	1	3
Mechanical Failure	2	0	0	0	0
Obstruction in Water	1	0	0	0	0
Cruise					
Total	11 (10%)	2 (15%)	2 (25%)	1 (13%)	3 (12%)
Emergency Landing	5	0	0	0	1
Other: CFIT	2	2	2	1	2
Amphibious Floats Wheels Down	1	0	0	0	0
Loss of Control	1	0	0	0	0
Distraction	1	0	0	0	0
Mechanical Failure	1	0	0	0	0
Taxiing					
Total	6 (5%)	0 (0%)	0 (0%)	0 (0%)	0 (0%)
Environmental: Wind	2	0	0	0	0
Mechanical Failure	2	0	0	0	0
Obstruction in Water	1	0	0	0	0
Environmental: Waves	1	0	0	0	0
Touch and go					
Total	6 (5%)	1 (8%)	0 (0%)	2 (25%)	0 (0%)
Loss of Control	3	0	0	0	0
Mechanical Failure	2	0	0	0	0
Stall on Approach	1	1	0	2	0
Unknown					
Total	2 (2%)	2 (15%)	2 (25%)	0 (0%)	0 (0%)
Grand Total	114	13	8	8	25

Percentage values may not equal 100%, due to rounding error.
N/A: not available.

In previously published ultralight studies, accidents into water have never been specifically discussed. The other published studies that were reviewed make no reference to a water landing. For that reason, only comparisons of aggregate data such as number of events, number of fatalities, and serious injuries is possible.

In a 2006 report on 66 accidents in the United States, 33% were fatal and there were serious injuries in 35%.[10] In a 2018

Table III. Number of Accidents by Environmental Factor.

ENVIRONMENTAL FACTORS	ACCIDENTS [*N* (%)]	ACCIDENTS W/ FATAL / SERIOUS INJURY [*N* (%)]	# FATAL INJURIES [*N* (%)]	# SERIOUS INJURIES [*N* (%)]	# MINOR INJURIES [*N* (%)]
None	63 (55%)	8 (62%)	3 (38%)	6 (75%)	17 (68%)
Strong / Gusty Winds	19 (17%)	3 (23%)	3 (38%)	2 (25%)	2 (8%)
Glassy Water	10 (9%)				1 (4%)
Unknown	8 (7%)	1 (8%)	1 (13%)		4 (16%)
Obstruction in Water	7 (6%)				
High Waves	3 (3%)	1 (8%)	1 (13%)		1 (4%)
Strong / Gusty Winds + Waves	2 (< 2%)				
Wake	2 (< 2%)				
Total	114	13	8	8	25

Percentage values may not equal 100%, due to rounding error.

Table IV. Ultralight Final Positions After Impact.

FINAL POSITION (% GRAND TOTAL)	INVERTED IMMEDIATELY	N/A	UPRIGHT	UPRIGHT, THEN INVERTED	TOTAL
Floated	28 (25%)	6 (5%)	21 (18%)		55 (48%)
N/A	5 (4%)	27 (24%)			32 (28%)
Sank Immediately	11 (10%)	11 (10%)	1 (1%)	1 (1%)	24 (21%)
Floated, then Sank			2 (2%)	1 (1%)	3 (3%)
Total	44 (39%)	44 (39%)	24 (21%)	2 (2%)	Grand Total = 114

N/A: not available.

report based on 307 accidents, 252 occurred in the United Kingdom, 35 occurred in Portugal, and 20 occurred in the United States.[6] The 2018 study reported that the fatal injuries occurred in 3% of the United Kingdom accidents, 46% of the Portuguese, and 30% of the accidents in the United States.

In indicating a mortality rate (defined as [# fatalities/# occupants] x 100) of 5%, our findings are in general agreement with those reported in the 2018 study for the United Kingdom and substantially lower than those for Portugal and the United States. The 5% mortality rate for the ultralight accidents in our study is lower than the finding of 13% for Canadian seaplane water accidents[9] and the finding of 15% for worldwide helicopter ditchings.[2,3,11]

Why is the occupant of a seaplane more than twice as likely to perish in a water accident as the occupant of an ultralight? There are several hypotheses to explain the differences in accident mortality, including the fact that in the event of an accident, Canadian seaplanes have been found to carry more passengers (2.3 occupants per accident[9]) than ultralights (1.4 occupants per accident). As such, more occupants are expected to be seated in the rear of the aircraft, which creates more difficult access to emergency exits than pilots or front row passengers and, in some cases, rear row exits are more complex to operate. In addition, GA-category seaplanes will often operate to more remote locations, land and take off at higher speeds than ultralights, and they are rarely configured with open or partially open cabins, which is the case for some ultralights. These differences between seaplanes and ultralights could influence how quickly rescue was accomplished, the amount of kinetic energy that was dissipated during the crash sequence, and the increased difficulty for occupants to egress the cabin. Our study did not attempt to explore further the apparent difference in mortality rates between ultralight and seaplane water accidents.

In a report of 200 cases involving home-built aircraft, compared to GA, home-builds had a higher rate of accidents associated with causal factors of mechanical failure (43% vs. 23% for GA) and crashing on takeoff and climb-out (36% vs. 22% for GA).[8] This report also noted that recreational flying and the age (60+) of the pilot were more often a factor in home-built accidents than in GA accidents. In 24% of the accidents in the current study, mechanical failure was determined to have been the primary cause. No ages were reported in any accident.

It has been reported that accidents originating during the takeoff and climb-out phase were more common with ultralights than with other types of aircraft.[10] Cruise flight was the most common accident phase for ultralight aircraft in that study (50%). In contrast, the current study found that landing was the most common flight phase (52%) in which the accident occurred, followed by takeoff (26%). The importance of remaining vigilant throughout the landing and takeoff phases of flight is further emphasized by its statistically significant association with sustaining a fatal or serious injury.

One study found that pilots with a low amount of flying time (less than 40 h) were significantly more likely to have been involved in fatal crashes and/or to crash because of losing control.[10] In the current study, there was not sufficient data to make any comment on the relationship between pilot hours of experience and the probability of an accident terminating in the water.

Gender, average age, and flying hours did not differ substantially in UK, Portuguese, and U.S. ultralight accidents.[6] No comparison to these figures could be made because little to none of this data was recorded in any Canadian accidents. Further, no data exists pertaining to the gender of any of the occupants, nor did enough data exist on pilot hours or training to make any reliable comparison.

Previous work demonstrated that warning time was critical to surviving a helicopter ditching.[3] Even though warning time was rarely noted in the TSB's data, it was clear from 89 (78%) narratives that the accidents occurred suddenly and unexpectedly. As a result, most occupants received no indications of an impending crisis until the accident sequence began to unfold. In these cases, we estimated that the warning time was less than 15 s.[3]

As these 89 accidents progressed, 4 of which had fatalities, there was minimal warning time for the pilot or passengers to prepare themselves mentally and physically for their impending immersion. Ultralights inverted in 46 (40%) accidents and sank in 13 of those cases. These factors are common to helicopter and seaplane ditchings.[2,3,11] Anyone aboard an ultralight that flies over water must be mentally and physically prepared for sudden unexpected immersion in water.[9] The additional complications and risks arising from immersion in cold water are relevant to some of these ultralight accidents because temperatures below 15 °C are common in large lakes and coastal waters during the Canadian ultralight operating season.

Limitations

Safety studies of the GA sector in many jurisdictions have been impaired by the absence of reliable information—the number of hours flown or the total number of aircraft movements in the sector each year. This has made it impossible to generate statistics comparable to those used in the commercial aviation sector, such as accidents per 100,000 flying hours. Ultralight safety studies are further impaired because in major jurisdictions such as the United States, ultralights are not required to be registered, so the size of the active fleet is unclear. For these cases, it is not possible to normalize based on the number of accidents or fatal accidents per registered aircraft and none of the existing papers mention whether any of the ultralights were involved in a water accident.

Similarly, the scale of ultralight operation worldwide is not widely known. In 1987 there were 15,000 such machines in the United States and, in 2010, there were 4375 in the United Kingdom and 410 in Portugal.[6] The number of ultralights in Canada, based on Transport Canada registration data, has grown steadily from about 3000 in the mid-1980s to about 8000 presently. During the same period, the GA fleet has ranged in size from 20,000 to 25,000 aircraft.[12] Additionally, the TSB occurrence and accident data that is readily available to the public does not contain any age information for the people involved.

Another weakness of the current study is that the data on water accident-related human factors such as water temperature, underwater egress training, restraint harnesses, and life jackets is very scant in the TSB records. Where we have nonetheless attempted to classify and analyze some aspect of the data such as warning time, we run the risk of the data being skewed and leading us to an incorrect conclusion. To mitigate this risk, we have limited our analysis and conclusions to only those factors where we had a degree of confidence. For other factors, such as water temperature, we have refrained from performing analysis or drawing conclusions, instead pointing out the need to consistently gather and report the missing data in our recommendations. Otherwise, how can regulators improve standards and manufacturers introduce new technology?

Conclusions

From 1990 through 2020, there were a total of 114 accidents where a Canadian ultralight aircraft terminated in water, with a mortality rate of 5%. This mortality rate is lower than the finding of 13% for Canadian seaplane water accidents[9] and the finding of 15% for worldwide helicopter ditchings.[2,3,11] Occupants of ultralight aircraft are advised to remain vigilant during landing and takeoff as these phases of flight were significantly associated with sustaining a fatal or serious injury in the event of an accident in water.

The prime object in accident investigation is to save lives, and the cause of the accident is not always the cause of death. As in previous studies of aircraft landing in water, the authors have often found scant evidence of many of the survivability factors that led up to the cause of death.

Recommendations

Transport Canada, the Canadian transportation regulator, should issue a bulletin available to all owners of ultralight aircraft, making them aware of the fact there will be little or no warning in the case of ditching and that it would be an advantage if they undertook a course in UET. For the TSB, it is recommended to develop an aircraft investigator checklist for all water accidents which includes human and survivability factors, including water temperature, warning time, use of harnesses or life jackets, evidence of swimming and diving ability, UET, and the availability and use of the emergency exits. Further, for the Transportation Safety Board, the Canadian accident investigation authority, it is recommended to collect more detailed accident information for ultralight accidents, filling in the many gaps noted previously, and to encourage other national accident investigation authorities to gather data for all of their ultralight accidents.

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Human Physiological Limitations to Long-Term Spaceflight and Living in Space

Lawrence H. Winkler

INTRODUCTION: Despite all our dreams and enthusiasm, the essential question of whether our species can ever live permanently in space remains unanswered. The 1975 NASA Ames Design Study on Space Settlements demonstrated how human physiology constrains and determines human habitat design in space. Our scientific understanding about the risks of and standards for microgravity (and rotation rate if centrifugally generated), ionizing radiation, and atmosphere pressure and composition, remains inadequate a half century later. In addition, there are newly recognized physiological challenges to living safely in space, including spaceflight-associated neuro-ocular syndrome (SANS), extravascular hemolytic anemia, and other factors that affect every human cell and organ system. A comprehensive review was conducted to establish what we have learned and what is still required to know about the pathophysiology of long-term space travel and living in space since my first report in 1978. The results determine not only how, but if we can realistically plan to inhabit the cosmos that surrounds us.

KEYWORDS: Stanford Torus, space medicine, life support.

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In the summer of 1975, a small group of engineers, scientists, and students participated in a NASA program to design a space settlement for 10,000 inhabitants sited at L5.[39] The technical director of the study, Princeton professor Gerald K. O'Neill, envisioned the colony as a cylinder with an interior "like the French countryside."[71]

What O'Neill failed to appreciate was the magnitude of control exerted on spacecraft design by safe physiological criteria.[32] Our group took great care to create an environment that adequately protected humans from the space hazards known about at the time (see **Table I**). The Stanford Torus evolved out of conservative necessity in the absence of more permissive space-based in vivo data.

As a life support consultant for the 1975 study,[103] I evaluated what we have learned about the physiological hazards of spaceflight[2,33,55] and the interval advances that may have made it safer.[69,109] This paper will review the hazards of long-term spaceflight and living in space, as well as the pathophysiological consequences and potential countermeasures. It will conclude with a narrative of what we have learned after almost half a century of innovation.

HAZARDS TO LONG-TERM SPACEFLIGHT AND LIVING IN SPACE (LTS/LIS)

Space is a physical environment inherently hostile to human habitation.[7] With an average proton density of 5.9 protons/m^3 and an average atomic density between galaxies of less than 1 atom/m^3, space is an imperfect vacuum of almost nothing, punctuated by plasma, orbital debris, and micrometeoroids. The extreme temperatures of space range from −272.15°C in the Boomerang Nebula in the constellation Centaurus, to 15,000,000°C at our sun's core (and hotter). However, with the right mix of spacecraft interior gas composition and temperature regulation, life support design can compensate for these first two hazards.

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TABLE I. Physiological Design Criteria 1975.

PHYSIOLOGICAL DESIGN CRITERIA	VALUE
Pseudogravity	0.95 ± 0.5 G
Rotation Rate	≤1 rpm
Radiation Exposure Limits	≤0.3 rem/year
Magnetic Field Intensity	0.6 ± 0.3 gauss
Atmosphere	
P_{O_2}	2.3×10^2 mb
PN_2	2.7×10^2 mb
P_{CO_2}	$<4.0 \times 10^2$ mb
PH_2O	1.3×10^3 mb
Temperature	23 ± 8°C

P_{O_2} = oxygen partial pressure; PN_2 = nitrogen partial pressure; P_{CO_2} = carbon dioxide partial pressure; PH_2O = water partial pressure

Radiation

Each of the three main types of space radiation possesses its special hazard profile. Large flux emissions of energetic ions from the sun occur as sporadic and cyclical solar particle events (SPEs). Spacecraft shielding and EVA suits can handle protons with energies less than 30 MeV, but higher fluxes from solar flares or coronal mass ejections may penetrate shielding and exacerbate the biological effects from other exposures. Acute radiation sickness (ARS) recovery may be hindered by changes in immune status, skin burns, blood loss, and slower wound healing. In addition, solar UV radiation causes an increased incidence of skin cancer.

The major concern for deep space missions, being both isotropic and constant over time, is galactic cosmic rays (GCRs). These are high atomic number, high-energy (HZE) particles with an energy spectrum of 1–10,000 MeV.[16] Every cell nucleus in the body will be traversed by a high-energy cosmic proton every 3 d en route to Mars, each with the potential for causing complex clustered double-stranded breaks in DNA.[108] The radiation field on Mars is a hundred times more intense than on Earth.[17]

Two diffuse bands of Van Allen belt charged particles are trapped in Earth's magnetosphere. The daily pass through the South Atlantic Anomaly (SAA) accounts for 50% of the cumulative radiation received by International Space Station (ISS) astronauts.[17] Because the zone contributes no exposure to missions beyond low Earth orbit, the key to avoiding its radiation is to traverse quickly.

Gravity

On Earth, gravity is necessary for rain to fall, water to drain, heat to dissipate, and air and water to separate. In the evolution of all planetary life, gravity has been a constant factor.[67] Small variations in this weakest of the four fundamental physical forces of nature have an impact on organism health and function.[40,95]

Gravitational effects on many-celled organisms are profound. Terrestrial survival required an inner or outer skeleton to cope with buoyancy loss and increased loading. Vertebrate postural stability, structural support, mobility, fluid distribution, and circulation hydrodynamics evolved.

Species that alternate between horizontal and vertical positions require more complex systems for balance/z-vector sensing, fluid regulation, and locomotion. Humans have developed a subconscious "1 g mentality." In microgravity, nothing is pushed together, everything is pulled apart. Subtle biological changes due to altered gravity are difficult to define over a single generation. Unlike plants, no vertebrate has completed a life cycle in microgravity. Humans have spent about 1% of a life cycle in space, far fewer than the 20,000 generations of 1-g evolution that resulted in our terrestrial adaptation.

Isolation and Confinement

Perhaps the most enigmatic hazard to human long-term space travel and living in space is species generated. Several inherent elements of spaceflight confinement threaten crew productivity, health, and mission success.

Spacecraft habitability and human-machine stressors. Lack of privacy, circadian rhythm alterations from constant sterile interior or short periodic exterior lighting, makeshift sleep facilities, lack of natural UV exposure, chronic vibration/noise, increased carbon dioxide levels, housekeeping and hygiene issues, clothing uniformity, and support systems separation can lead to feelings of isolation, loss of spatial capacity, altered consciousness, and impaired coordination. Ionizing radiation can modulate psycho-emotional status and exert an anxiogenic effect.

Sensory distortion from crew displays/interfaces, intelligent machines/tool interactions, challenges of hand-eye coordination, cognition, information processing, memory and workload levels, and dangers and risks associated with physical hazards (such as space debris and equipment failure or malfunction) can contribute to mission tension.

Psychological and psychosocial stressors. Menu-fatigue, "anorexia in space," limited possibilities for rescue, high-risk work conditions, sleep disruptions, homesickness and loneliness, and motivational decline can lead to apathy, fatigue, psychosomatic disorders, anxiety, and depression.

Heightened friction, social conflict, and strained interpersonal relations between crew and/or ground stations, disruptions in family life, sexual attraction and tensions, and multicultural and multinational factors (e.g., communication language barriers, stereotyping, cultural misunderstandings, technology interfacing, religion and holidays, habitat aesthetics and work, and differences in management and leadership styles) pose potential threats to team cohesion and stability.

Stressors absent in near-Earth missions can intensify in deep space. "Earth-out-of-view phenomenon" leads to disconnectedness from family and friends. Pressures of crew-ground communication delays and dependence on local resources to generate water and fuel for the return flight home could result in withdrawal, territorial behavior, asthenia, irritability, attention/concentration difficulties, heightened perceptual sensitivities, physical weakness, sleep and appetite problems, and distress synergism from the other contributing factors.

PATHOPHYSIOLOGICAL CONSEQUENCES

The cumulative combined effects of these LTS/LIS hazards have cellular and organ system consequences.

Cellular Dysfunction

The effects of ionizing radiation on human cellular biology were well-documented at the time of the NASA Settlements Study in 1975, but there was little evidence that microgravity could also affect cell function. We are now aware that intracellular architectural structures sensing gravitational load convert and amplify mechanical inputs into downstream biochemical signaling cascades.[20]

Depending on the interaction of the cytoskeleton, cell adhesion molecules, force-sensing proteins, mechanically activated ion channels, and gene expression, mechanotransduction pathways affect the entire cellular life cycle.[9] A filamentous viscoelastic F-actin-cytoskeleton regulates cellular size, volume, shape change, force generation, adherence, proteins, cell-membrane lipid bilayers, and neural ion channels.[87,105,106] The "tensegrity" (tensional integrity) cytoskeletal equilibrium is disrupted in microgravity by the decreased expression of actin, Arp2/3, and RhoA proteins.[56] Cytoskeleton linking to the extracellular matrix (ECM) requires integrin transmembrane receptor clustering to enable focal adhesion. Microgravity reduces the formation, number, and area of focal adhesions per cell, and so decreases adherence, migration, and viability.

The microtubule organizing center (MTOC) that separates chromosomes during cell division is also gravity dependent. Human T lymphoblastoid cells flown on the Space Shuttle demonstrated shortened microtubules extending from poorly defined MTOCs with DNA condensation and increased Fas/APO-1 protein characteristic of apoptosis.[51] Furthermore, microgravity causes more fluid and less viscid membranes, decreasing current fluctuations through high voltage mechanically activated ion channels, which alters cellular metabolism. Mechanical unloading in microgravity reduces gene expression of focal adhesion proteins (FAK, DOCK1, and PTEN), as well as those involved in dopamine synthesis and hypothalamic 5-hydroxytryptamine 2A synthesis. This delayed differentiation and the changes in the cytoskeleton, nuclear morphology, and gene expression that occur in microgravity raise potential concerns about tumor growth and wound healing.

Organ System Dysfunction

Metabolism/bioenergetics. In microgravity, dramatic body fluid shifts centralize blood volumes. The increased metabolic energy required to pump blood to the skin surface to enable evaporative heat loss is further frustrated by skin sweat biofilm that impairs convective heat loss, along with blunted thirst and lower fluid intakes causing decreased perspiration and dehydration. Astronauts return to Earth hyperthermic, dehydrated, and with muscle mass loss.

Pharmacology is also different in space. The absence of gravity affects drug absorption, distribution, and metabolism.[6,21,30] Changes in ingested matter size and density, capillary pressure, splanchnic congestion, gastric pH, and diminished gastric emptying (further exacerbated by antimuscarinic drugs for space adaptation syndrome) alter bioavailability. Adjustments in gut microbiota (decreased *Bifidobacterium, Lactobacilli, Akkermansia*, and *Ruminococcus*; increased *Pseudobutyrivibrio* and *Fusicatenibacter*), epithelial transport, and intestinal transit time decrease GI absorption. Then, the volume of drug distribution is decreased by diminished plasma volume, increased fluid deficit, compartmental redistribution, cardiovascular deconditioning, and a decline in plasma albumin, tissue perfusion, and lean body mass. These factors, together with a suspected greater blood-brain barrier permeability (based on animal studies), could result in increased drug concentrations. Lipid-hydrolyzing and proteolytic enzyme activity is also reduced in spaceflight. Hepatic drug catabolism is limited by less portal blood flow velocity and first-pass metabolism, as well as decreases in CYP-450 monooxygenase activity, UGT1A1 and OCT2 transcription, and biliary secretion. Blood volume contraction causes a drop in renal perfusion, creatinine clearance, urinary excretion, drug-binding macromolecule concentration (producing elevated free drug fraction, t1/2, and AUC), and altered urinary epithelial transport carrier expression and function. Additionally, radiation can adversely affect drug stability.

Nutrition. Food will not be found during any journey into deep space. NASA's prepackaged foods have a stated shelf life of about 2 yr, but a Mars trip requires 5 yr of processed provisions.[11] The persistent catabolic state of spaceflight occurs from limited preparation time, menu fatigue, requisite exercise regimens, and loss of taste and smell that reduces palatability.

Moreover, protein supplement consumption leads to amino acid oxidation with nitrogen and sulfur release that impact kidney and bone chemistry. Vitamin D deficiency can occur from lack of solar synthesis due to radiation shielding and inadequate food sources. Other vitamins are susceptible to inactivation during food preparation, radiation exposure, and long-duration missions. Calcium is lost by decreased GI absorption, bone recruitment, and increased urinary excretion (contributing to kidney stone formation). Supplemental dietary calcium doesn't reverse the negative balance. And finally, RBC neocytolysis promotes iron tissue storage associated with Fenton reaction-induced oxidative damage.

Endocrine. Spaceflight-induced stressors (e.g., G-forces of launch and landing; weightlessness; radiation; noise; isolation and confinement; performance requirements; sleep deprivation; and insufficient nutrition) modify hormonal levels and their effects on kidneys, bone resorption, muscle loss, immunity, glycemic control, and endothelial response. Sympathetic activation results in fight-or-flight neuroendocrine stress responses. The adrenal medulla produces more catecholamines, and the hypothalamic-pituitary-adrenal axis secretes extra adrenocorticotropin and cortisol. Downregulation of the hypothalamic-pituitary-gonadal axis decreases serum testosterone transiently to levels that approximate aging male syndrome. Higher increases of plasma growth hormone, prolactin, and catecholamine levels were noted after workload during spaceflight, as compared to preflight response. The hypothalamic-pituitary-thyroid axis generates less L-thyroxine and triiodothyronine, but the renin-angiotensin-aldosterone system increases angiotensin, aldosterone, and antidiuretic hormone. Less parathyroid hormone (PTH) is secreted by the calcium-parathyroid hormone-vitamin D axis and the insulin: glucagon axis increases serum glucose and insulin with a rise in insulin resistance.

Oxidative stress response augments reactive oxygen species (ROS), reactive nitrogen radicals, lipid peroxidation in erythrocyte membranes, erythrocyte superoxide dismutase and glutathione peroxidase, granulocyte superoxide and nitric oxide production, and urinary excretion of 8-iso-prostaglandin F (2alpha) and 8-oxo-7,8 dihydro-2 deoxyguanosine, with elevated markers of MDA (membrane damage), nitrotyrosine (protein damage), and 8-OHdG (DNA damage). Plasma and leukocyte lipophilic antioxidant levels, as well as concentrations of serum and salivary vitamin C and E, glutathione, and melatonin, are reduced.

Genetic

Spaceflight is detrimental to several genetic processes.

Meiosis (reproduction). Fertilization and gastrulation are negatively impacted.[64,75] Spermatogenic cells and ovarian follicles are sensitive to HZE particles (increasing the possibility of premature ovarian failure). Microgravity decreases testosterone synthesis and spermatogenesis. Fertilized ovum implantation is jeopardized by increases in sperm swim rate and apoptosis,[35,86] as well as vaginal acidity. Reductions in vaginal wall lubrication, endometrial thickening, and FSH-mediated ovulation occur.

Gestation and fetal development are compromised as well. Tadpoles on the SL-J mission initially grew normally but were unable to inflate their lungs.[99] Pregnant rats flown into space gave birth, but the pups couldn't attach themselves to their mother's nipples in microgravity and were cannibalized. Alterations in fetal cardiomyogenesis, calcium bone mineralization, and the development of the choroid plexus, vestibular, and sensorimotor systems might occur in microgravity. Human maternal risks include polyhydramnios and diminished progesterone production. Microgravity allows the fetus to sit higher in the womb, pressing upon the mother's diaphragm and making respiration more difficult. It may interfere with dropping by week 39.

Mitosis (carcinogenesis). NASA radiation exposure limits are based on Risk of Exposure Induced Death (REID) values: cumulative doses that will keep an astronaut's risk of developing fatal cancer to ≤3%—but there are uncertainties related to space radiation cancer risk predictions.[18] GCR exposure estimates derived from dosimeters aboard the Mars Science Laboratory predicted that human crewmembers could exceed career radiation exposure limits during just the in-flight portions of a Mars journey. The addition of SPE transit and Mars surface doses would put cancer risk into a more dangerous range.

Apoptosis (aging). During a long-duration ISS mission, the NASA Twins Study[25] demonstrated telomere shortening akin to changes observed with aging. Humans in space develop aging features accelerated tenfold from normal senescence on Earth.

Spaceflight and aging both result in decreased thermoregulation, plasma volume, thirst, visual and hearing acuity, taste sensation, immune competence, antibiotic sensitivity, aerobic capacity, cardiac output, baroreflex sensitivity, arterial elasticity, endothelial thickness and nitrogen oxide generation, epidermis, joint collagen, height, bone density, skeletal muscle mass, protein synthesis, strength and explosive power, growth hormone and GH exercise-response, testosterone, vitamin D3, insulin sensitivity, gastric motility and gut transit time and absorption, urinary continence, wound healing, cerebral mass and blood flow and oxygenation, sleep and circadian cyclicity, posture, balance, coordination, movement, and reaction time. In both cohorts, body fat replaces muscle and infiltrates the liver, and there are increases in renal stones, orthostatic hypotension, latent viral infection reactivation, aching joints, back pain, tender soles, and vertebral compression and bone fractures.

Immune System

The physical environment of space exacts a toll on innate and acquired vertebrate immune systems.[14] Innate immune cells are more radioresistant than acquired phenotypes. But T and B lymphocytes, the main components of acquired immunologic memory, are exquisitely radiosensitive. They eliminate other cells (damaged from viruses or carcinogenesis) and invading microbes with more precise responsiveness than innate system reactions.

Microgravity causes additional acquired immune dysregulation that consists of altered innate and acquired interactions, cytoskeletal disruption (with a reduction in peripheral monocyte-endothelial cell adhesion and tissue migration secondary to decreased CD26L and HLA-DR surface marker expression), and peripheral leukocyte number and distribution change[13,15] (a drop in specific subpopulation function; elevated granulocyte numbers but decreased function; less neutrophil ROS production during oxidative burst and phagocytosis; and fewer eosinophils). Impaired differentiation and maturation of all immune cells result in premature immunosenescence and overactive immunity syndromes (e.g., increased allergy, asthma, eczema, autoimmunity, and cancer risk).

B cells are affected by microgravity with reduced lymphopoiesis, proliferation, subset distribution, generation, frequency, antigen-specific response, immunological memory, and delayed hypersensitivity responses to recall antigens. Thymic and splenic atrophy and dysfunction result in reduced T cell development, output, and function (with changes in TCR signaling from cytoskeletal disruption; direct CD3/CD28-driven T-cell activation and response; monocyte accessory cell and macrophage[85] malfunction; cytotoxic NK cell and blastogenic activity; concanavalin A-induced mitogen proliferation and lymphocyte response; and mislocalization of Krt5 TECs in the thymic cortex). Circulating TLR2, TLR4, TLR6, and LPS-induced cytokine production and reactivity is reduced. A signaling shift toward the Th2 cell population leads to viral shedding and decreases in IL-1, IL-2, and IL-2 receptors; it also leads to increases in TNFα, IL-4, IL-6,[82] IL-8, IL-1 receptor antibody, thrombopoietin, vascular endothelial growth factor, IFN-γ, and leukocyte recruitment mediators.

Microbes respond differently to space stressors than humans.[63,84] Spaceflight augments microbial pathogenicity through changes in spacecraft commensal populations (a rise in fungal colonization causes an amplified astronaut immune response to fungal antigens); increased infectivity and microbial anatomic breach from impaired innate mechanisms (e.g., reduced monocyte *E. coli* phagocytosis); augmented virulence of *Salmonella typhimurium*, *Pseudomonas aeruginosa*, *Serratia marcescens*, and *Aspergillus*; and biofilm formation from bacteria (*Acinetobacter*, *Sphingomonas*, *Corynebacterium*, *Burkholderia*, *Bacillus*, and *Klebsiella*) and fungi (*Penicillium*, *Aspergillus*, *Cryptococcus*, and *Rhodotorula*).[19] Biofilms are responsible for 80% of chronic and recurrent infections and are associated with prostatitis, rhinosinusitis, otitis media, urinary tract infection, endocarditis, periodontitis, and infectious kidney stones. They also impair heat transfer and cause ISS equipment corrosion and mechanical blockages.

In the setting of tight crew proximity, more antibiotic resistance increases the risk of secondary infection. Decreased CD8+ cytotoxic T cell activation facilitates reactivation of latent viral infections such as human herpes, Epstein-Barr, varicella zoster, and cytomegalovirus.

Blood

Hematological. Upon entering space, all astronaut red blood cells are terrestrial born; after 120 d in flight, all RBCs are space born. Both erythrocyte populations are destroyed.[90] Hemolysis increases 54% over baseline as a function of space exposure duration,[91] independent of fluid shifts, EPO levels, and the RBC production environment. The mechanism(s) of this extravascular anemia are unknown. Consequences include elevated CO levels; decreased peripheral O_2 delivery; iron-mediated oxidative damage; free Hgb and heme-mediated endothelial dysfunction; increased compensatory RBC production; Hgb concentration, viscosity, and rheological burden; and higher nutritional demands. Effects can persist a year after long-duration space exposure and the anemia does not respond to exercise or nutritional countermeasures.

Coagulation. In 2019, an incidental obstructive left internal jugular venous thrombosis was identified in an astronaut 2 mo into his ISS mission. A nonobstructive jugular clot was identified in another crewmember.[54]

Virchow's triad, the three factors that contribute to venous thromboembolism, is as relevant in microgravity as on Earth. Blood stasis occurs in microgravity. Headward fluid shift is confounded by a lack of upper body venous valves impeding cephalad blood drainage. Jugular cross-sectional area increases by a factor of 7, JVP by a factor of 4.[59] Stagnant and retrograde jugular venous flow occurs in more than 55% of ISS crewmembers with a decrease in musculovenous pump activity. Hypercoagulability increases with a rise in fibrinogen synthesis rate, fibrinogen α-chains, D-dimer levels, thrombin-antithrombin complexes, prothrombin F1+ F2, and modulator activation.[45] Vessel wall remodeling from rheological changes, reduced venous flow, and proinflammatory change and oxidative stress lead to increased local tissue injury, thrombotic markers, procoagulant molecule expression, extracellular matrix, low-density lipoprotein (LDL) uptake, and lipid synthesis with enhanced atherogenesis.[45]

Integument

Skin. Three categories of skin changes occur in spaceflight. Epidermal stratum corneum thins secondary to an increase in cell molting time and diminished barrier function, hydration, and elasticity. Sloughing and coarsening make for "rough hands and soft feet." Dermal collagen content increases and changes in ECM gene expression result in matrix degradation. Melanin content is reduced. Skin microbiota/commensals are recolonized with uncommon microorganisms (e.g., ascomycetous *Cyberlindnera jadinii*).

A significant proportion of ISS crew (40%) develop skin rashes (1.12 rashes per flight year vs. 0.044 per year on Earth) across a spectrum of conditions.[22] Diminished ambient humidity and temperature lead to dry skin (xerosis) and acute flares of atopic dermatitis/eczema (requiring sedating antihistamine and systemic corticosteroid medication). Contact dermatitis occurs secondary to irritants (micropore tape, fiberglass, beta cloth, ECG chest wall electrode patches, gloves, face masks, and headphones).

Additional factors predispose certain individuals to skin infections. Air filtration is constant. Hygienic use of wet wipes, no-rinse shampoos, and soaps, as well as increased contamination from skin shedding, result in a rash incidence 5× higher than found in submariners. Immune system dysregulation results in delayed wound healing. Habitat microbiota are characterized by higher virulence, antibiotic resistance, and faster growth (due to low shear stress and low turbulence). *S. aureus* and pathogenic fungi colonization increase (with crew transmission). Mir spacecraft were colonized with *E. coli*, *Serratia marcescens*, *Legionella*, spirochetes, and dust mites. Reductions in *Gammaproteobacteria* populations are associated with inflammation and allergy sensitization.

Four main types of skin infection present more commonly. Latent viral reactivation has already been described above. Cellulitis occurs more readily from *Staphylococcus* and *Streptococcus* colonization. Treatment of acne vulgaris is more difficult because of the need to avoid minocycline and isotretinoin side-effects. Antifungal therapy of dermatophytosis is also limited; gels and powders are restricted because of inhalation/flammability risk.

Other dermatologic conditions are notable. Skin doses from SPEs are 510× higher than seen by internal organs. The severe erythema, blistering, and necrosis of cutaneous radiation syndrome (CRS) can occur from a single exposure of ionizing radiation >3 G_y. U.S. astronauts have 3× the risk for localized basal and squamous cell carcinoma. Urticarial allergic reactions may arise due to decompression sickness. The treatment for psoriatic exacerbations is limited.

Synovial joints/cartilage. Most of what we know about the effects of spaceflight on cartilage[24,79] come from 30-d murine studies on BION-M1.[46,47] Articular cartilage (AC) and sternal fibrocartilage (SC) respond differently to microgravity:[23] SC is loaded by cyclical lung expansion and, since mice continue to breathe in microgravity continuously, no cartilage breakdown occurs; cyclical compressive loading of AC in microgravity causes damage at the point of greatest cartilage-to-cartilage contact during weight-bearing. Radiation has a compounding effect on cartilage damage;[102] cartilage has limited capacity for repair and microgravity induces a flexor bias in joint position.

Bone. It is energetically costly to maintain a dense skeleton for fewer weight-bearing activities. Healthy astronauts lose bone mass 10× faster than post-menopausal women on Earth. Vertebral and lower limb skeletal sites are especially susceptible to bone loss from microgravity mechanical unloading. Diminished osteoblast production, cytoskeletal tensegrity, adhesion, increased osteoclast activity, sclerostin expression, and loss of 'piezoelectric strain' occur.[42] Elevated serum calcium decreases circulating PTH, renal active vitamin D activation, and calcium gut absorption, causing a rise in urine calcium and nephrolithiasis propensity.

Expanded iron stores create unbalanced bone remodeling mediated by Fenton reaction oxidative stress. Net endogenous acid production foods, high sodium, and an elevated animal protein to potassium ratio increase endogenous acid production (which is neutralized by the $CaCO_3$ released during bone resorption). Spacecraft CO_2 concentrations are 10× higher than on Earth.

Rodents exposed to space-relevant doses of radiation experience accelerated resorption (especially cancellous bone). The cumulative result is an increased fracture risk which persists postflight.[37,96,97] Trabecular architecture may never return to normal. Because muscle mass and strength recover faster than bone, the risk of injury to tendon insertion sites and avulsion fractures is increased.

Cardiovascular

Hemodynamic/structural adaptations. In short-duration spaceflight, hydrostatic gradient loss results in a 2-L cephalad fluid shift, higher upper body intravascular pressures, central vasculature distension, and increased venous return. Astronauts experience neck vein congestion, "puffy" faces, "stuffed" noses, and "chicken legs."

Elevated cardiac preload causes a 20% distension of cardiac chamber size with increased left ventricular end-diastolic volume, carotid, aortic, and cardiac baroreceptor stimulation; ANP-induced vasodilatation with a decrease in systemic vascular resistance (SVR); and renin-angiotensin-aldosterone system inhibition.

Hypovolemia results from a 10–15% drop in plasma volume (PV) with intravascular and extracellular fluid moving transcapillary to interstitial and intracellular compartments, exacerbated by smaller fluid intake secondary to motion sickness and diuresis.

A reflex 46% increase in stroke volume (SV) and 24% rise in cardiac output (CO) occurs without any change in mean arterial pressure or heart rate. The drop in apparent central venous pressure (CVP) is due to the hydrostatic pressure column loss effect being less than the lung/thoracic cage expansion effect:

$$\downarrow CVP = \uparrow TCVP + \downarrow\downarrow IPP$$

where TCVP = transmural CVP and IPP = intrapleural pressure from thoracic expansion.

The heart atrophies by 10% after a 10-d spaceflight (secondary to decreased metabolic demand and O_2 uptake), changing its configuration from elliptical to spherical.

In long-duration spaceflight (≥6 mo), the effective circulating PV is still reduced 10–15%, and systolic, diastolic, and mean blood pressures have dropped by 8 mmHg, 9 mmHg, and 10 mmHg, respectively, which increases pulse pressure, elevates SV by 35% and CO by 41%, and drops SVR by 39%.

Heart rate is lower or unchanged. No upregulation of autonomic sympathetic activity occurs. LV mass decreases by 12% ± 6.9% with a concomitant drop in preload, contractility, and afterload.[34,38,94]

Cosmic radiation and the heart. Terrestrial murine cardiac studies of orbital plane entrance GCR radiation equivalents have demonstrated coronary artery fibrosis, smooth muscle degeneration, and extracellular deposition 15 mo after single dose 0.1–0.2 G_y exposure, elevated aortic stiffness and ex vivo aortic tension 8 mo after single dose 1 G_y exposure, and increased aortic lesions, carotid intima-media thickening, and atherosclerosis after single dose 2 G_y exposure.

Cardiovascular disease deaths are greater than fourfold in low Earth orbit astronauts, and more than fivefold in Apollo lunar astronauts.[8] For a 40-yr-old man on a 1000-d exploratory Mars mission, the estimated cumulative radiation exposure of 0.5–1.0 Sieverts will result in a 1.3–13% higher lifetime risk of cardiovascular death.[4,34]

Clinical Consequences

Reduced exercise and work capacity. Total peripheral oxygen delivery is the product of cardiac output × arterial oxygen content (the amount of oxygen bound to hemoglobin plus the amount of oxygen dissolved in arterial blood):

$$\dot{V}O_2 = \left[HR \times SV\right] \times \left[1.34 \times Hgb \times SaO_2 + 0.003 \times P_aO_2\right]$$

In spaceflight:

$$\downarrow \dot{V}O_2 = \left[\downarrow HR \times \downarrow SV\right] \times \left[1.34 \times \downarrow Hgb \times SaO_2 + 0.003 \times P_aO_2\right]$$

The sum effect of these reductions results in a decline in peak aerobic exercise capacity (with decreased convective and diffusive oxygen transport), a drop in anaerobic threshold, and impaired thermoregulation. Deconditioning is greater in those who start with higher maximal aerobic capacity.[29]

Spaceflight-associated neuro-ocular syndrome (SANS). Found in 66.7% of astronauts who have undergone long-duration space flight missions in microgravity,[50,101,108] the threat of spaceflight blindness is serious enough for NASA to label SANS a top "Red Risk" danger that crews will face during deep space missions.[74]

The mechanism of SANS visual impairment is multifactorial and muddled. Symptoms of headache, pulsatile tinnitus, diminished visual acuity, and scotomata occur, along with: ophthalmoscopic signs of cotton wool spots, nerve fiber glutting, choroidal folds, and optic disc edema (21.2% with class 3–4 papilledema); increased cerebral free water volume; and increased biochemical markers of brain damage and morphological brain changes.

Although some ocular structural changes from SANS may persist for years after spaceflight, no crewmember has yet experienced permanent blindness postflight.

Neck vein thrombosis. The ISS internal jugular vein thrombus was treated successfully. If future astronauts require prophylactic anticoagulation, what additional risks to space habitability will exist in bleeding-prone crew with a high fracture hazard potential?

Postflight orthostatic intolerance/reacclimation. Post-flight syncope from decreased PV, SVR, vasoconstrictor responsiveness, and baroreceptor function despite aggressive pre-re-entry fluid-loading protocols[65] remains problematic. In 20–30% of short-duration flights, astronauts are unable to maintain upright body position; this figure rises to 83% for astronauts returning from long-duration missions. Landing on another celestial body could result in catastrophic consequences.

Arterial remodeling When blood pressure is low, endothelial cells secrete vasoactive molecules (angiotensin II, endothelin-1, and ROS) that increase vasoconstriction.

In microgravity, hydrostatic pressure gradient loss results in transmural pressure redistribution along vessel walls, cellular remodeling, and vascular functional changes.[62,70]

Arteries in the lower leg undergo a decrease in intima-media thickness (IMT), cross-sectional area, and adrenergic responsiveness, as well as an increase in endothelial vascular smooth muscle cell (VSMC) nitrogen oxide release and vasorelaxation.

Upper body arteries undergo more pronounced changes. Increased carotid and femoral IMT (20% after 1 yr on ISS) and carotid cross-sectional area (10%) result from augmented mesenchymal stem cell differentiation to tunica media VSMCs.

Extracellular Ca_2+ influx occurs through upregulated voltage-dependent Ca_2+ channels. Activated calcineurin translocated to the nucleus results in VSMC dedifferentiation, proliferation, remodeling, and loss of "contractile" phenotype.

Increased ECM production, cell apoptosis, NO release, cellular cytoskeleton damage (from microgravity mechanical unloading), and vascular stiffness on the order of 17–30% also occur. The endothelium undergoes more oxidative stress, as well as inflammation multicellular spheroid formation and apoptosis.

Monocyte chemoattractant protein, chemokine ligand 5 protein CCL5, and neutrophil gelatinase-associated lipocalin promote neo-angiogenesis.

Spaceflight-associated CVD risk factors of radiation exposure, elevated total cholesterol, oxidized LDL, insulin, iron, inflammation, circulating catecholamines and psychosocial stressors, and changes in diet, exercise, and sleep routines promote accelerated atherosclerosis.

Cardiomyopathy. Microgravity-induced deconditioning and remodeling from strain/stress and pressure–volume changes results in cardiac sphericity; decreased LV compliance and diastolic suction lead to diastolic dysfunction and reduced early ventricular filling that lowers SV. The drop in cardiac workload causes an LV mass reduction of 10–20% (~12% after just 10 d onboard). Cardiomyocytes are also sensitive to ionizing radiation.[60]

Disturbances of automaticity, rhythm, and conduction. Electrocardiac disorders that have been observed in spaceflight include bigeminal rhythm on the Moon's surface (Apollo 15); 14 beats of nonsustained ventricular tachycardia (MIR); persistent tachyarrhythmia (MIR-2 EVA); ventricular couplets and triplets; ST-segment and T-wave changes during physical exertion; HR variability loss from augmented vagal output (associated on Earth with an increased Sudden Cardiac Death-Hazard Ratio of 2.12); QTc-prolongation (associated on Earth with polymorphic ventricular tachycardia); and transient AV-block, supraventricular premature beats, ventricular premature beats, and junctional rhythm (especially during lower body negative pressure sessions). Increased left atrial size and changes in p-wave morphology that may predispose to atrial fibrillation have been observed postflight.[44]

Respiratory

No structural adaptive changes are observed in spaceflight and no degradation in lung function is seen upon return to Earth. However, there are potential sources of lung damage in flight.[77] These consist of strong SPE radiation causing acute inflammation, which predisposes to pulmonary fibrosis, decompression stress, and pathogenic microbe inhalation (murine studies demonstrated compromised *Klebsiella pneumoniae* clearing, with increased morbidity), and particulate toxic dust/aerosol exposure, which, by settling out along peripheral airspaces, increases toxicity.

GI

Gut. The first symptoms of acute radiation syndrome (ARS) manifest in the gut. Radiation induces GI serotonin secretion which binds to brain receptors that mediate vomiting. This can be problematic, especially in EVA suit confinement.

With that said, spaceflight affects the entire GI tract.[107] Mastication and deglutition are compromised because the jaw opens with gravity on Earth and keeping the mouth shut requires energy in microgravity. There is a decrease in mandibular bone density and salivary amylase production, as well as masseter muscle atrophy and an increase of both metalloproteinases and secretory immunoglobulin A. Smad signaling pathway activation causes proliferation and differentiation of human periodontal and dental pulp stem cells.

The stomach exhibits slow wave motor dysfunction, hypersecretion, and impaired mucosal barrier function. The intestinal tract sees changes in digestion, hemodynamics and lymphodynamics, intestinal mucosal permeability, and intestinal flora and microecology.

The GI microbiome is a virtual organ with over 1000 species of bacteria. It facilitates carbohydrate fermentation and absorption, metabolic activity (salvaging energy from indigestible compounds), vitamin synthesis, gut and systemic immune regulation, epithelial barrier integrity, competitive repression of pathogenic microbes, and angiogenesis.

Spaceflight alters crew space gut microecology[81,92,98] with a decrease in protective *Bifidobacterium*, *Lactobacillus*, *Faecalibacterium prausnitzii*, and *Akkermansia;* an increase in pathogenic *Serratia marcescens*, *Staphylococcus aureus*, *S. hominis*, *S. haemolyticus*, *S. epidermidis*, *Bacteroides*, pathogenic *E. coli*, *Clostridium difficile*, *Salmonella typhimurium*, *Alloprevotella*, *Parasutterella*, *Pseudomonas aeruginosa*, *Candida albicans*, and *Aspergillus fumigatus*; transformation of symbionts to pathobionts (increasing intestinal permeability and opportunistic virulence and pathogenicity); and an increase in antibiotic resistance.

The liver is a radiation-sensitive organ that also responds to microgravity[41,61] with glycogen accumulation, altered plasma protein production (upregulated gluconeogenetic polypeptide and downregulated lipid peroxidation stress response protein synthesis), and elevated bile acid secretion which decreases retinol (vitamin A) secretion. CYP-450 monooxygenase activity is halved, impairing drug metabolism. There is an increase of oxidative stress and a decrease in S_{16}-containing antioxidants. Decreased portal vein blood flow and first-pass metabolism predisposes to portal endotoxemia/hepatocyte apoptosis. Diminished hepatic lipid metabolism leads to a 19% rise in serum cholesterol and could contribute to NAFLD/NASH metabolic liver disease/cirrhosis.

Murine research has shown that the pancreas becomes atrophic in spaceflight, causing elevated plasma glucose, insulin and C-peptide secretion, glucagon, and heat shock protein HSP70 expression.

GU

Microgravity causes interstitial edema, alterations in urinary protein composition, and decreased renal blood flow and urinary albumin and sodium excretion.[76] Examination of renal histopathology in rats after exposure to simulated microgravity revealed glomerular atrophy, interstitial edema, and degeneration of renal tubular cells.[52]

Decreased fluid intake, hypercalciuria, and nanobacteria could facilitate CaC_2O_4 renal stone formation. Urodynamic changes and anticholinergic therapy for space sickness predispose to acute urinary retention. Urinary tract infections are more frequent.[5]

Neuromuscular

Ocular. In addition to SANS, astronauts are prone to cataracts, foreign bodies, and corneal abrasions.

Olfactory/gustatory. Spaceflight smells like a mélange of welding fumes, burnt steak (or burnt almond cookies), walnuts, motorbike brake pads, a pile of wet clothes after a day in the snow, gunpowder, brimstone, and sherry secondary to polycyclic aromatic hydrocarbons and ozone.

Alterations of taste are related to dry air, background noise masking, stress, circadian dysfunction, rehydrated food, and nasal and sinus stuffiness from cephalic fluid shifts. Food tastes as bland as "eating with a head cold."

Polyreceptive control of sensorimotor function. Despite vestibular nuclei plasticity, simultaneous afferent signal conflict from gaze center, oculomotor, corticocerebellar, and proprioceptive input can cause symptoms of disturbed equilibrium, balance, locomotion, and fine motor control in microgravity.[10,73,88]

Astronauts have a 75% incidence (92% in long-duration missions) of space adaptation syndrome. Symptoms include apathy, depression, and disinclination for work. They can persist or reoccur up to 14 d during or after spaceflight. Sensory conflict and limbic neural mismatch may both contribute to causation.[49]

CNS. The effects of ionizing radiation on the mammalian central nervous system have been well-studied.[43,72,80] On a structural level, neurogenetic inhibition of stemlike neural precursor cells (NPCs), astrocytes, and oligodendrocytes is observed along with a decrease of dendrite complexity and dendritic spine numbers. A reduction in capillary numbers and barrier function, microvessel segments, and endothelial cells leads to blood-brain barrier compromise. MRI features of widespread tissue changes without necrosis are noted.

Molecular and cellular alterations result from oxidative stress accompanied by enzymatic changes, proinflammatory cytokine production, and proliferation of microglial and astrocyte activation markers. Radiation causes peripheral monocyte and T lymphocyte infiltration, reduced microvascular adhesion molecules, and changes in synaptic protein and glutamate-gated ion channel levels, acetylcholine and dopamine pathways, and genetic expression.

Radiation impacts electrophysiological function. Decreased resting membrane potential, input resistance, and long-term potentiation lead to impaired cell excitability, reduced memory formation capacity, and synaptic plasticity.

Behavioral consequences of radiation exposure include attention/vigilance, reaction time, learning, memory, cognition, mood and emotional control, and social interaction. There are uncertainties in space radiation CNS risk prediction based on animal models.

Sleep/circadian cyclicity. Human circadian timing system evolved in 1 g. Spaceflight is associated with a diminution in sleep time, slow-wave sleep, and REM sleep; REM latency; and an increase in the latent period for falling asleep and number of arousals. Hypnotic use is pervasive among astronauts despite any performance impairment of potentially hazardous activities requiring complete mental alertness or motor coordination that may occur the day following ingestion.

Cognition. The "Space Fog" of short-duration spaceflight sits on a continuum of cognitive dysfunction which could potentially culminate in the "Space Brain" and dementia of long exposure.[12]

Behavioral. The explorer Richard Byrd took only two coffins, but 12 straightjackets on his expeditions to Antarctica in the 1930s. NASA ranks behavioral risk second only to radiation exposure as a threat to successful exploration class missions. Dysfunctional behavior can result from neurobehavioral, cognitive, psychological, or psychosocial causes from mission-related, individual, cultural, family, and interpersonal and crewmember interaction factors.

Muscle. In microgravity, site-specific antigravity muscle atrophy progresses quickly. Plantar flexor peak force lessens by 20–48% after 6 mo of spaceflight and the number of Soleus type I fibers decreases by 21% after only 17 d of spaceflight (STS-78 mission Shuttle Astronaut B had myofibril atrophy and mitochondrial rounding in postflight soleus biopsies corresponding to decreased force and increased shortening velocity of single Ca^{2+}-activated muscle cells).[100]

Muscle strength is lost because of unloading (disuse atrophy), diminished neural drive (denervation atrophy), and increased protein catabolism from stress and undernutrition.[1,89] Astronauts become taller in microgravity and the lengthening spine becomes a source of mechanical back pain and disk herniation. Weakened tendons and ligaments predispose to ankle injury and Achilles tendon rupture.

Other Illnesses

Microgravity causes more dental problems (barodontalgic tooth pain, caries, periodontal disease, gingivitis, and periapical abscesses in Shuttle-MIR cosmonauts), ENT disorders (barotitis, sinus headache, epistaxis, and deafness), and traumatic injury. Terrestrial human illness could also occur de novo in space. Combined effects can be additive, subtractive, or synergistic. Return to Earth from long-duration missions may be difficult or impossible.

COUNTERMEASURES TO THE HAZARDS OF LTS/LIS

The external vacuum environment and temperature extremes of space can be easily mitigated with a heated gas ratio atmosphere pressurized to nominal sea level on Earth.

Passive bulk shielding is the only current practical means of limiting space radiation exposure,[58] but the mass requirements and cost are high and secondary nuclear interactions can be deleterious.[66] Other radiation countermeasures, radioprotectors, and radiomodulators[93] have dubious benefit.[68] Active treatment of radiation exposure is reserved for situations which are usually already unfortunate.

Countermeasure advances in the reduction of negative effects from microgravity include the mobile lower body negative pressure (LBNP) "gravity" suit,[3,31] aerobic and resistance (ARED) exercise,[83] intermittent short-arm centrifuge use,[48] and their combinations.

The LBNP suit is limited by individual specificity, changing astronaut biometrics during spaceflight, and intermittent utilization cycles of reconditioning and deconditioning. The omnidirectional lower body forces are not the same as the Z vector forces in 1 g.

Aerobic exercise is insufficient to maintain upright exercise capacity, orthostatic tolerance, or musculoskeletal mass and function, and it diverts critical crew time from operational tasks.

Exercise countermeasures do not produce the same level of mechanical loading possible on Earth—ISS workouts are limited to skeletal muscles that move the limbs and torso, but most muscle groups cannot be exercised (small face and finger muscles get weaker in spaceflight). Resistance exercise also heightens SANS risk.

Intermittent short arm centrifuge use ± exercise causes unpleasant vestibular, Coriolis and cross-coupling effects, motion sickness, lateral strains on exercising lower body joints, and low footward forces. None of these options will prevent most of the adverse consequences of microgravity. A more consistent continuous solution requires an ideal level of sustained artificial gravity. Until evidence accumulates to the contrary, the most reasonable level is the most conservative (i.e., 1 G). Nothing has changed to soften or dislodge this recommendation since the 1975 NASA Space Settlements Study.

The most practical achievable way of generating artificial gravity with current technology is with centrifugal force.[57] The next most pressing issue to resolve is rotation rate. We have a plethora of experimental data on terrestrial rotation rate tolerability with the subject longitudinal axis prone in 1 G, and parallel to the axis of rotation during locomotion. Some investigators have suggested that these results infer adaptability to faster rotation rates. But in space, the longitudinal body axis will be orthogonal to the axis of rotation, and Coriolis forces will cause motion sickness and increased injury risk at lower angular velocities. The answer to the rotation rate question will have to wait for human studies in space. Until then, the optimal tolerable rotation rate to produce 1 G is 1 rpm.[36,104]

Despite the development of sophisticated preflight, inflight, and postflight countermeasures to the potential negative effects of isolation and confinement, mental health becomes more brittle as a function of mission duration. There are also issues of physician–patient confidentiality, and preflight decisions regarding single gender crews (to minimize complications of crew cohesion/performance), compulsory appendectomies (to eliminate risk of acute appendicitis), and mandatory blood group compatibility (to provide a blood source for limited transfusion).

Some specific organ system countermeasure progress has occurred to reduce bone and muscle loss, nephrolithiasis, postflight orthostatic hypotension, and circadian dyscyclicity. The study of human physiology in space is an ongoing work in progress, but it is unclear if this research will find robust solutions to compensate for our fragility and enable us to undertake long-term missions or live in space within an envelope of acceptable risk.

WHAT WE'VE LEARNED SINCE THE 1975 NASA SPACE SETTLEMENTS STUDY

The Stanford Torus Study was published almost five decades ago, well before several new areas of pathophysiological concern had emerged. The Human Genome Project and advances in our understanding of gene expression have been revolutionary. We have a more profound appreciation of cell death pathways secondary to ionizing irradiation; cellular and organelle microstructural, functional, maturation, differentiation, and proliferation changes secondary to microgravity; oxidative stress; adaptive immunity dysregulation, microbial pathogenicity, viral reactivation, and biofilms; spaceflight-associated hemolytic anemia and venous thrombosis; endothelial dysfunction, atherosclerotic coronary artery disease, and LDL dyslipidemia; SANS and the oculo-cerebral glymphatic system; and 'Iome' connectivity (microbiomes, genomes, epigenomes, proteomes, transcriptomes, metabolomes, immunomes, and the space exposome). However, the life support standards and recommendations for long-term spaceflight and living in space remain the same.

CONCLUSION

Dr. Louis Friedman, cofounder of The Planetary Society, maintains that space travel by humans will stop at Mars.[26,27] I asked him whether this conclusion derived from the physical or the physiological limitations of long-term spaceflight.

> "Neither actually. It's because of the pace of evolution—human and technological. Human space travel and human space capability is evolving VERY slowly. Even if humans get to Mars in this half century, we certainly won't explore it much within the whole century. In that same time period, technology will continue to advance rapidly with stuff we can't predict in robotics, AI, VR, and other information processing.
>
> So it's kind of a dual conclusion—Mars will keep us busy for a long time… and by then there will be no reason and no advantage and no social interest in humans going beyond when they will already be doing virtually."[28]

Dragging a few individuals of our fragile species interstellar inside complex, massive rotating, radiation shielded starships may prove more cumbersome and expensive (and vainglorious) than the virtual exploration and colonization we could achieve with rapidly evolving parallel technologies.

It may be possible to re-engineer the human genome to resist microgravity-related bone loss with a G171V mutation[110] and muscle atrophy with myostatin gene K153R alteration,[89] and even protect against cosmic radiation effects with CRISPR/Cas9-mediated genome editing.[53] We might consider sending "seedships" to Goldilocks or robotically terraformed planets, using generational succession, synthetic hibernation,[78] or robot-frozen zygote missions. But why would we want to spread ourselves through the universe like a time capsule when we could use our SMARTS (Solar sails, Miniaturization, AI, Robots, Telescopes, Solar gravitational lenses)?

Being unable to travel and live in deep space with our current protoplasm will not destroy our dreams and enthusiasm to inhabit the cosmos that surrounds us, but it may encourage us to take better care of the one place in the universe we know can sustain life as we know it.

There may also be extraterrestrial intelligent AI robots heading our way, despite the silence of the Fermi Paradox.[23] If (or when) someone from somewhere comes calling, we may be working from home.

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Dedicated to the late MIT Professor Laurence 'Larry' R. Young.

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A Comprehensive Look Behind Team Composition for Long Duration Spaceflight

Alexis Gangeme; Benjamin Simpson; Gabriel G. De La Torre; Tricia L. Larose; Ana Diaz-Artiles

BACKGROUND: How to determine team composition is one of many key topics when developing humanity's next deep space exploration programs. Behavioral health and performance among spaceflight teams are key aspects impacted by team composition and cohesiveness.

METHODS: This narrative review highlights areas of consideration for building cohesive teams in long duration spaceflight environments. The authors gathered information from a variety of team-behavior related studies that focused on team composition, cohesion, and dynamics, as well as others topics such as faultlines and subgroups, diversity, personality traits, personal values, and crew compatibility training.

RESULTS: The literature suggests that team cohesion occurs more easily when individuals are similar to one another, and deep-level variables such as personality and personal values have a greater impact on crew compatibility than surface level variables such as age, nationality, or gender. Diversity can have both positive and negative impacts on team cohesiveness.

CONCLUSION: Team composition, as well as pre-mission conflict resolution training can greatly impact group cohesion. This review aims to map areas of concern and assist with crew planning for long duration spaceflight missions.

KEYWORDS: human spaceflight, extreme environment, team composition, subgroup, gender.

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Humanity is entering an exciting new era of space exploration. With the introduction of the U.S.-led Artemis Program, the Chinese Lunar Exploration Program, and growing commercial activity in human space exploration, humanity's presence in outer space is expanding. While development is ongoing for these proposed activities, questions remain regarding who will be sent on these exploration-class missions.

Compatible crew teams are imperative to ensure the success of long-duration missions. Investigations across the literature have been explored to better understand the intricacies behind team composition and the most promising variables, some of which are listed below, that can predict a team's behavior.

- Deep-level variables take time to emerge, but they highly contribute to team cohesion.
- Mixed-gender crews display some advantages to team cohesion compared to all-male crews.
- Subgroup formation and groupthink pose threats to crew performance.
- Individualistic and collectivistic orientations of an individual play an important role in forming their personality and personal values.

This paper will discuss many such variables by examining findings reported across spaceflight literature as it relates to team composition and conflict resolution training.

Team cohesion is affected by both surface level (e.g., age, race, gender) and deeper level (e.g., personality traits, personal values) characteristics, which must be considered when composing long duration spaceflight (LDSF) crews. As outlined in the NASA Human Research Roadmap,[27] there are further descriptors to consider in crew compatibility assessments. Several deep-level psychological factors can be predictors of team performance,[2] but the driving elements of these factors are poorly understood. Elements such as communication tendencies, team cohesion and coping strategies, cultural diversity, individualism vs. collectivism, personality traits and personal

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values, and the dynamics between insider and outsider groups are all elements that affect team performance. Even when composing highly compatible crews, pre-mission training is highly important to further foster group compatibility.[11,21]

METHODS

This manuscript serves to outline some of the most prominent categories impacting team cohesion for LDSF crews. We began this analysis by reviewing topics related to developing teams for space exploration provided under the NASA Human Research Roadmap.[27] This provided keywords and topic categories to explore through our wider survey across various digital repositories containing prior works in these areas (including PubMed, Google Scholar, and ResearchGate).

This review discusses emerging topics such as the potential issues associated with the development of romantic relationships in long-term isolated groups and their implication in future LDSF missions. It also discusses how established topics such as groupthink, subgrouping, scapegoating, and other social phenomena should impact the selection criteria for LDSF crews. It further discusses pre-mission training strategies, which can help with addressing group conflict before it becomes unmanageable. Included are several analog studies of polar environments, as these are widely considered to be analogous to spaceflight environments, as well as several spaceflight simulation studies, including SIRIUS-19, Mars-105, Mars-500, and HI-SEAS II, III, and IV.

No environment on Earth is a perfect analog to spaceflight, and isolation study participants are not subjected to as stringent selection criteria as astronaut crews. These studies, however, provide valuable insight into potential pitfalls which may be experienced by future LDSF crews.

RESULTS

Team Cohesion

The psychological function of individual members of a crew is highly impactful to mission success. Although many factors in LDSF environments will impact the crew's psychological well-being, prime among them is crew composition and its impact on team cohesion.[25] In past missions, astronauts were selected on an individual basis.[10] Highly skilled individuals were selected based on their ability to perform a task, with little regard given to their interactions in a team setting.[35] In NASA astronaut culture, self-confidence became a central characteristic early in crewed spaceflight, and behavioral problems were not prioritized by NASA for this reason.[41] This contrasts with the selection process of Russian cosmonauts. Psychological problems caused by the isolated environment of space have long been recognized by the Russians, who have a history of psychological training and testing before flight.[19,21] Since the construction of the International Space Station (ISS), NASA, the European Space Agency (ESA), and other agencies have increasingly recognized the importance of psychological factors and of astronauts' abilities to work as a team.[10,26] Individual-based methods of determining crew selection, such as "the right stuff", are good at predicting individual performance, but do not account for how individual skill and team dynamics will combine to impact the desired mission outcomes.[3] Team composition researchers have demonstrated that traditional selection methods, which are focused on selecting the best person for each role, may not produce the most successful crews.[6,30,35] Selecting compatible crewmembers will become increasingly important as spaceflight duration increases. Mission planners ought to assemble teams of individuals that have compatible personality traits.[31] Cohesion will be more easily obtained by assigning compatible members to a team instead of forcing harmony between incompatible individuals.

Cohesion in a crew can be defined as "the degree to which group members desire to remain in the group". This term can be divided into two camps: 1) interpersonal cohesion, and 2) task cohesion.[25] Interpersonal cohesion refers to the individuals' attachment and relationships with each other. LDSF will require a certain amount of interpersonal cohesion among crewmembers due to the isolated and confined conditions. Task cohesion refers to the individual team members' commitment to a shared goal and is generally considered to have more impact on team success than interpersonal cohesion.[25] In tasks measuring team performance under temporal stress, Zaccaro and Lowe found that groups with a high degree of task cohesion performed better than other teams, but that interpersonal cohesion had no effect on team outcome.[25,46] However, in a simulated survival experiment where teams were tasked with ranking 15 items in order of importance to the situation, Zaccaro and McCoy found that groups that ranked high in both task and interpersonal cohesion outperformed any other team cohesion combination.[25,47] A crew ranking highly in both interpersonal and task cohesion will likely perform best in LDSF missions because they will demonstrate a "shared commitment to the task" while also satisfying the social needs of the group.[25] Both surface-level variables and deeper-level variables can contribute to group cohesion.[3,6] Cohesion is more easily obtained when individuals are similar to one another. Initially, surface-level attributes detract from group cohesion.[6] These variables increase demographic faultlines (hypothetical dividing lines that split groups into homogeneous subgroups based on aligning demographics or values), and subgroups (smaller groups of individuals with similar attributes within the larger group) may form.[6] Any individual difference can create faultlines, but gender and racial diversity have been found to increase faultline strength more than diversity in other categories.[3] However, surface-level differences are less impactful with time and group exposure, and they are found to have less significance on team cohesion than deeper-level variables in closely knit groups.[37] Cohesion can also be encouraged through group training and pre-mission contact.[21] Individuals tend to form close relationships with those they frequently encounter[3] and this tendency can be used to strengthen relationships between crewmembers before crew departure. Although cohesion is found to improve group performance in tasks that require coordination, rely on communication, or take place in complex task environments, it can also cause problems within isolated groups.[3,25] Cohesion can encourage groupthink, a social phenomenon that occurs when a group's desire for harmony causes members to agree to popular in-group decisions without critical evaluation, leading to faulty decision-making outcomes. In some cases, individual behaviors that do not contribute to productivity can become a group norm and reduce overall performance.[25] LDSF is a prime environment for the development of groupthink behaviors due to the space crew's small size and separation from outside personnel.[10] Characteristics of groupthink include illusions of invulnerability, reluctance to disagree with decisions made within the group, and stereotyped views of people outside the group. Groupthink often develops as a coping mechanism used to "ensure cohesion and group agreement" within small and isolated groups.[39] It can also lead to disharmony between the spaceflight crew and mission control (MC) due to a tendency for the isolated group to displace negative emotions onto MC personnel rather than to fellow crewmembers.[6] Thus, groupthink poses a substantial threat to crew performance[26] and indicates that "promoting group cohesion" and "maintaining positive relationships within a group" will not necessarily result in successful mission outcomes.[39]

Subgroup Formation

Space analog studies have found that subgroups can form based on surface-level variables such as gender and nationality, as well as on nondemographic characteristics such as values.[6,34] Subgrouping is not always harmful, but it can result in conflict that could be detrimental to mission success.[6] Members of a subgroup generate beliefs and attitudes about insiders and outsiders of the group, which can be a barrier to communication and acceptance of ideas between subgroups.[37] Surface-level characteristics such as race, gender, and profession are immediately evident, and are an easy basis for faultlines, which could lead to the formation of homogeneous subgroups.[37] The alignment of multiple subgroups strengthens faultlines, further separating the subgroup from the whole. Subgroups can have a disruptive effect on crew performance because when a group or individual does not integrate into the crew, it can result in "withdrawal or isolation".[6] Furthermore, the isolated group or individual is then at risk of becoming the subject of group hostilities and is often the "scapegoat" blamed for problems experienced within the group.[6] Crosscutting subgroups to ensure that individuals belong to multiple subgroups within the overall team helps to promote individual- rather than subgroup-based interactions.[37] Mars-105 tested several hypotheses regarding the efficiency of several new criteria for group and individual psychology for a crewed mission to Mars.[44] One hypothesis under study was that culturally heterogeneous crews are a risk factor for the development of group cohesion.[45] This hypothesis was made on the basis that individuals in culturally diverse groups may differ in value-orientation and may hold preconceived ideas of one another's values.[45] The study consisted of six participants: four Russians and two representatives of ESA. It was found that the group fractured into stable subgroups by the end of the isolation period. By the midpoint of the isolation period, there was a decrease in crew cohesion, resulting in pairs forming among the group who preferred to communicate with each other rather than with the group as a whole. Closer relationships between some subjects and tension between others were based on mutual perceptions of similarity. In other words, subgroups formed among individuals who perceived other members to be similar to themselves.[45] The data were found to be "in close agreement with the hypothesis" that culturally heterogeneous groups are a risk to a well-consolidated crew. However, some of the pairs formed were among crewmembers from diverse cultural backgrounds, and these pairs formed more on the basis of similar value orientations than on any cultural characteristics. The study also found that the development of pairing was related to the lack of a functional role structure and the lack of a strong leader who could unite the crew as a whole.[45] Though the risk of subgroup formation may be higher among culturally heterogeneous crews, the fracturing of the crew into subgroups could potentially be mitigated by defining crewmembers' roles, including a group leader who encourages unity and group participation among crewmembers. In spaceflight, values such as "working hard", "working with others", "personal goals and achievements", "hedonism", and values within "collectivism vs. individualism" are all important variables that can form the basis of a subgroup.[4,6] LDSF crews will spend an extensive amount of time together, so compatible deeper-level variables are likely to be very important to compatible crew composition. During crew training and preparation, cultural and gender stereotypes often contribute to crewmates' perception of each other's values.[6,32] Surface-level differences provide clues for quick categorization, but time and exposure tend to neutralize the negative effect of surface-level differences.[37] Conversely, although deep-level variables take time to emerge, their impact on group cohesion strengthens as crews gain more experience interacting with one another.[37]

Gender Composition

There are several aspects to consider regarding sex and gender and its impact on LDSF. Here we will focus on the impact of gender on crew composition and cohesion. Several analog studies have found that the addition of women to isolated groups has either a positive or neutral effect on team cohesion.[25] Women were first permitted in U.S Antarctic stations in 1969.[40] Captain Brian Shoemaker, a former commander of U.S Support Force Antarctica led all-male crews early in his career and later commanded integrated crews. He observed that women had a stabilizing force in the winter-over parties.[40] More importantly, he found that male-female integrated crews were more productive than male-only crews from the past. Other experienced Antarctic managers supported this observation.[40]

Although mixed gender crews have been found to be more cohesive and productive than all male crews,[40] there are concerns to be considered. Romantic relationships have been found to have a disruptive effect on crew interaction and cohesion.[40] Persistent, unwanted attention has occurred and has a negative impact on the pursued party. Gender can be a stressor for both men and women when the groups are of a similar age, and interpersonal problems related to sexual tension in mixed gender crews can negatively affect crew performance.[25] For example, in HI-SEAS II, III, and IV (i.e., HM4, HM8, and HM12), the crews were not provided with guidelines regarding crew relationships and were given the freedom to decide on relationship boundaries as a team. As a result, romantic relationships formed in "at least one" of the studies. To protect crew privacy, the number of relationships and the specific studies in which each relationship occurred were not disclosed. But it was recorded that "at least one" relationship ended during the course of a study that resulted in strain among the crew. The end of this relationship led to "at least one" additional romantic relationship in the crew, which caused further distress. Although several crewmembers were opposed to romantic relationships among the crew, most were supportive of, or indifferent to, potential romantic relationships. Further, "at least one" stable relationship formed in a crew that lasted through the end of the experiment, with both participants remaining integrated with the rest of the crew, which helped to "stabilize group dynamics and provide comfort".[16]

The possibility of romantic relationships among crewmates in heterogeneous and homogeneous crews should not be ignored when composing LDSF crews. These relationships can have a disruptive effect in crew interactions, but whether romantic relationships should be prohibited between crewmates or if crews should be allowed to use their own discretion in LDSF missions is yet to be determined.[16,25] Further study of the effects of romantic relationships in isolated crew environments on team moral would likely help determine the necessary guidelines for crew romantic interactions in LDSF environments. The increased stability observed in mixed-gender crews in analog environments suggests that pitfalls associated with sexual tension can be avoided in properly trained crews.[40]

The intersection of gender and cultural background is also a source of contention in mixed-gender crews.[6,39] According to Goel et al. "some space-faring cultures have lower expectations and hold negative stereotypes about the role and ability of women".[12] Different cultures have varying expectations about appropriate interactions between genders. These expectations can lead to division between crewmembers.[28] However, it is important to remember that cultural and gender sensitivity training can mitigate these misunderstandings.[22] Stuster notes in "Bold Endeavors Lessons from Polar and Space Exploration" that "problems appear to have been not directly attributed to mixed crews, but rather to the behavioral consequences of immaturity, faulty personnel selection, and inadequate pre-mission training for both male and female members of the crew".[40]

Several analog studies of mixed gender groups in extreme or isolated environments have been conducted, but studies of all-female crews in environments comparable to spaceflight are less common. Here we will examine four studies: one mixed gender confinement campaign and three all-female analogs:

1. SIRIUS-19, a confinement campaign lasting 4 mo that studied the nonverbal and verbal behaviors of a Russian-American crew of six individuals: three men and three women.[39,43]
2. A team of six British military women who completed an expedition to traverse the Antarctic continent.[8]
3. A multinational four-woman crew engaged in a 6-wk trek across Greenland.[29]
4. A four-woman Antarctic expedition team who successfully skied to the South Pole, but failed to meet their original goal of traversing the Antarctic Continent.[17]

In the SIRIUS-19 study, nonverbal and verbal data collected from six test subjects, three men (two Americans, one Russian) and three women (Russian), were analyzed to determine behavioral patterns between crewmates in isolation.[43] Factors such as facial expressions, visual/body/object interactions, interaction and lack of interaction between subjects, etc., were recorded to investigate the differences between male and female coping strategies in isolated environments. The data showed that female subjects ranked highly in facial expressions, such as smiling and laughing, compared to men, who were more interactive than female subjects. Collateral actions, which are indicators of discomfort, were more prevalent in male subjects (453 demonstrations) compared to female subjects (361 demonstrations). These data suggest that: 1) collateral actions could be a cause of stress on group interactions, and 2) women's expressive behavior could indicate an action that facilitates involvement in group life.[43]

In SIRIUS-19 the 'tend-and-befriend' stress response was also monitored in participants.[39] "Tend-and-befriend" is an alternative stress response to fight-or-flight characterized by an increase in prosocial behavior expressed by providing support to others (tend) then seeking support from them in turn (befriend). The study found that both men and women displayed high levels of emotional energy, supporting the hypothesis that tend-and-befriend behavior is displayed by both genders. These results were also found to be true in Mars-500, an all-male study where emotional energy was found to gradually increase during the entire study.[39]

Both men and women invest in social relationships during confinement, but in past studies women have been found to display more concern for the well-being of crewmates than men. Stress is compounded for women in mixed-gender groups as opposed to all female groups.[28] Leon explains in "Men and Women in Space"[28] that, "while men confided problems and concerns to women in the group, there was not a reciprocal expectation or encouragement for women to share their concerns with their male teammates." This stands in contrast to what was observed in SIRIUS-19, where both male and female participants exhibited high levels of emotional investment in crewmates. Leon also explains that in all-male expedition teams, members rarely share personal concerns with teammates and have shown "patterns of strong competitiveness" between members. But observations made of mixed-gender

Antarctic work groups show that women will sometimes take on the role of "peacemaker" in small groups, which helps to reduce competition and tension between male participants.[28,29]

The all-female military trek displayed investment in crew interaction and viewed "honesty in communication" as essential to the group's success.[8] A leading source of conflict in the group's dynamic was a disagreement about the "pace vs. distance" strategy for completing the trek.[8] The group held evening meetings to plan a strategy for the following day's trek where members stated their opinions, although the group leader decided the final strategy. Tension grew in the group during the second half of the expedition in which two crewmembers wanted to ski for longer periods each day to achieve a greater daily distance, while the remainder of the group wanted to continue with the leader's plan to maintain a steady pace and avoid injury.[8] The conflict was resolved by the leader who called members to discuss "personal goals vs. team goals" to determine shared team goals they could agree to. Tension was noted between the team's leader and a subordinate member of the team; however, the leader's effective communication strategy helped to avoid the creation of faultlines within the group.[8] This suggests that an effective leader can encourage group cohesion. As discussed in the case of Mars-105, the pairing of study participants began at the midpoint of the study and communication between the group as a whole was reduced due to participants' preference for communication within their subgroups.[45] Within the all-female military trek, a strong faultline could have formed on the basis of different pace vs. distance strategies. Communication between the crewmembers encouraged by the group leader helped to dilute the possibility of subgroup formation on this emerging faultline.

Both the nonmilitary all-female Antarctic trek and the Greenland trek expressed concern for the well-being of teammates as a primary stressor in the group.[17,29] This contrasts with findings in mixed-gendered crews, where interpersonal concerns were second to environmental concerns. Overall, female crewmembers express more concern than men about maintaining interpersonal relationships. Evaluations of Antarctic groups accumulated over 10 yr have indicated that interpersonal tension negatively impacts both men and women, but lack of group cohesion has a greater impact on women than men.[13,29] Both nonmilitary female crews reported social support as a primary coping mechanism in times of stress.[17] The hypothesis under investigation in the all-female Antarctic trek was that an all-female group in an isolated and extreme environment would be comparable to a mixed-gender group, but would display more sensitivity to emotional concerns. This hypothesis was supported in the study and there is favorable evidence for the all-female trek in Greenland to support this claim as well. The all-female military trek placed a high value on group communication and group members outside of the leader's conflict with a subordinate crewmember claimed to have been affected by the conflict and the group mood. With few studies conducted on all-female groups, these findings may be group dependent rather than universal.

Examinations of mixed-gender groups in isolated environments have indicated that heterogeneous crews are more productive and cohesive than all-male crews of past decades.[40] More studies are needed on crews composed entirely of female participants to reach definitive conclusions about female crews operating in extreme environments. Although there could be issues inherent in mixed-gender crews, including sexual tension and jealousy, they can be mitigated by proper training and careful crew selection.

Diversity in Cultures, Nationalities, Values, and Personalities

Cultural diversity, diversity in nationalities, and diversity in personality traits and personal values are significant factors regarding crew composition.[18]

Cultural diversity. When looking at cultural diversity, one important topic is collectivism vs. individualism. Collectivism gives priority to the group and individualism gives priority to the individual. These two cultural styles have huge implications for communication behavior, self-guiding goals, and an individual's outward perception.[14] Characters with individualistic values tend to value achievement and independence, personal responsibility, and their personal goals over those of the group.[7] Collectivist individuals value group goals over individual goals and avoid seeking competition and personal recognition in groups.[14]

All individuals fall somewhere on the 'individualism-collectivism continuum'.[14] Palinkas et al. conducted a study on individualistic-collectivistic cultures stemming from distinct nationality groups (United States, Russia, Poland, China, and India) participating in an 8-mo isolation and confinement study.[33] It was found that in more collectivist cultures (Russia and China), individuals avoided burdening team members with emotional stresses (Chinese team), but also sought support from fellow team members (Russian team). Individuals from more individualistic national cultures (United States) were less likely to seek emotional or material support from others.[33]

Diversity can be divided into three subcategories: separation, variety, and disparity.[7,15] These subcategories serve as the basis for understanding more typical variables in diversity (e.g., culture, race/ethnicity, and gender).[7,15] It can be unclear what should be considered a "diversity variable of interest". Clear and universally accepted definitions for diversity variables are lacking.[7,15] Bell et al. argues in "Getting specific about demographic diversity variable and team performance relationships: a meta-analysis" that the reason for so many ambiguities and inconclusive results reported in other work regarding diversity is due to the oversimplification of diversity within these studies.[7]

Diversity in nationalities. Diversity of nationalities in team composition merits additional investigation.[5] Organizations worldwide (NASA, Roscosmos, Japan Aerospace Exploration Agency, ESA, Canadian Space Agency, Chinese National Space Administration, etc.) have all contributed astronauts toward space-based activities. The degree of cross-nationality interaction is a key consideration for future space exploration programs. Nationality can be used as a surface-level indicator of personal values, as individuals tend to uphold the cultural values of their nations.[6] Personal values are a deeper-level variable that can affect team cohesion.[6] As such, diversity of nationalities can have a negative effect on team cohesion when personal values among the crew do not align.[6] However, Bell et al. state that a review of crew diaries across 10 space-missions/analogs have suggested that nationally heterogeneous crews experience less deviant behavior than homogeneous crews.[6] This evidence indicates that diversity of nationalities in LDSF missions can have either a positive or negative affect on crew cohesion.[6]

In the early years of spaceflight, one nation's space agency would host crewmembers from other nations.[42] These missions of multinational crews were fraught with dissatisfaction and frustration on the part of the "guest" nations. Division was not only based on nationality but also on the status of "host crews" and "guests". Guests were rarely granted full coworker status by hosting crews and they were often prevented from doing meaningful work. Although the host typically spoke well of their foreign colleagues, they distrusted their competence operating the "home team's" spacecraft. This changed with the creation of the ISS. Multinational crews are now the norm rather than the exception.[12] Space exploration benefits from multinational collaboration, which supplies a larger pool of talent, encourages diplomacy between nations and defers a great deal of expense. But if one nation leads the expedition to Mars it will be important to avoid an insider-outsider dichotomy among multinational crews, both in the ship and with ground control. International crewmembers occasionally have had language barriers with a foreign nation's MC or felt isolated due to lack of support from an MC that had different expectations from that of their home nation.[24] A truly international Mars mission should consist of not only a multinational flight crew, but also a mission control with representatives from multiple nations.

One study looked at the values and interpersonal perception of other crewmembers from the perspective of cosmonauts.[44] This study showed emergent features of certain individual traits and personal values and showed that the cosmonauts tended to idealize their foreign counterparts while being more critical of their fellow cosmonauts.[44] More research is needed on multinational-mixed crews, especially those containing crewmembers from countries with fast-growing space capabilities.

Personality traits and personal values. Introversion vs. extroversion, adherence to tradition, individualism vs. collectivism, self-direction, and many other character attributes affect the dynamics of a team. This section will explore two categories: personality traits and personal values.[1]

Personality traits at the team-level (such as "agreeableness") should be highly considered when selecting astronauts for LDSF missions.[6] Anania et al. expresses a dichotomy of 'selecting in' vs. 'selecting out' candidates, which emphasizes the need to understand team-based personality considerations.[1] In "Psychology and culture during long-duration space missions", the authors argue that selection of astronauts should not only consider individual personality traits, but also interpersonal skills, with recognition that "agreeableness" and "low aggressiveness" have led to higher performing teams.[18] Individual crewmember selection must be considered in the context of how a given member will perform on the team. One disagreeable team member can disrupt the performance of the entire crew.[6]

Corneliussen et al. conducted an analysis of 10 Danish military personnel deployed to Greenland on a 26-mo rotation to study personality traits, personal values, and the development of conflict in isolated and confined environments (ICE) to evaluate their relevance to potential LDSF crews.[9] The participants completed a variety of assessments/questionnaires (e.g., Portrait Values Questionnaire, Triarchic Psychopathy Measure, structured interviews, and the NEO PI-R) and it was determined that the most successful individuals displayed a "dominance of positive traits and a low propensity for callous and emotionally dysregulated behavior".[9] Positive traits included high levels of boldness (adventurous, emotionally resilient, socially poised), benevolence (being well meaning), consciousness (a desire to do all tasks well and to place importance on obligations to others), and agreeableness (kind, sympathetic, cooperative, etc.).[9] Personal values held by individuals may contribute to their adjustment to ICE. Subjects who self-identified and displayed "stability over time with values of hedonism (enjoyment), self-direction, and benevolence" tended to perform well in ICE.[9] The value of benevolence was also found to contribute to a sense of camaraderie within the group, which Corneliussen et al.[9] suggests may be of particular importance for maintaining cohesion in small groups in ICE. This field study helps to identify positive personality traits that may be useful in LDSF crews. However, it must be noted that the subjects of this study "were not comparable to astronauts/cosmonauts in academic and professional level".[9] In addition, the group studied was all men, and thus may not be fully applicable to mixed-gender or all-female groups.

Personal values are a broad set of goals which motivate a person's actions and serve as their guiding principles. There have been several studies regarding the analysis of personal values in teams.[36,38,45] In a 105-d simulated space mission with six men (two Russian cosmonauts, one Russian medical doctor, one Russian sports physiologist, one German mechanical engineer, and one French airline pilot), the individuals were given a portrait-value questionnaire once a month and certain personal values were rated higher than others.[36] The entire crew was divided into three subgroups that were centered on certain personal values (one subgroup valued hedonism, the second subgroup valued tradition, conformity, and benevolence, and the third subgroup had less distinct personal values overall).[36] The investigation found that personal values tended to become more heterogeneous among the crew over time and argues that personal values are important for understanding interpersonal compatibility.[36]

A study looking at interpersonal perceptions of cosmonauts across several ISS missions found values of motivation, intellectual level, knowledge, self-discipline, sociability, and friendship as some of the most important values among the crewmembers.[44] Self-direction, stimulation, universalism, and benevolence are among the highest rated values among crews.[38] Values of tradition, security, achievement, and power were rated low among participants.[38] Some values may be situationally dependent and not universally applicable.[36] These studies point to similar trends in benevolence and self-motivation as some of the most important personal values to hold when considering space exploration class missions.

Dynamic Crew Training

Deep-level values take time to emerge in teams who work closely together, but it is unlikely that selected crewmembers possess all the optimal characteristics in the ideal proportions.[20] Even within highly compatible and cohesive crews, some degree of conflict will be unavoidable. Even though selecting compatible individuals for LDSF may help reduce the potential for irreconcilable conflicts, this does not reduce the need for group training in conflict resolution practices.[19,21] Kass et al. suggests that from the time of crew selection to flight, dynamic group training sessions should be a part of astronaut preflight training, as this will provide crews with experience and strategies to maximize team effectiveness and resolve conflict.[19]

Kass and Kass suggest that there are essential areas of group processing that lead to developing an effective team.[20] These areas include morale, norms, decision-making, handling conflict, and power and leadership struggles.[20] Groups who have been trained in group processing "tend to promote greater psychological health and intragroup management, increased ability to cope with stress and adversity, and increased ability to work toward a shared goal".[20] Such groups also display increased tolerance and appreciation for cultural differences and the advantage of having differing perspectives available to solve a problem.[20] In addition, in the all-military Antarctic trek discussed in "Gender Composition", it is evident that the presence of a strong leader capable of leading the group in decision-making discussions to resolve conflict was effective in preventing the formation of a potential faultline, suggesting that a leader and crew who are effective in these areas are less prone to subgrouping than groups less versed in decision making, handling conflict, and power and leadership struggles.[8] However, it has been shown that leaders have the ability to "contribute stability or add stress" to the group environment.[22] And studies undertaken by Kass et al. have indicated that group reactions to situations do not tend to shift from pre- to post-mission assessments, indicating that changes in handling conflict and communication styles do not occur naturally and need to be trained in crews to achieve the desired results.[22,23]

In a 264-d spaceflight simulation that analyzed conflict handling models of three crews of four people, it was found that all crews scored highly for "accommodating", and lower in "collaborating", with middling scores in "competing, avoiding, and compromising".[23] There was no statistically significant change in these behaviors in the pre- to post-isolation portions of the experiment.[23] Accommodating behavior is used to maintain a cooperative environment among crew, but can be over relied upon and discourage collaboration.[23] Collaborative crews will "merge perspectives and integrate solutions"[23] while accommodation is an expedient way to avoid immediate conflict.[23] An overreliance on accommodation can lead to problems not being addressed and a buildup of tension both within the flight crew and between the flight crew and MC.[23] Crews trained in conflict management may be able to better handle conflicting ideas among crewmembers and promote collaboration rather than accommodation.[22,23] A crewed mission to Mars will require coordination between multiple teams. Conflict will arise within and between these teams, but it is possible for groups to identify and resolve potentially serious conflicts before they become unmanageable.[21,23]

In conclusion, as humanity ventures beyond low Earth orbit, it will become increasingly important to assemble not just competent, but compatible crews. A crewed mission to Mars will necessitate longer periods of isolation and confinement than were experienced by spaceflight crews in the past. With communication delays from the spacecraft to Earth lasting up to 40 min, crewmates will need to rely on one another during times of crisis and boredom alike. It will be essential to provide careful consideration to crew selection to maximize compatibility and cohesion.

This paper discussed the impact of surface- and deep-level variables on team cohesion and determined that deeper level variables such as personality and personal values will have a greater impact on crew compatibility overall than surface level variables such as nationality and profession. A cohesive group will operate as a unit and not fracture into subgroups. Characteristics such as gender, race, nationality, and profession will impact crew cohesion and can be foundations for subgroups, but there is no evidence with regard to crew compatibility to suggest that diversity in these categories is inherently incompatible. Even in highly compatible crews, dynamic group training sessions pre-mission are advisable to maximize the crew's ability to manage conflict.

A final note of consideration is the importance of social support and enthusiasm for an endeavor as monumental as a crewed mission to Mars. Space agencies are already renewing exploration outside of low Earth orbit. Many space agencies and even private organizations are likely to participate in LDSF ventures in the coming decades. Collaboration between nations has occurred throughout the history of spaceflight and is likely to intensify as humanity takes its next steps out into our solar system. Group compatibility and cohesion can be achieved across demographic lines. When composing future LDSF crews, we ought to remember that the triumph of exploration need not be owned by one nation, gender, or race, but shared by all humanity.

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Motorized 3D Ultrasound and Jugular Vein Dimension Measurement on the International Space Station

Courtney Patterson; Danielle Kathleen Greaves; Andrew Robertson; Richard Hughson; Philippe Louis Arbeille

BACKGROUND: Internal jugular vein (IJV) congestion occurs during spaceflight. Historically, IJV distension on the International Space Station (ISS) has been quantified using single slice cross-sectional images from conventional 2D ultrasound with remote guidance. Importantly, the IJV is an irregular shape and highly compressible. Consequently, conventional imaging is susceptible to poor reproducibility due to inconsistent positioning, insonation angle, and hold-down pressure, especially when controlled by novice sonographers (i.e., astronauts). Recently, a motorized 3D ultrasound was launched to the ISS that mitigates angulation errors and has a larger design, allowing for more consistent hold-down pressure and positioning. This short communication compares IJV congestion measured with 2D vs. 3D methods during spaceflight.

METHODS: IJV was measured prior to and following a 4-h venoconstrictive thigh cuff countermeasure. Data were acquired from three astronauts approximately halfway through their 6-mo missions.

RESULTS: The 2D and 3D ultrasound results were not congruent in all astronauts. 3D ultrasound confirmed that the countermeasure reduced IJV volume in three astronauts by approximately 35%, whereas 2D data were more equivocal. These results indicate that 3D ultrasound provides less error-prone quantitative data.

DISCUSSION: These data are the first to compare 2D and 3D methods during spaceflight in the same participants by using a known countermeasure that reduces IJV congestion. The current results demonstrate that 3D ultrasound should be the preferred imaging method when trying to measure venous congestion in the IJV, and that 2D ultrasound results should be interpreted with caution.

KEYWORDS: spaceflight, astronaut, vein compliance, vein volume, countermeasure, occlusive thigh cuffs.

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Venous ultrasound is a tool that has become high priority for spaceflight health research following the emergence of thrombosis[6] and spaceflight neuro-ocular syndrome[7] as major health risks. Venous congestion, caused by the cephalad fluid shift that occurs in microgravity, is posited to play a role in the development of both conditions. Venoconstrictive thigh cuffs (e.g., Russian Braslets) have been proposed as a possible countermeasure to combat this fluid shift by restricting venous outflow from the lower limbs.[3–5]

Traditional 2D ultrasound can be used to measure the internal jugular vein (IJV) cross-sectional area (CSA) at either a single location on the neck, or continuously between the clavicle and the mandible (**Fig. 1**, top left panel). As the IJV CSA is not uniform along its entire length,[8] the continuous method can provide a more representative view of venous distension. Continuous imaging requires manual movement of the probe along the length of the IJV, introducing potential errors which can lead to invalid measurements and poor reproducibility due to variation in insonation angle, inconsistent landmarking, and variation in hold-down pressure that results in partial or total collapse of the IJV. These sources of error can be minimized by having an experienced sonographer controlling the ultrasound

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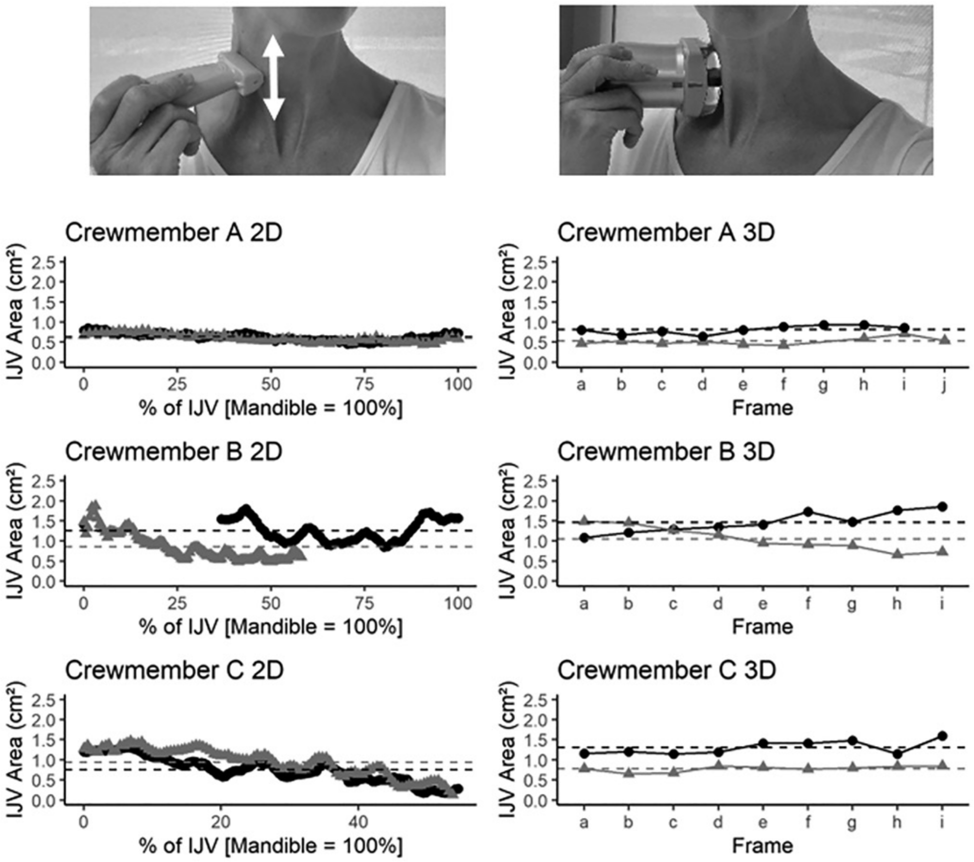

Fig. 1. Images of a participant holding the 2D ultrasound (left) and the motorized 3D ultrasound probe (right) over the right internal jugular vein (IJV). The 2D probe is manually moved up the neck to acquire images from the clavicle to the mandible; the 3D probe is motorized and the head automatically moves at a constant speed over the length of the probe head, which is approximately 3.6 cm. IJV cross-sectional area is reported for baseline (black) and, after 4 h of thigh cuff inflation (gray), by the two methods. Unreliable imaging prevented quantification of area (2D method) along the entire length of the IJV for Crewmember B.

probe, but, on the International Space Station (ISS), inexperienced crew are normally directed by remote guidance.

Motorized 3D ultrasound has several advantages over 2D. First, the probe head is large (4.5 × 5 cm vs. the 4.5 × 0.5 cm linear probe), typically covering over half the length of the neck (Fig. 1, top right panel). This allows the probe to be positioned against the clavicle and trachea consistently during repeat measures. Second, the scan speed (for sequential images) is programmed to remain constant, covering 3.6 cm in 4 s, with insonation angles corrected automatically. Third, the hold-down pressure along the length of the neck can be minimized, since the surface area in contact with the skin is large and maintained by gel (or water on ISS) across the surface area of the motorized probe front head. The ultrasound scan head moves within the front head, allowing the probe casing to maintain fixed contact with collarbone and trachea.

Imaging with motorized 3D ultrasound has been used previously during dry immersion, which induced a significant cephalad fluid shift. After 2 h, 3D ultrasound indicated that IJV volume was increased in groups with and without thigh cuffs, but the change was attenuated in the group wearing cuffs.[1,2] To date, 3D ultrasound has not been used to quantify IJV distension with and without thigh-cuffs during spaceflight.

This brief report describes the results of 2D and 3D imaging acquired via self-scan by three crewmembers who wore thigh cuffs for 4 h at the midpoint of their 6-mo mission on ISS. Images from 2D and 3D ultrasound of the IJV were collected prior to donning thigh cuffs and after having worn the cuffs for 4 h. The images were self-acquired by crewmembers who were relatively inexperienced sonographers. Each crewmember was voice-guided remotely by an experienced sonographer on Earth, with the assistance of near real-time video feeds. The objective was primarily methodological: to compare IJV volume obtained using 2D and 3D methods by a relative novice, done both at rest and after an intervention that was expected to reduce IJV volume. Secondarily, the objective was to investigate the overall ability of thigh cuffs to reduce cephalad venous congestion during spaceflight by quantifying the changes to IJV distension. We hypothesized that the 3D method would show a change in volume more consistently than 2D, and, secondarily, that IJV distension in this small group of astronauts on ISS would be reduced after 4 h of thigh cuff wear.

METHODS

Data were collected as part of the Canadian Space Agency Vascular Echo experiment. The protocol was approved by the University of Waterloo Office of Research Ethics, Johnson Space Center Committee for the Protection of Human Subjects, NASA Human Research Medical Review Board, European Space Agency Medical Review Board, and Japanese Space Agency Research Ethics Board (NASA IRB Pro1222) in accordance with the Declaration of Helsinki. Written informed consent was collected and session constraints were: no caffeine, blood pressure, allergy, or acid reflux medications; no decongestants, sleeping pills, central nervous system stimulants, or nonsteroidal anti-inflammatories for 24 h prior to testing; and no exercise on the day of testing and 2 h post-prandial.

Subjects

Three astronauts (1 woman, 2 men; height = 180 ± 2 cm, weight = 79 ± 13 kg, age at launch = 43 ± 4 yr) were included in the study.

Equipment and Protocol

Ultrasound sessions on the ISS were completed in the morning, prior to donning the thigh cuffs (Pre-cuff), and after 4 h of thigh cuffs, with the cuff still in place (Cuff). During each session, consecutive ultrasound scans were performed with two probes, using a customized Orcheo Lite scanner (ECHO Sonoscanner, Paris, France). First, the 2D scans were collected using a 17-mHz linear probe. Participants were remotely guided by a sonographer on Earth to place the probe at the right clavicle (with the IJV in the center of the image) and slide up the neck toward the mandible while maintaining light contact pressure (Fig. 1, left). The length of time it took to image from the clavicle to the mandible varied. The 2D slide was repeated three times, and the image with the most consistent IJV wall was selected for analysis. Second, the 3D scans were collected using a custom motorized 3D linear probe (described above) which was placed by the participant at the right clavicle, in contact with the trachea, using light contact pressure (Fig. 1, right). The sonographer on the ground adjusted the image as necessary, then initiated the automated, robotically controlled 3D capture sequence. Three repetitions of the capture were completed, and the best image was analyzed. No statistics were completed on data due to the small sample size.

Analysis

The 2D ultrasound imaging was analyzed by extracting individual frames from the exported cine video file (~120–350 frames per cine) (VLC Media Player; https://www.videolan.org/vlc/index.html). The IJV CSA in each frame was quantified semiautomatically using the ellipse tool in ImageJ (http://imagej.org/) and adjusted manually. Any frame when the probe was stationary or the IJV walls could not be identified was discarded. Frames were then normalized to the distance covered by the scan, where the first frame at the clavicle was made 0% and the final frame at the mandible was made 100%. All measurements were averaged to quantify mean IJV CSA across the vessel.

The 3D ultrasound analysis was completed using customized software on the Orcheo Lite scanner (**Fig. 2A**). The software automatically pulls nine images of IJV CSA, which are then measured by manually tracing the inner wall of the vessel in each of the nine images using the track pointer of the device (**Fig. 2B**). Mean CSA value and scan length (3.6 cm) were used to calculate IJV volume. In addition, all measurements were averaged to quantify mean IJV CSA across the vessel in order to facilitate comparison to the 2D data.

RESULTS

Compared to 2D ultrasound, IJV CSA was larger with 3D ultrasound during Pre-cuff (3D: 1.19 ± 0.34 cm^2; 2D: 0.84 ± 0.35 cm^2) and smaller with 3D ultrasound during Cuff (3D: 0.79 ± 0.28 cm^2; 2D: 0.83 ± 0.33 cm^2) (Fig. 1). The intraindividual absolute and relative change in IJV CSA between Precuff and Cuff measurements was inconsistent

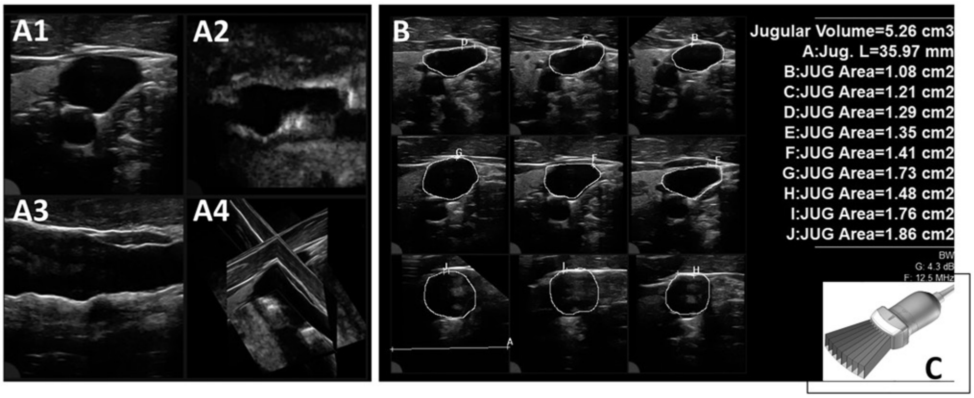

Fig. 2. Left panel shows the 3D scan acquisition planes (A1–A3: transverse, c-plane, and sagittal, respectively) and the user-movable transverse and sagittal axes (A4). In the A4 panel, the user slides the axial planes to optimize the internal jugular vein. Right panel (B) shows the 9 cross-sections of a representative IJV, and their corresponding areas taken equally spaced over 35.97 mm perpendicular to the long axis, moving from the collarbone toward the mandible. Inset (C) schematic shows the beamforming pattern used to create the nine cross-sections.

Table I. Internal Jugular Vein (IJV) Cross-Sectional Area (CSA) for All Crewmembers Using the 2D and 3D Ultrasound.

		IJV AREA (cm^2)		
CREWMEMBER	**ULTRASOUND**	**PRE-CUFF**	**CUFF**	**% CHANGE**
A	2D	0.63 ± 0.10	0.60 ± 0.10	−5%
	3D	0.81 ± 0.10	0.52 ± 0.09	−36%
B	2D	1.26 ± 0.27	0.85 ± 0.34	−32%
	3D	1.46 ± 0.27	1.06 ± 0.30	−28%
C	2D	0.76 ± 0.32	0.93 ± 0.34	+24%
	3D	1.31 ± 0.17	0.78 ± 0.07	−40%

2D CSA was the average of multiple measurements along the length of the IJV. The plane of the image could not be guaranteed to be 90° to the neck. 3D CSA was the average of nine sections taken equally spaced by the internal software of the Sonoscanner ultrasound. Each image was adjusted by the software to be perpendicular to the neck.

between 2D and 3D methods (**Table I**). Using 3D ultrasound, thigh cuffs were associated with ∼35% reduction of IJV distention, with CSA being reduced in all 3 participants. With 2D ultrasound, CSA was reduced during Cuff in only two of three participants. In contrast, Crewmember C appeared to have a 40% increase, rather than decrease, in IJV distension with thigh cuffs (Fig. 1, Table I).

DISCUSSION

In this brief report, we confirmed that the use of thigh cuffs over 4 h reduced IJV CSA and volume in three astronauts. This report is limited to three astronauts because the 3D probe was not launched to ISS until part of the way through the Vascular Echo study. Additional astronauts were studied with thigh cuffs using only the 2D method. Interestingly, those data displayed similar ambiguity and inconsistent results to the 2D data presented here. Those 2D-only datasets have not been included because no 3D comparison data is available. The motorized 3D ultrasound technology mitigates human scanning errors created by nonexpert sonographers, even under remote guidance, by equalizing down pressure, controlling probe speed (which is important for reconstructing a realistic 3D view), and correcting the angle of insonation. Historically, IJV scans completed on the ISS have relied on 2D ultrasound, using conventional nonmotorized ultrasound, with remote voice-guiding from Earth.[3] The IJV is an irregular shape (see Fig. 1 and 2), so a long section with multiple CSA measurements should be analyzed to appropriately assess changes in volume. The current results demonstrate that when trying to capture a continuous image along the length of the IJV, using a motorized 3D ultrasound should be the preferred imaging method, and any 2D ultrasound results should be interpreted with extreme caution. It is not realistic to expect a nonsonographer crewmember to rigidly maintain the angle of insonation while sliding the probe 6 cm along their own neck. The motorized probe, even though it only covers 4 cm, has the clear technological advantage for correct angle of insonation. These data are the first to compare the outputs of both methods during spaceflight and with the same participants in the context of a known intervention/countermeasure that reduces IJV congestion.

In conclusion, although Hamilton et al.[3] provided visual evidence of the impact of thigh cuffs on IJV CSA, this is the first study to quantify the effects of cuffs at multiple levels of the IJV during spaceflight. Using only the 3D data, we found that 4 h of wearing thigh cuffs reduced venous congestion by ∼35%. While conventional 2D ultrasound in the hands of an expert sonographer can quantify IJV CSA at the bedside, astronauts are generally not skilled sonographers, and motorized 3D ultrasound provides quantitative analysis that is preferable to assess microgravity-induced changes in volume of the irregularly shaped IJV.

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Tolerance of Centrifuge-Simulated Commercial Spaceflight in a Subject with Hemophilia A

Isaiah A. Reeves; Rebecca S. Blue; Serena Auñon-Chancellor; Michael F. Harrison; Ronak Shah; William E. Powers

INTRODUCTION: With increasing engagement of commercial spaceflight participants in spaceflight activities, the evaluation of individuals with medical conditions not previously characterized in the spaceflight environment is of particular interest. Factors such as acceleration forces experienced during launch, reentry, and landing of spacecraft could pose an altered risk profile in some individuals due to known disease. Bleeding diatheses present a unique concern in the spaceflight environment given hypergravity exposure and, particularly, the potential for injury resulting from transient or impact acceleration.

CASE REPORT: A 26-yr-old Caucasian man with severe hemophilia A and no detectable endogenous Factor VIII (FVIII) volunteered for participation in hypergravity exposures simulating spaceflight. His treatment regimen included 50 IU $\cdot$ kg^{-1} FVIII-Fc fusion protein intravenous administration every 96 h, with supplemental FVIII administration as needed for injury or bleeding. The subject experienced two profiles at the National Aerospace Training and Research Center (NASTAR), with maximum exposure +4.0 G_z, +4.5 G_x, 6.1 G resultant, and maximum onset rate <0.5 $G_z \cdot s^{-1}$ and +1 $G_x \cdot s^{-1}$. The subject reported no abnormal events during the profiles other than brief mild vertigo. No petechial hemorrhage, ecchymosis, or other bleeding was noted during or after profiles. Supplemental FVIII was not required before, during, or after exposure.

DISCUSSION: Inherited bleeding disorders present several potential concerns that must be evaluated prior to spaceflight participation. Cautious review and management of medical history, adherence and barriers to treatment, duration of spaceflight and longitudinal management concerns, and a thorough and detailed risk/benefit assessment may provide a future pathway for inclusion of individuals with hematological disorders in commercial spaceflight.

KEYWORDS: hemophilia A, bleeding diathesis, Factor VIII, human centrifuge, hypergravity, commercial spaceflight, acceleration, hematology.

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With increasing engagement of commercial spaceflight participants (SFPs) in spaceflight activities, the evaluation of individuals with medical conditions not previously characterized in the spaceflight environment is of particular interest. In addition to the physiological changes that occur in spaceflight, factors such as acceleration forces experienced during launch, reentry, and landing of spacecraft could potentially affect preexisting medical conditions or pose an altered risk profile in some individuals due to known disease. Bleeding diatheses present a unique concern in the spaceflight environment given hypergravity exposure and, particularly, the potential for injury resulting from transient or impact acceleration. Given that hematological abnormalities are generally disqualifying for military service and career astronaut fitness-for-duty standards,[10,25] there are little to no published data on the clinical response of individuals with known bleeding disorders in a high-acceleration environment.

Known hematologic complications of hypergravity exposures, especially from sustained exposure to greater than +6 G_z acceleration, include cutaneous petechiae attributable to capillary rupture in dependent and unsupported areas of the body, sometimes termed "G-measles".[16] This condition is generally

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self-limited and associated with mild discomfort. In addition, less frequently reported hematologic or vascular sequelae of hypergravity (generally $+G_z$) or associated anti-G straining maneuvers (AGSM) and protective garments include hematomas,[5,20] phlebitis,[30] and one case report of large vessel dissection.[3] Data regarding sustained exposures in alternative vectors ($\pm$ G_y, $+G_x$) are more limited, though prior studies have evaluated layperson tolerance of up to $+4$ G_z and $+6$ G_x sustained acceleration, with no evidence of known hematological or vascular sequelae associated with these profiles.[7–9] Recurrent Valsalva in various environments is correlated to ocular sequelae, including subconjunctival hemorrhage, preretinal macular hemorrhage, superchoroidal hemorrhage, vitreous hemorrhage, and Valsalva retinopathy.[13,32] In addition, any transient hypergravity exposure from off-nominal, impact, or traumatic environments (such as hard landings or crashes) would pose a substantial risk to unmitigated hematological disorders and bleeding diatheses.

The most common inherited bleeding disorders are von Willebrand disease, which affects roughly 1% of the general population, and hemophilia A, or Factor VIII (FVIII) deficiency, with an incidence of approximately 1:5000 male births.[15,18,29] Bleeding disorders (including hemophilia A) exist on a clinical spectrum, with symptoms and sequelae dependent upon the levels of FVIII. Severe hemophilia A is generally defined as FVIII levels below 1%, and it is associated with an increased risk of life-threatening and spontaneous bleeding.[27,28] However, with the advent of recombinant FVIII products, affected individuals are often treated prophylactically to prevent bleeding episodes[24,27] or mitigate hematological consequences resulting from trauma.[28] In a case where FVIII levels are maintained, via prophylaxis, above the threshold required for hemostasis, the risk of serious bleeding is significantly decreased.[27] Lifespan and functional capacity expectations for an individual with well-controlled hemophilia are similar to those of other individuals in the general population.[15,24]

There are recent data to suggest that individuals with a variety of systemic diseases and conditions, if well-controlled, can tolerate the acceleration forces associated with short-duration commercial spaceflight launch and return profiles.[8,9,31] Here we report a case of a young male subject with severe hemophilia A on exogenous FVIII factor replacement and his response to variable and sustained $+G_x$ and $+G_z$ acceleration forces during centrifuge-simulated spaceflight.

CASE REPORT

A 26-yr-old Caucasian man with severe hemophilia A and no detectable endogenous FVIII volunteered for participation in hypergravity exposures simulating suborbital spaceflight. The subject was diagnosed at 15 mo of age and has been treated throughout his life with prophylactic recombinant FVIII therapy. At the time of the study, his treatment regimen included $50\,\mathrm{IU} \cdot \mathrm{kg}^{-1}$ FVIII-Fc fusion protein intravenous administration every 96 h, with supplemental FVIII administration as needed for any injury or bleeding episodes. His condition was being actively managed by a hematologist at a major academic medical center and he provided documented history of stable condition for several years, no frequent bleeding episodes or hospitalizations since reaching adulthood, no hemarthrosis or baseline disability, no recent use of supplemental FVIII outside of his normal dosing schedule (for at least several months), and full preservation of basic musculoskeletal function and activities of daily life. Prior to participation, he provided documentation of current physical and medical status, with no other significant medical history or physical limitations reported aside from a generalized caution from his hematologist to avoid high-risk contact sports. A pharmacokinetic (PK) study had been performed on his current treatment regimen, demonstrating that his regimen provided >100% factor availability on the first day of his 4-d cycle, >20% on the second, >5% on the third, and >1% on the fourth, as well as that any emergent FVIII administration would promptly raise FVIII levels to >100% (within 1 h of administration). Given the novelty of his medical condition in a hypergravity environment, his medical history, current status, and effectiveness of treatment regimen were closely reviewed prior to participation by a panel of board-certified Aerospace Medicine physicians with additional certifications in Internal Medicine, Critical Care Medicine, and Emergency Medicine.

The subject participated in two centrifuge profiles in a single day at the National Aerospace Training and Research Center (NASTAR) centrifuge (at Environmental Tectonics Corporation, Southampton, PA). The first profile approximated a suborbital spaceflight in a winged vehicle where the occupant was seated semi-upright for both launch and reentry, resulting in $+G_z$ and $+G_x$ sequential exposures on ascent and combined simultaneous $+G_x$ and $+G_z$ exposures during descent (maximum exposure $+4.0$ G_z, $+4.5$ G_x, 6.1 G resultant). Each phase of acceleration was <2 min and G-onset rates were $<0.5\,\mathrm{G} \cdot \mathrm{s}^{-1}$ in the $+G_z$ direction and $<1.5\,\mathrm{G} \cdot \mathrm{s}^{-1}$ in the $+G_x$ direction. The duration of time at peak $+G_x$ and $+G_z$ was <5 s. The second profile simulated a capsule launch in which an abort procedure occurred with activation of a launch escape system (LES). The profile provided a rapid $+G_x$ acceleration (maximum $+3.3$ G_x, onset rate $+1\,\mathrm{G} \cdot \mathrm{s}^{-1}$) during the LES simulation, followed by descent acceleration of maximum $+1.9$ G_x (onset rate $<0.5\,\mathrm{G} \cdot \mathrm{s}^{-1}$). Subsequent profile acceleration exposures representing drogue and main parachute deployment were followed by a simulated water landing and sinusoidal waveforms representing capsule motion on water. Finally, the profile included brief transient $-G_z$ acceleration (maximum -0.74 G_z with sustained $-G_z$ exposure time <1 s) during simulated drogue deployment and landing, similar to expected acceleration profiles of an actual LES abort. Between transient $-G_z$ accelerations, the gondola occupant's head is at rest at between 0° and −15° head-down positioning due to seatback angle. The centrifuge profiles included audiovisual capabilities to add to the fidelity of the simulation. The participant was continuously monitored with real-time audio and video communication.

The subject participated in centrifugation on the second day of his normal 96 h treatment regimen (approximately 24 h after the most recent FVIII dosage). Prior to the initiation of centrifuge runs, the subject's vital signs, including resting blood pressure (BP) and heart rate (HR), were recorded. The subject was taught AGSM and the "hook" (L-1 closed-glottis variant) maneuver, plus indications for use. He was advised to use lower extremity muscular strain during any $+G_z$ exposure and to initiate the hook maneuver, but to reduce or eliminate Valsalva effort in the absence of symptoms (visual changes or light-headedness). He was also cautioned against sudden head movements during centrifuge trials, in order to avoid triggering Coriolis symptoms. Supplemental FVIII was available for use if needed and the subject was monitored during both centrifuge profiles by two board-certified aerospace and emergency medicine physicians.

Data was collected post-centrifugation in the form of questionnaires about symptoms and monitoring of physical condition in the following days. The subject reported no abnormal events during the simulated flights other than brief mild vertigo, which resolved prior to the completion of each run, and a transient inversion sensation associated with the slight head-down angle and cyclical onset/offset of hypergravity during the descent portion of the second profile. No petechial hemorrhage, ecchymosis, joint discomfort, effusion, or other bleeding was noted during or after acceleration exposures. He reported use of lower extremity strain throughout all $+G_z$ exposures, but noted no visual symptoms at any time; following the initial $+G_z$ exposure in the first profile, he did not further employ the hook/Valsalva portion of AGSM.

The subject was able to ambulate normally immediately upon exiting the centrifuge and had no immediate adverse effects from the experience, nor any apparent neurovestibular imbalance. Following the centrifuge runs, the subject continued his normal FVIII treatment regimen with no changes. There was no indication for use of supplemental dosing of FVIII at any time during or after the centrifuge experience. The subject continued to self-monitor for several days and noticed no delayed symptoms.

DISCUSSION

As far as the authors are aware, this represents the first reported case of an individual with an inherited bleeding disorder undergoing acceleration forces approximating those of spaceflight launch and landing. In the setting of chronic, well-controlled, and stable disease on an effective treatment regimen, this individual tolerated the hypergravity exposures well and without any adverse effects or bleeding. Additionally, there was no need for alteration of his baseline treatment regimen or administration of supplemental FVIII products outside of his standard prescribed management due to any concern or injury from the hypergravity exposures. In this case, aeromedical risk was considered acceptable after review by trained and experienced aerospace medicine physicians. The subject's prior PK studies demonstrated that his expected FVIII activity on the second day of his treatment regimen was ≥20%, a level which is associated with minimal risk of bleeding outside of major trauma.[6] Practitioner familiarity with centrifuge profiles and relative risk of traumatic injury during centrifugation helped to limit risks and ensured appropriate informed consent prior to participation.

In consideration of the generalizability of this experience, it is important to highlight both the clinical spectrum of inherited bleeding disorders and the large variability in treatment regimens and outcomes. In this case, the individual, while having severe disease by definition, has been treated prophylactically with regular FVIII infusions since diagnosis early in life and, subsequently, achieved a preservation of normal quality of life and functional status. This is in stark contrast to individuals with severe inherited bleeding disorders and no access to care, poor adherence to treatment regimens, or treatment in an "on-demand" regimen, in which factor products are administered only after bleeding or symptoms have occurred. When treated sporadically, insufficiently, or not at all, severe hemophilia is profoundly detrimental to health and associated with high risk of spontaneous bleeding, including life-threatening events such as gastrointestinal or intracranial hemorrhage.[15,27] For reference, prior to the introduction of clotting factor concentrates in the 1970s, life expectancy for severe hemophilia was generally 10–20 yr, due to the high likelihood of severe spontaneous hemorrhagic episodes and complications from such events.[19] Since the late 1990s, substantial advances have been made in the management of inherited bleeding disorders, including recombinant (nonhuman plasma-derived) products and novel therapeutics extending half-life and providing alternate routes of administration.[4,15]

From the perspective of commercial SFPs, inherited bleeding disorders present several potential concerns that must be evaluated prior to participation. Because of the clinical variability of hematological disorders, it will be essential to first assess the baseline management of the condition prior to discussing possible risks from the spaceflight environment. As a corollary to spaceflight considerations, aeromedical certification for piloting activities in an individual with a history of hemophilia or similar bleeding diatheses is variable and dependent upon the certification body. While the International Civil Aviation Organization (ICAO) considers severe hemophilia A to be incompatible with flight duties,[17] the Federal Aviation Administration (FAA) requires case-by-case evaluation due to the aforementioned heterogeneity of hematological conditions.[14] FAA Special Issuance of Medical Certification in the case of hemophilia requires a review of current clinical documentation and a detailed status report of the condition, followed by a review by hematology subject matter experts in consultation with the FAA medical review panel.[14]

One published case report in 2013 described an individual with severe hemophilia A, who only received "on-demand" FVIII administration, seeking First Class medical certification.[33] In this case, a hematology consultant recommended Special Issuance only if prophylactic factor administration could be required prior to flight. As the FAA does not generally provide directed treatment requirements, the case ultimately resulted in denial based on frequency of bleeding episodes, joint injury from recurrent hemarthrosis, the patient's current on-demand treatment regimen, and an unenforceable need for treatment adherence to ensure safe piloting duties.[33] This case highlights another concern to be weighed when considering approval of an individual with hemophilia A for spaceflight activities. Insufficient management of the disease burden throughout life may have manifestations other than the risk of acute bleeding episode: recurrent hemarthrosis or similar non-life-threatening events may result in mobility or functional restrictions that could manifest as limitations in a high-risk environment. For example, while SFPs may not be responsible for nominal operational activities, in the case of an in-flight emergency, all vehicle occupants may be required to engage in critical operational actions or rapid evacuation. A thorough evaluation of functional capacity is warranted to rule out any critical limitation from prior disease sequelae that may ultimately pose a risk in a spaceflight environment. Medical comorbidities additionally predisposing to vascular injury (e.g. connective tissue disorders, Ehlers-Danlos, Marfan) may further compound bleeding risk if present concomitantly with a bleeding disorder.[22] Other considerations may be necessary if the individual in question has a more operationally critical role during the spaceflight (for example, pilot vs. participant).

One method by which individual treatment of bleeding disorders is optimized in clinical practice, and which may have useful implications for aeromedical certification, is through PK studies; indeed, risk analysis in this case was partly based upon the subject's PK studies and known FVIII activity on his current treatment regimen. Various factor concentrate products and individual variability will result in differing response to any given treatment regimen. PK studies can help individualize care by demonstrating effectiveness of treatment over time, most commonly through standard clotting factor assays such as FVIII activity levels. Thus, prophylactic treatment can be targeted to achieve factor levels sufficient for clotting for all or the majority of the time between scheduled doses.[15,17] Often, an FVIII activity level greater than 1% is sufficient to reduce bleeding (i.e., conversion from severe to moderate hemophilia) as part of a prophylactic treatment regimen. Treatment remains an individualized process, and a higher target of 5–15% or greater may provide further benefit in certain individuals. Regardless, it is not necessary to have 100% FVIII activity to prevent bleeding episodes.[32]

In some cases, FVIII administration can result in the development of neutralizing antibodies, or inhibitors, rendering factor replacement therapy unsuccessful.[2,11,15] In most cases, such inhibitor development occurs in childhood or adolescence;[12] thus, as commercial spaceflight participation presumably would require an age of majority to allow for acceptance of informed consent, failure of replacement factor would most likely have been previously recognized. Further, development of inhibitors would not be expected to be subtle or rapid enough to result in a sudden factor resistance in adulthood with unexpected clinical manifestations at the time of a brief spaceflight experience.

For individuals with well-controlled disease and no functional limitations, there is a possibility that spaceflight experience may be tolerated with minimal or no impact related to the bleeding disorder. Further considerations in the spaceflight environment include the logistical and practical considerations of managing the condition (for example, during remote or isolated periods around the launch, such as any prelaunch quarantine or a remotely located launch facility), as well as the treatment needs during spaceflight. A short-duration suborbital flight, for example, would be far easier for disease management than a longer orbital flight, where treatment regimens would potentially require pharmaceutical administration while in orbit. In such circumstances, the benefits of prophylactic and maintenance therapy must be weighed against the constraints of infusion frequency, storage and management of pharmaceuticals (for example, need for refrigeration), and challenges of on-orbit administration, particularly as many products may require administration every 48–96 h.[1,2] The majority of treatment products for hemophilia require intravenous administration,[2] which presents unique challenges of its own in a microgravity environment.[21,26] However, other bleeding disorders, like von Willebrand disease, can sometimes be treated adjunctively with therapies like intranasal desmopressin (DDAVP), and newer treatments for hemophilia include those with subcutaneous injections.[4,23] Such treatment options may further enable consideration for including individuals with hematological disease in more varied flight environments.

Commercial spaceflight provides a unique pathway for individuals with previously disqualifying conditions to potentially engage in spaceflight activities. This report suggests that a young, otherwise healthy individual with a severe bleeding disorder that is well-managed and stable can physiologically tolerate acceleration forces similar to those that would be experienced by a commercial SFP in a short-duration spaceflight. There are important and substantial limitations to the generalizability of this information, and many factors contribute to the risk of injury or bleeding beyond those simulated in this study. However, from the perspective of widening the spaceflight experience to those individuals affected by chronic and severe medical conditions, it is important to continually broaden research endeavors and better characterize these risks, thus providing a framework for aeromedical evaluation. Ultimately, the decision to include an individual with bleeding diatheses, including hemophilia, in commercial spaceflight activities will be determined by a risk assessment and acceptance of such risk by both the potential SFP and the industry provider, through guidance from trained and experienced aeromedical practitioners. Cautious review and management of medical history, adherence and barriers to treatment, duration of spaceflight and longitudinal management concerns, and a thorough and detailed risk/benefit assessment may provide a future pathway for the inclusion of individuals with hematological disorders in commercial spaceflight.

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Heart Rate Variability of a Student Pilot During Flight Training

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BACKGROUND: Heart rate (HR) indicates the number of beats per minute (bpm) of the heart, while heart rate variability (HRV) indicates the temporal fluctuation of the intervals between adjacent beats (NN). HRV expresses neuro-cardiac activity and is generated by heart-brain interactions and dynamics related to the function of the autonomic nervous system (ANS) and other components (e.g., body and ambient temperature, respiration, hormones, blood pressure). We are carrying out a series of experimental investigations with the aim of studying HRV in student pilots during training.

CASE REPORT: For this purpose, we used a Holter electrocardiograph equipped with three channels and five electrodes positioned on the chest of the subject who participated in our investigation. The case report refers to a student pilot who, during a flight mission with the instructor, had to face a forced landing and a flap failure. We report data based on analysis of the time domain and frequency domain related to operations on the ground before the flight, during the flight, and on the ground after the flight.

DISCUSSION: Our initial conclusion is that the extent of HRV constitutes an "energy store" for better cardiac performance in eustress activities. During advanced tasks, the "Total Power" of the heart decreases because the RR intervals are forced toward low values, where the heart is less able to be modulated by its many controllers. Furthermore, this experimental protocol can be useful to flight instructors for the training process of student pilots.

KEYWORDS: cardiac function, heart rate variability, flight training, eustress.

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Contraction of the heart occurs in an autonomous and rhythmic way since it contains pacemaker cells that can initiate depolarization of the atrial and ventricular cells via conducting tissue. The main groups of these pacemaker cells are located at the level of the sinoatrial and atrioventricular nodes (secondary starter).[10] The time course of the electrical events preceding the mechanical ones can be recorded as an electrocardiogram.

The frequency of contractions of the heart (systoles) per minute (heart rate) is an important parameter for understanding the function of this organ, but it does not explain its physiology or modulation. For example, a frequency of 70 bpm expresses a general trend of the heart rate (HR) but does not indicate the distribution during a given minute; there is no information about the time between one beat and the next (RR-Int). In other words, the detailed heart rate variability (HRV) cannot be described by the HR alone. Thus, within certain limits, this fluctuation does not express a malfunction, but rather a physiological behavior, given the conditions of dynamic equilibrium that distinguish the functioning of complex biological systems.

It is well known that the sinus rhythm is irregular under steady-state conditions.[7] The fluctuations that are evident between adjacent beats are negligible if one considers average values over time. However, their genesis appears to be linked to complex and nonlinear interactions between the various

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physiological systems involved in modulation.[7] The HRV is therefore a property of interdependent regulatory systems that operate at different time scales. It reflects a balanced action regulated by the sympathetic nervous system (SNS) and parasympathetic nervous system (PNS), as well as blood pressure (BP), vascular tone, gas exchange, the intestine, and perhaps even the facial muscles.[3]

When an organism prepares to face new tasks or improve acquired, predictable, or emergency situations, a series of new operating conditions is established involving organs and systems; these affect parameters such as BP, amplitude and frequency of the respiratory rhythm, the hormonal sphere, and the function of the myocardium. In essence, a kind of stress response occurs in which both the SNS and PNS play roles of primary importance.[1,4,11]

A recent study conducted at the Department of Cellular and Molecular Medicine, University of Arizona College of Medicine, showed that the HR can be used to assess the cognitive commitment of students. The results of this survey suggest that the analysis of the HR trend is a valid method for quantifying and interpreting a learning process in its various facets.[2]

Many parameters affect the performance of the heart. A learning process that occurs in conditions of extreme individual variability will have a success that depends on several concomitant factors. In this context, we proceeded to carry out a series of experiments with the aim of quantifying the HRV in student pilots who are preparing to obtain a flight license for private use (PPL), as well as in students who already have a PPL and theoretical part (ATPL), but who continue their studies in order to acquire a commercial pilot license (CPL). The final goal of our investigations was to determine whether the HRV could give indications about evolution of the learning process, framed in a broad autonomic and motivational context.

For this purpose, we are performing experimental procedures on both PPL and CPL student pilots during the instrumental flight training phase (CPL-IR) on a voluntary basis, with a guarantee of confidentiality for the purposes of processing personal data.

In this case report, we describe the results obtained from the HRV analysis of a PPL student pilot trainee who, for reasons of confidentiality, we will call "the subject".

CASE REPORT

The experimental protocol has been approved by the National Civil Aviation Authority (Aeromedical Section) of the Italian Republic.

Before the experimental session and immediately after his arrival, the subject was equipped with five noninvasive electrodes, positioned in areas of the thoracic skin, and connected to a three-channel Holter (ECG Biomedical, BI9100), which remained active until completion of the experimental session. The flight track (altitude, direction, and time) of the aircraft for the entire duration of the flight allowed us to correlate the times at which the flight activities scheduled by the instructors took place with the Holter recordings; this was followed by analysis. The aircraft used was a Tecnam.[12]

The training mission consisted of three phases: (1) a ground phase that included a briefing with the flight instructor; (2) an in-flight phase during which, in addition to normal operations, the student had to manage sudden emergencies such as a forced landing and a flap failure. A ground phase (3) including a debriefing was scheduled at the end of the mission.

Apart from the initial arrival and waiting time (a & w), we defined three time phases: before ground flight operation*s* (bfo), in-flight operations (dfo) and postflight ground operations (afo). During the flight, the instructor suddenly created two emergency conditions. The first related to a forced landing (FL) and the second related to a landing under flap failure conditions (FF). The HRV was quantified according to the guidelines of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology (Task Force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996).[5] We assessed the HRV based on the time domain and frequency domain analysis.[9]

In the time domain, we quantified the mean of all RR-wave intervals and their averages before, during, and after various tasks. In the frequency domain, we quantified total power (TP) that mainly reflected the level of the autonomic nervous activities (both parasympathetic and sympathetic nervous system) and high frequency normalized units (HF, nu) versus low frequency normalized units (LF, nu) to emphasize the balance between the sympathetic and parasympathetic arms of the autonomic nervous system.

The duration of the Holter recording was 152 min, with a number of total beats of 13,793. The average HR was 90 bpm [minimum value = 66; maximum = 135, minimum HR (minute), tachycardia beats = (2.7%) 366, bradycardia beats = 0, RR-Int = 669.9 ms]. The standard deviation of the interbeat intervals of normal sinus beats was 87 ms, very low frequency = 469.5 ms^2, low frequency = 1086.6 ms^2, and high frequency = 266.5 ms^2.

Fig. 1 depicts the mean of RR-intervals for all flight missions; RR-interval averages in bfo, dfo and afo; and LF versus HF normalized units.

The mean RR-intervals were quite variable, although a common trend was observed in the RR-Int parameter: a decrease of values in the dfo compared to the bfo and afo values. The comparison between LF and HF normalized units shows an increasing tendency of the former and a downward trend of the latter.

Fig. 2 depicts the time and frequency domain analysis when the subject was faced—in flight—with two sudden events: a forced landing and a flap failure. The histograms compare the values found in the two emergencies. During the forced landing, the RR-Int was slightly higher than before, while during the flap failure the RR-Int was lower than before.

Concerning the frequency domain values for the specific FL and FF tasks, it can be seen that during the FL task, the total power increases and then decreases, while during the FF it decreases, and then increases. Comparative analysis of the LF

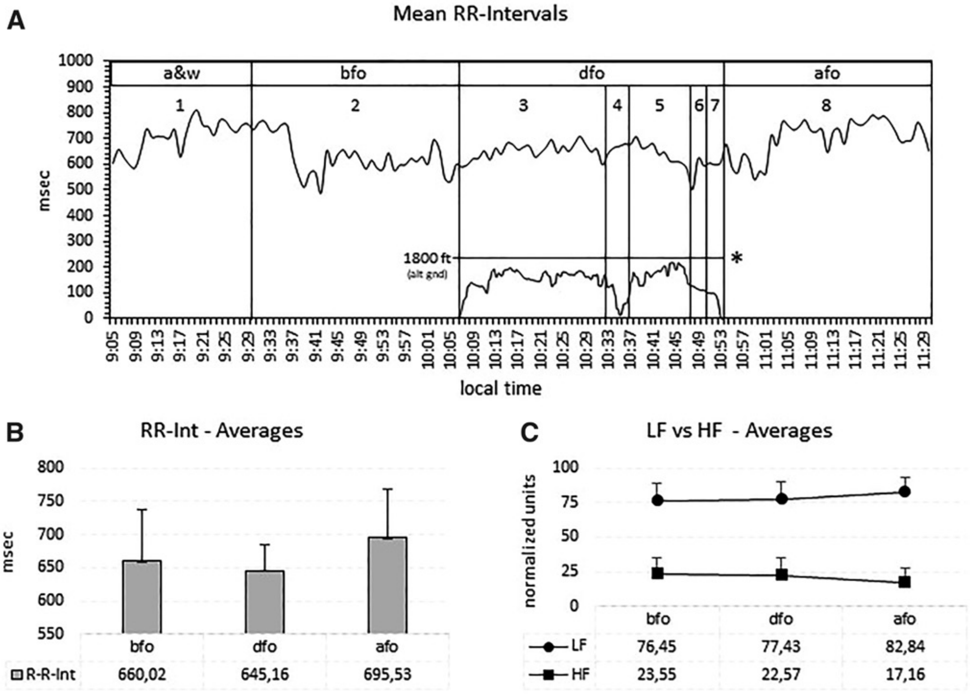

Fig. 1. A.) Plot of Mean RR Intervals and time of the start and end of each task. [1, arrival and waiting (a & w); 2, before flight operations (bfo); 3, during flight operations (dfo), navigation, and maneuvers before forced landing; 4, dfo (forced landing); 5, dfo (before flap failure); 6, dfo (flap failure); 7, dfo (landing); 8, after flight operations (afo)]. The insert inside marked with an asterisk indicates the flight time and the ground altitude (alt gnd) of the aircraft. B.) RR-Interval averages before (bfo), during (dfo), and after flight operations (afo). C.) Low frequency (LF) versus High Frequency (HF), normalized units (n.u.).

and HF normalized data for forced landing and flap failure indicates that, in both tasks, the LF increased during the FF task, but it was more pronounced in the FF task. However, the HF decreased in both cases, although the decrease was more pronounced in the FF task.

DISCUSSION

The progress of the subject's training depends on many variables. They include information analysis; level of attention and vigilance; memorization processes; learning technique; situation awareness; avoidance and management of errors; cooperation and communication; personality; attitude and behavior; self-discipline; workload; state of alertness; stress; and fatigue.[13]

As the subject proceeds with his mission, he will begin to put into place mechanisms such as acquisition, planning, implementation, verification, correction, and improvement of his performance, as well as anticipation processes (feedforward mechanisms) that are fundamental for the construction of a probable scenario. In other words, he begins an adventure that will see him engaged, together with his flight instructor, in a game where progress and outcome will depend on his will and desire to succeed. In doing so, he will try not to disappoint himself or his instructor.

The mammalian heart is innervated by the autonomic nervous system through its sympathetic components (SNS) and parasympathetic components (PNS). In resting conditions, the control of the PNS predominates over that exercised by the SNS. A human heart beats at a rate of about 70 bpm, but if it is deafferented by parasympathetic control, its rate increases to above 100 bpm. However, moderate parasympathetic stimulation may stop the heartbeat for a short time.[6] Moreover, from a temporal point of view, the parasympathetic effect is more rapid than the sympathetic effect, with a ratio of about 5:1. The relationship between the PNS and SNS branches is complex and evolves both linearly and nonlinearly. For this reason, it should not be described as a system where the gain or loss of one component is perfectly balanced by the loss or gain of another component in an equal and opposite sum. Increased PNS activity may be associated with a decrease, increase, or no change in SNS activity.[8]

An aircraft flight and all related activities presuppose performances that result from concomitant actions of organs and systems, starting with all divisions of the nervous system and continuing to involvement of central and peripheral mechanoreceptors and chemoreceptors. The data obtained from our experiments lead us to two types of consideration, one concerning pilot training and the other concerning cardiac function. Continuous and nonlinear interaction between organs and systems affects the intensity and duration of the parameters described above.

Time domain analysis showed that the decrease of RR-Int in dfo compared to bfo is due to the fact that, during this phase, the subject is trained on new tasks or reviews those that were previously learned but not yet definitively acquired. In other words, the HRV reflects the variations in a subject's performance in relation to the level of achievement of a given task.

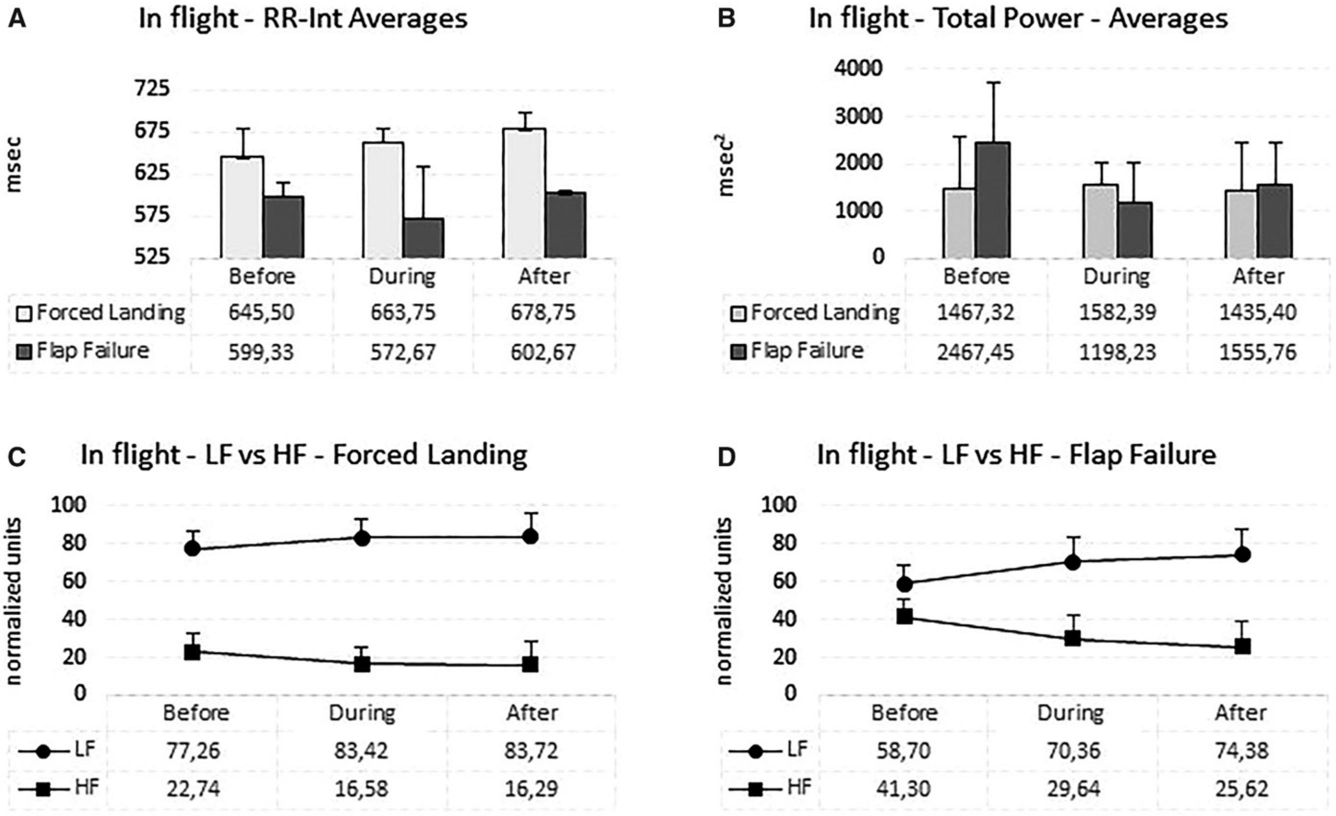

Fig. 2. Comparison of time domain and frequency domain of data related to forced landing and flap failure. A.) In-flight RR-Interval averages. Before forced landing and before flap failure (before); during forced landing and during flap failure (during); after forced landing and after flap failure (after). B.) In-flight Total Power averages. Before forced landing and before flap failure (before); during forced landing and during flap failure (during); after forced landing and after flap failure (after). C.) Low Frequencies (LF) versus High Frequencies (HF), normalized unit averages in forced landing. Before forced landing (before), during forced landing (during), and after forced landing (after). D.) Low Frequencies (LF) versus High Frequencies (HF), normalized unit averages in flap failure. Before flap failure (before), during flap failure (during), and after flap failure (after).

Thus, a decrease in HRV indicates a condition of eustress, while an increase indicates better control of the performance. In afo conditions, HRV parameters tend to be restored, but this is not always the case in the short term. HRV shows the variation of intensity and duration, so that the interaction between the SNS and PNS determines new dynamic balances. Therefore, the information from other organs and systems, connected with the heart by the circulatory stream, is also affected. Reducing RR-Int results in decreased HRV; this places the heart in an unfavorable condition for further performances. Conversely, an increase in RR-Int translates into a return of HRV towards modulability values which make the heart perform again.

For power spectrum analysis, our data show that HRV can exhibit good oscillations if the cardiac machine is near resting condition; otherwise, it will work with reduced power. The comparison of the normalized values of the low frequencies (expression of sympathetic activity) and the high frequencies (expression of parasympathetic activity) are consistent with the concept that an organism (phenotype), in variable states of alert, responds to what is foreseen by its biochemical architecture and physiology (genotype). The autonomic nervous system plays a primary role in this case.

The activity of SNS is prevalent when an organism operates in conditions of intense work, both foreseen and unexpected. HR increases with consequent decrease in HRV. To this must be added the fact that an unexpected task can fit into an already intense functional context. Both parameters described above are very useful for quantifying heart performance.

In conclusion, the amount of HRV constitutes an “energy store” for better cardiac performance in eustress activities. During advanced tasks or emergency situations, the “total power” of the heart decreases because the RR intervals are forced toward low values, where the heart is “less willing” to be modulated by its many controllers. Flight activity involves continuous demanding tasks that can be potentially “read” through analysis of the HRV; a high HRV ensures better management of tasks that require a greater commitment of the cardiovascular function. Furthermore, this experimental protocol can be useful to flight instructors for the training process of student pilots.

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A Flight Helmet-Attached Force Gauge for Measuring Isometric Neck Muscle Strength

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INTRODUCTION: Fighter pilots must withstand high G_z-forces that can damage the cervical spine. Strength of the cervical musculature is of vital importance when it comes to preventing these G-induced neck injuries. However, there is very little evidence on valid neck muscle strength measurement methods for fighter pilots. The aim of this study was to examine the validity of a commercial force gauge attached to a pilot's helmet for measuring isometric neck muscle strength.

METHODS: A total of 10 subjects performed maximal isometric cervical flexion, extension, and lateral flexion with the helmet-attached gauge and with a weight stack machine, which was used as a reference. Electromyography (EMG) activities were recorded from the right and left sternocleidomastoids and cervical erector spinae muscles during all measurements. Paired *t*-tests, Pearson correlation coefficient, and Wilcoxon's test were used to analyze the data.

RESULTS: Difference of mean force values between the devices was statistically significant in all directions. Pearson correlation coefficient varied between 0.73 and 0.89 and it was highest in cervical flexion. EMG activities were significantly different only in the left CES during flexion.

DISCUSSION: The helmet-attached gauge is a valid tool for measuring isometric neck muscle strength and is best used as a means to compare individual differences in strength levels or to track the progress of strength development.

KEYWORDS: fighter pilots, neck muscles, force measurements.

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Fighter pilots are repetitively exposed to high G_z-forces that can cause flight-duty-limiting neck injuries. The large cervical range of motion required by modern aiming technology, such as the joint helmet-mounted cueing system (JHMCS), further augments the G_z-induced neck strain.[12] According to Coakwell et al.,[4] maximal cervical rotation needed by the "check-six" movement is one of the most common causes of acute neck injury under high G_z-loading. Additionally, JHMCS has changed the helmets' weight distribution, which increases the risk of injury.[7] It has also been shown that visual function is a major component of postural control and can have an effect on injury risk as well.[2]

Strong neck muscles can prevent these G_z-induced injuries by stabilizing the cervical spine and preventing transmission of forces to the vertebral structures.[4] For example, it has been shown that functional full-body strength training can decrease neck muscle activation and rating of perceived exertion under high G_z-loading.[9] Strength training interventions can also mitigate neck pain prevalence among fighter pilots.[6] Thus it is important to be able to reliably assess fighter pilots' maximal neck muscle strength.

Selistre et al.[11] carried out a meta-analysis on the validity and reliability of different clinical tests made for neck muscle strength assessments. Cervical flexor and extensor endurance test and a hand-held dynamometer (HHD) showed good to moderate intra- and interrater reliability, but the authors were unable to get unequivocal results on the validity of these tests. Instead, Ashall et al.[1] reported that the validity of the HHD was sufficient when compared with a wall-mounted dynamometer, even though peak forces were systematically lower with the

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HHD. Furthermore, it has been reported that the HHD showed excellent correlation when isokinetic measurements were used as reference.[10] Other devices that have been validated in scientific literature include the David Back Clinic 140 and the Multi-Cervical Rehabilitation Unit.[3,8]

It is evident that previous studies have examined the validity of different metrics for neck muscle strength in a variety of ways. In addition, most of the studies have concentrated on the reliability of these metrics rather than the validity. The purpose of this study was to examine the validity of a commercial force gauge connected to a fighter pilot's helmet by comparing it with a cervical extension and flexion weight stack device. Force measurements were coupled with EMG recordings from both the sternocleidomastoids (SCM) and cervical erector spinae (CES) muscles. The hypotheses of this study were that the helmet-attached force gauge would correlate well with the weight stack device and that there would be no differences in neck muscle EMG activities.

METHODS

Measurements were conducted within the same week on two separate days. On the first day, subjects performed maximal isometric cervical extension, flexion, and lateral flexion to the left and right with the weight stack machine; on the other day, the same tests were done using the helmet-attached force gauge. Before the measurements, subjects were instructed to perform a brief warm-up with unloaded head movements. All the raw force and EMG signals were collected through an A/D-converter to Signal 4.0 software for analysis. Subjects were randomly recruited from voluntary students of the University of Jyväskylä. A total of 6 male subjects (age: 25 ± 2 yrs.) and 4 female subjects (age: 26 ± 4 yrs.) were recruited.

The Helmet-Attached Force Gauge

The force gauge used in this study was a typical commercial strain gauge built by Sauter AG (Basel, Switzerland). The other end of this gauge was connected to a fighter pilot's helmet via one y-shaped cable. In order to channel the raw force signals to Signal 4.0, this gauge was connected to another strain gauge, and they were calibrated by using weight plates.

The two connected gauges were mounted to a stationary vertical bar. Each subject's torso position was standardized by a foam tube that was placed between the subject and a pad that was connected to the vertical bar. In order to minimize torso movement, the tube had to stay in place. The subject was sitting in a chair without using the back rest and with their hands resting on their thighs. The distance between the gauges and the helmet was adjusted such that the cables were tight and the subject's head was in neutral position during force production.

Subjects were first instructed to do 2–3 warm-up attempts at 50% of their expected maximum effort. After this, subjects executed two maximal isometric contractions that lasted 3 s each with 2 min rest between the attempts. Only the better result was taken into account. This protocol was repeated in all four directions.

The Weight Stack Machine

A David G140 weight stack machine (David Health Solutions Ltd., Helsinki, Finland), made for strengthening the cervical musculature, was used as a reference device. Because of a built-in strain gauge, maximal isometric force can be recorded in this device by locking the head support in place. Analog force signals were channeled from the gauge to Signal 4.0 through an A/D-converter.

Measurement position was standardized by adjusting the seat to a correct height and locking the chest support in place; instructions for the correct position were given by David Health Solutions. Subjects performed warm-up attempts and maximal isometric contractions with the same protocol as with the helmet-attached gauge. The measurement settings with both the helmet-attached force gauge and the weight stack machine are depicted in **Fig. 1**.

EMG Measurements

EMG activities were recorded from the right and left SCMs and CES with Noraxon Telemyo TM2400R (Noraxon Inc., Scottsdale, Arizona). Bipolar silver chloride electrodes were placed on the muscles according to SENIAM guidelines.[5] Signal amplification was set to 2000 and sampling frequency was set to 1000 Hz. The ground electrode was placed on top of the spinous process of the C7 vertebra. Background noise had to stay between ± 10 μV. RMS amplitude was calculated from the raw EMG signals within a 500-ms timeframe by using the peak of the force signal.

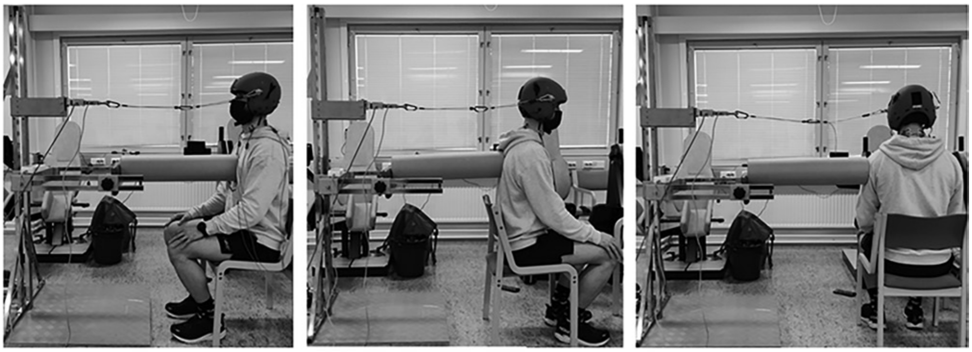
Statistical Analysis

All statistical analyses were done by using IBM SPSS 26.0. A Shapiro-Wilk test was used to check the normality of the data. A two-tailed Pearson correlation coefficient was used to correlate the force measurements between the helmet-attached gauge and the weight stack machine, and a paired samples *t*-test was used to compare group means. A paired samples Wilcoxon test was used to compare means of EMG activity.

RESULTS

Differences of mean forces between the devices are presented in **Fig. 2**. The difference was smallest in flexion (Sauter: 165 N ± 79 N, David: 195 N ± 62 N), whereas in all other directions, differences were almost identical. The largest absolute forces were achieved in extension (Sauter: 228 N ± 68 N, David 327 N ± 109 N). Flexion forces were greater than lateral flexion forces with the helmet-attached gauge and vice versa with the weight stack machine. Correlation between the devices was strongest in flexion ($r = 0.89$) and weakest in lateral flexion to the right ($r = 0.73$). Correlation graphs are presented in **Fig. 3**.

The only significant difference in mean EMG activities between the measurement conditions was observed from the left CES during flexion. The right CES also showed a distinct difference, although not statistically significant ($P = 0.07$). Overall, CES showed the highest activity in extension, whereas SCMs showed the highest activity in flexion. Ipsilateral muscles



1A. Extension (Sauter) 2A. Flexion (Sauter) 3A. Lateral flexion (Sauter)

1B. Extension (David) 2B. Flexion (David) 3B. Lateral flexion (David)

Fig. 1. Measurement positions with the Sauter force gauge (1A-3A) and with the David G140 (1B-3B).

showed higher activity than contralateral muscles during lateral flexion. Mean RMS amplitudes of each muscle in each measurement setting are presented in **Fig. 4**.

DISCUSSION

Maximal isometric neck muscle strength measured with the helmet-attached force gauge was found to have a good to excellent correlation with the weight stack device. Correlation was strongest in cervical flexion and weakest—but still statistically significant—in lateral flexion. Despite the correlation, the helmet-attached gauge showed significantly lower absolute force values than the weight stack device. The only difference in neck muscle EMG activities between the devices was found from the left CES during flexion. These results are in line with previous studies that have investigated the validity of neck muscle strength assessment methods.

It was hypothesized that there would be a strong correlation between the devices and that neck muscles show similar EMG

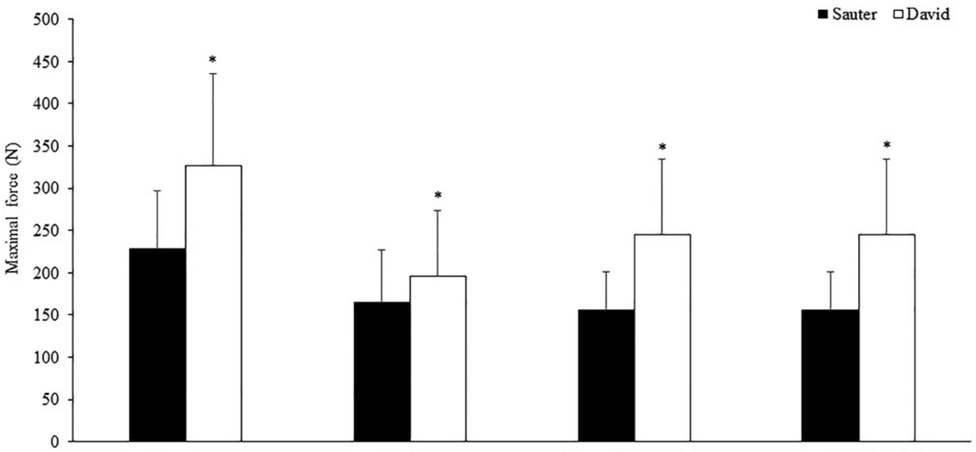


Fig. 2. Mean (+SD) maximal force results measured with the two devices. Error bars represent the standard deviation. *$P < 0.05$.

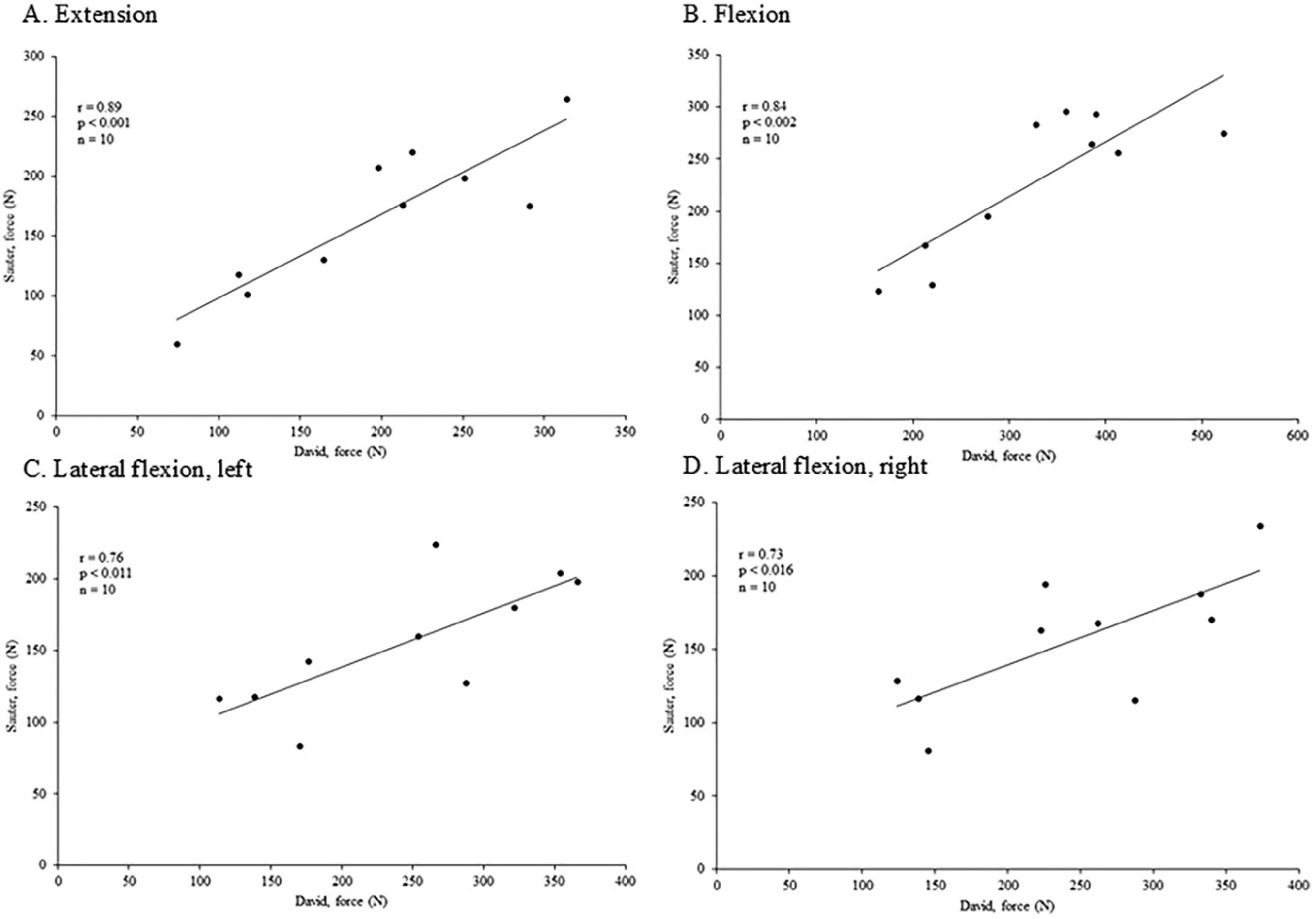


Fig. 3. Force correlations between the Sauter force gauge and the David G140.

activity during force production. The results of this study indicate that this hypothesis was correct. The aforementioned difference in the activity of the right CES during flexion most likely resulted from either EMG crosstalk or subjects' individual differences. This is supported by the fact that the CES function as antagonists to the SCMs in cervical flexion, which mean that their activity should be relatively low during this movement pattern. Another possible explanation for this is that the cables of the helmet-attached gauge allowed the head to subtly tilt, which led to the activation of muscles involved in lateral flexion.

The higher force values of the weight stack device cannot, therefore, be explained by different neck muscle activation patterns. Instead, the location of the built-in strain gauge might have affected the results. Subjects produced force to the upholstered part of the device, which was roughly a couple of feet away from the alleged location of the strain gauge. This might have created unwanted leverage. Due to difficulties in isolating the exact location of the strain gauge, it was not possible to evaluate how much error it might have caused.

The other potential explanation is that the weight stack device had a solid torso support pad, which might have led to unnoticeable isometric thoracic extension or flexion. Because of the elastic foam tube used with the helmet-attached gauge, it was easier to detect excessive torso movement and redo bad attempts. In addition, the pilots' helmet fitted a bit loosely for some of the subjects, which might have also caused small errors.

Another limitation of this study is the fact that the measurements were not conducted on actual pilots. This can probably be seen most clearly in the absolute maximum force value, not in the correlation. Also, the neck muscle activities might have been slightly different with fighter pilots because they are accustomed to neck muscle strain. Finally, a relatively small sample size can be considered a limitation as well.

The helmet-attached force gauge is a valid tool for isometric neck muscle strength measurements. These types of strain gauges are very inexpensive when compared to other devices, such as the weight stack device used in this study. In addition, their portability makes them extra valuable for field testing. The helmet-attached gauge should be used as a tool to examine fighter pilots' individual differences in isometric neck muscle strength, but absolute force values presented by this gauge should be interpreted with caution.

As a clinical tool, the helmet-attached force gauge can be used to track the progress of neck strength development in order to determine whether pilots are at risk of developing

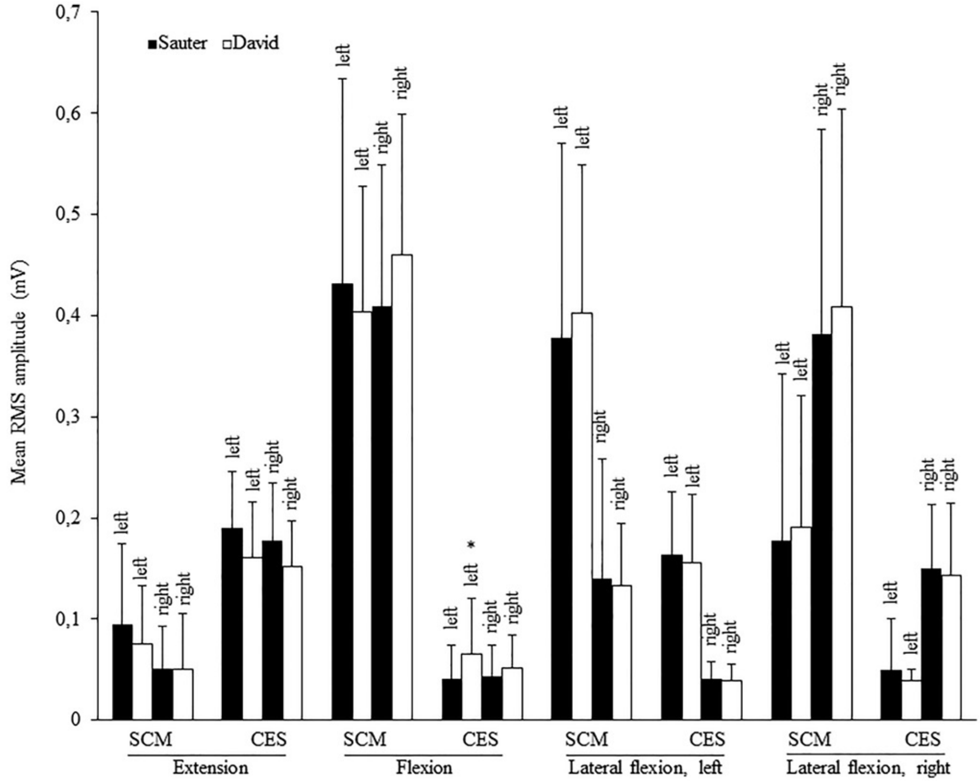


Fig. 4. Mean RMS amplitude for each muscle in all measurement conditions. Error bars represent the standard deviation. *$P < 0.05$.

flight-duty-limiting neck injuries. Also, it should be noted that this force gauge measures only isometric strength, which has its limitations when compared to concentric and eccentric muscle actions that occur during high-performance flights.

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HIF-1 Sensor in Detecting Hypoxia Tolerance at High Altitude

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INTRODUCTION: An episode of prolonged exposure to high altitude can cause hypoxia and have significant health consequences. In people with a high-altitude disorder, the body reacts by producing a protein called hypoxia-inducible factor (HIF), which triggers a series of physiological changes and serves a central role in the hypoxia response. Its activity is regulated by the oxygen-dependent degradation of the HIF-1α protein (HIF-1A gene). Therefore, the effects of low oxygen tension in high altitude were explored using fluorescent sensors of hypoxia.

METHODS: The development of the sensor provided more sensitivity for detecting hypoxia by generating a calibration of optimized parameters such as reagent concentrations, reagent volumes, and device dimensions.

RESULTS: There is a high sensitivity and specificity in detecting the changes of HIF-1α protein hypoxia using the feasibility hypoxia test. This would enable point-of-care (POC) testing and individual self-administration, resulting in faster and more accurate results that can be used for a robust diagnostic approach and enhanced health surveillance, particularly in high-altitude exposure.

KEYWORDS: HIF-1a (hypoxia-inducible factor 1alpha), hypoxia, high altitude, HIF-1 sensor.

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Aircrews exposed to high altitude with longer durations are at a higher potential risk for detrimental health consequences. The altitude and other environmental features are of concern for aircraft safety.[10] For safety reasons, proper acclimatization is important for those traveling to high altitudes. While the effect is most dramatic at altitudes greater than 8000 ft (2438 m) above sea level, it becomes noticeable even at 5000 ft (1524 m) above sea level.[5,6] Among other important changes (e.g., decreases in temperature and ambient humidity), the defining environmental feature at high altitude is a drop in barometric pressure, which causes a decrease in the partial pressure of oxygen at every point along the oxygen transport cascade from ambient air to cellular mitochondria.[1,11] Subsequently, there is also a decrease in the Po_2 at every point along the oxygen transport cascade from inspired air to the alveolar space, arterial blood, tissues, and venous blood. The higher the elevation attained and the longer the duration of spaceflight, the greater the drop in Po_2 in the human body. These declines in oxygen tensions trigger a variety of physiological responses in the cardiovascular system over a period of minutes to weeks after the initial altitude hypoxia exposure, all of which enable the individual to adapt to the hypoxic environment. Indeed, short-term altitude exposure can directly or indirectly affect the vascular tone of systemic resistance vessels and enhances ventilation and sympathetic activity through the activation of peripheral chemoreceptors.[12]

Ascent to high altitude is associated with physiological responses that counter the stress of hypobaric hypoxia by increasing oxygen delivery and altering tissue oxygen utilization via metabolic modulation.[3] At the cellular level, the transcriptional response to hypoxia is mediated by the

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hypoxia-inducible factor (HIF) pathway and results in promotion of glycolytic capacity and suppression of oxidative metabolism.[2] Hypoxia inducible factor-1 (HIF-1) plays a key role in oxygen homeostasis by facilitating oxygen supply to the tissues under hypoxic conditions, as during acclimatization to hypobaric hypoxia or in the hypoxemia or inflammation molecular response. HIF-1 is found in almost all body tissues. Under normoxic conditions, it is degraded through hydroxylation, but it does not undergo degradation in the presence of hypoxia.

Retrospective studies conducted after the Second World War give an account of a significant number of unexplained military aircraft accidents that were suspected to be due to hypoxia.[4,6,7] Detection of possible hypoxia exposures during postmortem investigation of aircraft accidents has implications for determining flight safety. A study conducted by Tripathi et al. from 1986 to 1995 in Army Aviation helicopters flying high-altitude sorties revealed 29 accidents, and hypoxia was a contributing factor in 24% of those cases.[9] Pilot incapacitation attributable to hypoxia has been confirmed as the cause of the crash of IAF MiG 29 at Sirsi, Karnataka, on April 11, 2002.[8]

In this study, we decided to explore the effectiveness of the hypoxia sensor, which could potentially be used as a diagnostic tool for detecting physiological changes due to hypoxia at high altitude during a long spaceflight.

METHODS

Lateral flow immunoassay (LFIA) is a qualitative chromatography that provides very simple, rapid, on-site detection of a target and serves as a portable analytical platform that specifically detects antigens or antibodies. LFIAs are typically composed of a sample pad, a conjugated pad, a nitrocellulose membrane, and an absorbent pad, as shown in **Fig. 1**.

Since the hypoxia marker has been identified as HIF-1a, the protein was examined using the "Dot Blot" approach known as Dot Blot analysis. This is a technique for detecting, analyzing, and identifying proteins; it is similar to the western blot technique except that protein samples are not separated electrophoretically—instead, they are spotted directly onto the membrane or paper substrate through circular templates. The concentration of HIF-1a protein was purchased and detected using monoclonal antibodies against HIF-1a.

RESULTS

The feasibility of HIF-1a is shown expressed in athletes after moderate exercise intensity. This research demonstrated that an effective hypoxia tolerance device is achieved by using the sensors. By accepting HIF-1a as a protein marker, the assay proved the presence of hypoxia signals in human subjects

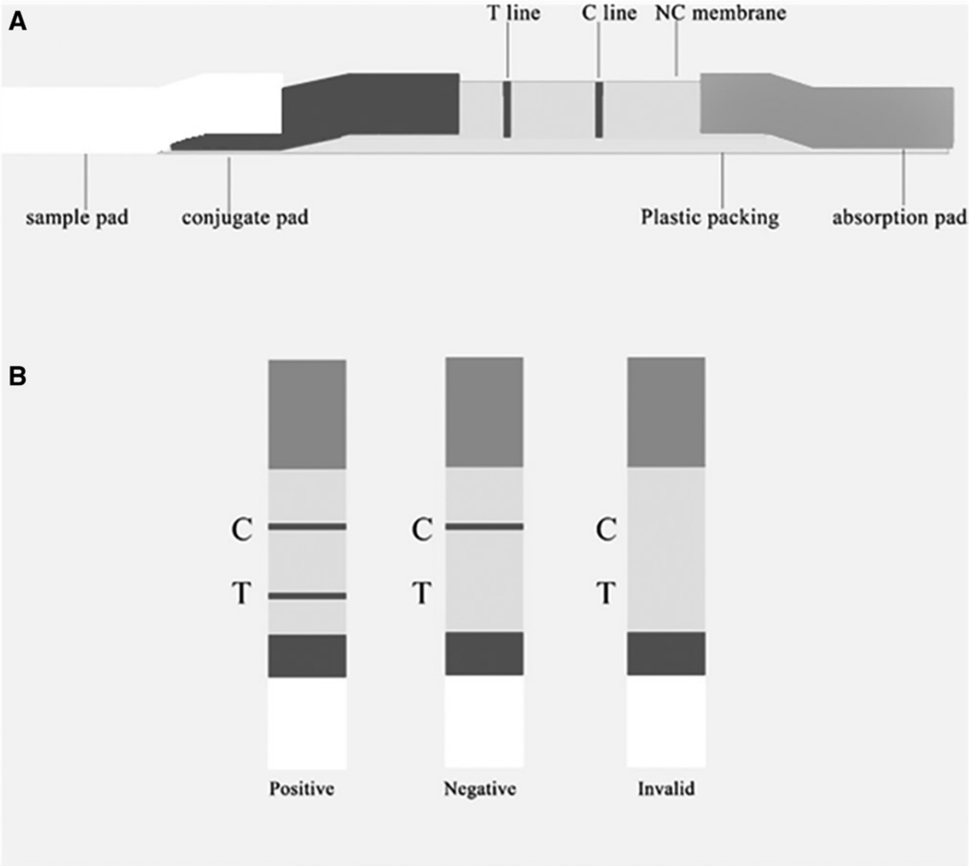

Fig. 1. Images and design of the lateral flow strip.

after moderate exercise intensity. Based on the compression feature, a sensor for the hypoxia tolerance device was produced. A desirable sensor should not only be highly sensitive and selective, but also capable of directly viewing results on the device, making it portable. Such devices could be utilized in settings with limited resources, close to the patient, and outside of a laboratory.

DISCUSSION

Monitoring HIF levels within cells and tissues provides a measure of the extent of hypoxia and hypoxic gradients. Hence, detection of hypoxia often relies on strategies for the detection of HIF protein expression. There are several techniques to detect hypoxia by targeting HIF protein, including western blot, immunoassay (e.g., ELISA, Luminex), immunohistochemistry, and flow cytometry. These techniques require specialized equipment and complex data analysis. It also takes time to get the results. Due to the importance of early detection of hypoxia to avoid acute symptoms and the limitation of detection by using the current techniques, we developed lateral-flow assays to detect hypoxia early via targeting the HIF protein.

In conclusion, this study exploited new technology to develop a hypoxia sensor to detect the risk of developing hypoxia, which has been recognized as one of the foremost physiological threats at high altitude. The development of strip-based detection enables the use of an enzyme-linked assay in a lateral-flow device to provide a more sensitive, precautionary screening tool for detecting the risk of and preventing hypoxia for aircrews.

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Aerospace Medicine Clinic

This article was prepared by Robert Wright, M.D., M.P.H., and Luke Menner, D.O.

You are the flight surgeon attached to a U.S. Air Force (USAF) flying squadron. A healthy and experienced 36-yr-old male aviator presents to the Flight Medicine clinic with a few months of atraumatic bilateral shoulder and hip pain that awakens him from sleep. He also reports recurrent night sweats a few times a week and daily fatigue. His joint pain is worse at night and in the morning, however, it improves after about 1 h with movement and over-the-counter ibuprofen. He denies past medical history, surgeries, or use of other medications or supplements. He also denies previous joint injuries, bug bites, recent travel or deployments, rash, weight change, easy bleeding or bruising, personal or family history of malignancy or rheumatic diseases, cold intolerance, depression, or sleep problems. He is not actively flying and is uncertain if his symptoms would interfere with flight duties. His physical examination and vitals are unremarkable, with no joint swelling, palpable thyroid, pallor, rash, or lymphadenopathy. Laboratory screening for bony and hematologic malignancy, chronic infection, fatigue, and inflammatory/rheumatic etiologies (e.g., erythrocyte sedimentation rate/C-reactive protein, rheumatoid factor, anticyclic citrullinated peptide, antinuclear antibody, creatine kinase) is normal. Hip/shoulder X-rays are normal, and magnetic resonance imaging shows mild joint effusions in both shoulders and the left knee, with no masses or lesions. His symptoms are initially controlled with naproxen (500 mg) twice daily; however, his symptoms progress, and he develops joint swelling in his hands and feet. Rheumatology consultation is obtained. His 2010 American College of Rheumatology-European League Against Rheumatism classification criteria score was 6 due to diffuse joint involvement and duration of symptoms, so he was diagnosed with seronegative rheumatoid arthritis (RA).[1] The aviator's RA flare is initially managed with oral prednisone and a combination of disease-modifying antirheumatic drugs (DMARDs), including methotrexate (MTX) with folate and hydroxychloroquine (HCQ), which led to a significant improvement in symptoms.

1. This pilot is seeking a return to flying status after achieving remission of RA. He is asymptomatic with no headaches, neck pain, upper extremity paresthesias or weakness, vertigo, or tinnitus. He has a normal musculoskeletal and neurological exam. Which studies should be obtained prior to recommending return to flying status for this pilot?
   - A. Complete blood count, comprehensive metabolic panel, erythrocyte sedimentation rate/C-reactive protein.
   - B. Cervical spine X-rays with flexion and extension, anteroposterior, lateral, and odontoid views.
   - C. Morning cortisol and adrenocorticotropic hormone stimulation test.
   - D. Chest X-ray, pulmonary function test.

ANSWER/DISCUSSION

1. B. RA is a chronic autoimmune disease affecting ~0.5% of U.S. adults and is characterized by synovial inflammation leading to progressive joint destruction, with the potential for severe articular and extra-articular manifestations of aeromedical concern.[1] DMARDs, such as MTX, HCQ, tumor necrosis factor inhibitor biologics, and glucocorticoid adjuncts, can have significant side effects of aeromedical concern such as pneumonitis, retinopathy, cytopenias, hypersensitivity reactions, and neuropsychiatric events, as well as new and reactivated infections. One complication is cervical-spine disease, which affects up to 86% of RA patients and includes disease etiologies such as atlantoaxial instability (AAI) or subluxation (AAS) due to synovial inflammation in the atlantoaxial joint, facet joints, and spinal ligaments.[10] Direct repetitive trauma through hyperflexion or hyperextension, such as during a high-G maneuver or ejection, may cause severe neurological impairment or death due to brain stem, spinal cord, and vertebral artery compression and injury.[10] The USAF restricts aviators with RA to non-ejection-seat aircraft to reduce the likelihood of such catastrophic complications.[8] Aviators with RA should be screened for cervical spine disease with cervical spine X-rays, including anteroposterior, lateral, odontoid, and flexion-extension views, every 2–3 yr

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as ~50% of RA patients with radiographic instability are asymptomatic.[1,10] Early treatment with novel DMARDs can prevent long-term progression, disability, and comorbidities.[10] If aviators become symptomatic, they should be brought off flying status and referred for magnetic resonance imaging of the cervical spine with dynamic flexion-extension and neurosurgery evaluation.[10]

2. Since this USAF pilot with RA is being treated with maintenance HCQ, which annual test should be obtained while being treated with this medication?
   - A. Retinal exam by optometrist or ophthalmologist.
   - B. Complete blood count.
   - C. Liver function tests.
   - D. Electrocardiogram for QT evaluation.

ANSWER/DISCUSSION

2. A. HCQ retinopathy is a "bulls-eye" maculopathy with central, extensive parafoveal retinal pigmented epithelium loss associated with severe and irreversible vision loss.[9,11] Clinical symptoms of aeromedical concern include: dropout of letters from words when reading; photophobia; blurred distance vision; reduced night vision; visual field defects ("parafoveal scotomata"); and flashing lights.[9] The exact mechanism of HCQ toxicity to retinal foveal photoreceptors and retinal pigmented epithelium is unknown.[11] The disease is highly prevalent, affecting ~7.5% of patients after 5 yr and ~20–50% after 20 yr.[11] Incidence is higher with specific risk factors per the American Academy of Ophthalmology 2016 guidelines, such as high dosage (>5 $\text{mg} \cdot \text{kg}^{-1}$ actual body weight) (odds ratio = 5.67), renal impairment (given that HCQ is renally excreted) (odds ratio = 2.06), and preexisting macular disease.[11] Screening is important as the disease is common and structural changes that may precede symptoms are detectable on common objective tests, such as spectral domain optical coherence tomography. Early detection of retinopathy and cessation of HCQ can potentially stop progression and yield visual improvements. However, effects are usually irreversible, as structural defects on spectral domain optical coherence tomography persist and—due to the long half-life of HCQ—may even progress for months to years.[11] It should also be noted that screening guidelines vary by organization.[11]

3. Since this aviator is being treated with MTX, which treatment would NOT lower his risk for MTX-associated pneumonitis (M-pneu)?
   - A. Daily vitamin C.
   - B. Calcium/vitamin D supplementation.
   - C. Folic acid.
   - D. Daily acetaminophen.

ANSWER/DISCUSSION

3. C. MTX is a common first-line DMARD in both the United States and Europe.[1,5] One severe side effect of aeromedical concern seen with this medication is M-pneu, a subacute hypersensitivity reaction and drug toxicity in alveolar cells to MTX that affects ~0.3–12% of patients with RA, usually within 1 yr of starting MTX.[6,7] Many common side effects of the medication, such as gastrointestinal, hepatic, and bone marrow toxicity, are more common with high doses prescribed for oncologic indications, not rheumatologic dosages. Typical dosing for RA is between 15–25 $\text{mg} \cdot \text{wk}^{-1}$, and most side effects can be prevented with daily folic acid supplementation. However, M-pneu is not preventable with folate supplementation.[7] Patients typically present with nonspecific pulmonary symptoms such as cough, dyspnea, and fevers, and lab work may demonstrate eosinophilia.[6] Chest X-ray shows a nonspecific interstitial pneumonia-type presentation, and chest computed tomography may show ground-glass opacities followed by fibrosis, which may explain restrictive pulmonary function tests commonly found in patients with M-pneu.[6] M-pneu is a diagnosis of exclusion. More likely diagnoses that should be ruled out are viral pneumonia, including SARS-CoV2, other atypical pneumonia etiologies, and RA-interstitial lung disease—although the latter typically has a more chronic course.[6] Flight risks include: worsening of hypoxia at altitude; G-intolerance; acceleration atelectasis; and even incapacitation or death. An ~13–30% death rate has been reported per multiple small retrospective cohorts with potentially higher risk if M-pneu occurs within 6 mo of initiating MTX.[6,7] Given the potentially severe outcomes of M-pneu, MTX should be stopped and patients evaluated in the emergency department to consider admission for immunosuppression with steroids, and rarely cyclophosphamide or tocilizumab.[6,7] Most patients fully recover, although recurrence with MTX treatment is common.[6]

4. Which common adjunct medication used with DMARDs during RA flares that this patient was treated with may be associated with neuropsychiatric events such as depression, delirium, mania, and psychosis?
   - A. Folic acid.
   - B. Prednisone.
   - C. MTX.
   - D. Adalimumab.

ANSWER/DISCUSSION

4. B. Oral glucocorticoids are commonly used as adjuncts to DMARDs to treat RA flares.[1,5] Although aviators are unlikely to fly during an active RA flare, it is important to be aware of medication complications from these commonly used drugs that may impair flight duties.[3] Besides potentially developing exogenous Cushing's syndrome or secondary adrenal insufficiency, long-term steroid usage can lead to neuropsychiatric events that are not conducive to flying duties, such as mood disorders, psychosis, and suicide.[3] In a large 2012 retrospective cohort in the United Kingdom, new oral glucocorticoid prescriptions among ~373,000 adults treated by primary care physicians led to a significantly increased risk of severe neuropsychiatric events relative to ~1.2 million nontreated patients; a ~7-fold increased risk for suicide, 5-fold for delirium, 4-fold for mania, and 1.5-fold for panic disorder were observed in adjusted models.[3] The absolute risk was ~22 per 100 person-years, which is well above the 1% risk for severe annual events accepted by the aeromedical community.[3] However, these results may not be generalizable to active aviators, who are likely at decreased likelihood of developing neuropsychiatric events than this study population for a few reasons. First, aviators should not be flying with active RA or other diseases where steroids are indicated, such as pneumonia, asthma, chronic obstructive pulmonary disease, or temporal arteritis. Second, 24% of the exposed population had a history of mental illness, while aviators with a history of significant mental illness would likely be disqualified from flying duties. Also, aviators, especially military aviators, are younger than the study average of 57 yr old. Older age was associated with an increased likelihood of certain mood disorder events. Lastly, aviators with RA would be treated with lower dosages of prednisone than the average study participant, equaling $10\,\text{mg} \cdot \text{d}^{-1}$ per the American College of Rheumatology and up to $20\,\text{mg} \cdot \text{d}^{-1}$ per the Federal Aviation Administration (FAA). Lower dosage glucocorticoids had lower risk in the study, although some residual risk was seen in $11–20\,\text{mg} \cdot \text{d}^{-1}$ vs. $10\,\text{mg} \cdot \text{d}^{-1}$ or less for delirium and panic disorder (hazard ratio 1.85, 95% confidence interval 1.57–2.17 and hazard ratio 3.42, 95% confidence interval 1.53–7.67), respectively.[3] The highest rates of neuropsychiatric events occurred in individuals prescribed daily prednisone doses of 40 mg or higher. Nevertheless, this is a medication side effect worth remembering should an aviator with RA present with new mood symptoms to your clinic.

AEROMEDICAL DISPOSITION

Your pilot was taken off flying status due to the severity of his articular symptoms and RA diagnosis. He was ultimately granted a non-ejection-seat waiver to reduce atlantoaxial instability/subluxation complications during aviation operations with follow-up required in 1 yr. Waiver was recommended for a few reasons. He was in prolonged remission per Rheumatology for greater than 6 mo, with a Clinical Disease Activity Index score of 0 and no impairment in fine-motor functioning of hands or feet that would affect aviation duties. Also, he had successfully tapered off of MTX and prednisone with intact hypothalamic-pituitary-adrenal axis function and was doing well on HCQ without side effects or retinal disease. He requires annual rheumatology and optometry evaluations.

Aviators with RA are allowed to fly in the USAF with certain restrictions. They can be considered for a waiver if in disease remission per Rheumatology, with no extraarticular manifestations while taking aeromedically approved medications without adverse side effects.[8] As of 2022, the only aeromedically approved medications in the USAF are sulfasalazine, HCQ (with a normal dilated ocular exam), adalimumab, infliximab, and etanercept (U.S. Air Force. Official Air Force aerospace medicine approved medications, 2022 Sept. 21. Available to those with access.).[8] Aviators on non-aeromedically approved medications can be considered for waiver on a case-by-case basis. Also, systemic steroid usage is neither allowed for flying duties nor waiverable, and usage for more than 3 wk requires demonstration of an intact hypothalamic-pituitary-adrenal axis.[8] Aviators are restricted to non-ejection-seat aircraft due to the potential for catastrophic complications from atlantoaxial instability/subluxation.[8] From 2015–2022, 22 of 28 RA waivers were approved for USAF aviators.

The FAA also allows aviators with RA to fly if they meet Conditions AMEs (Aviation Medical Examiners) Can Issue criteria, which include stability per Rheumatology, mild to moderate symptoms without limitations, and disease limited to joint(s) with normal complete blood count and liver and renal function.[4] If they fail to meet these criteria, they are deferred to the FAA and may be considered for Special Issuance. The FAA allows ≤20 mg prednisone-equivalent daily, MTX, HCQ with normal eye exam, and six different biologics for aviators with variable required no-fly time after each use.[4] The U.S. Navy considers RA disqualifying.[2] The U.S. Army considers potential waivers for RA if the aviator is asymptomatic and treated with aeromedically acceptable medications (U.S. Army Aeromedical Activity. Systemic rheumatologic diseases. In: Aeromedical policy letters and aeromedical technical bulletins. 2021:211-212. Available to those with access.).

Rheumatoid arthritis is a common disease that may cause significant aeromedical concerns. Early diagnosis and treatment are critical for patient health and return to flight status. Frequent monitoring is necessary to detect disease progression and potential medication side effects.

Wright R, Menner L. *Aerospace medicine clinic: seronegative rheumatoid arthritis.* Aerosp Med Hum Perform. 2023; 94(6):488–491.

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JUNE 1998

Jet lag (National Institute for Psychosocial Factors and Health, Karolinska Institute, Stockholm, Sweden): “As part of a research program of sleep/wake disturbances in connection with irregular work hours and time zone transitions, the study aimed to describe the spontaneous sleep/wake pattern in connection with a westward (Stockholm to Los Angeles) transmeridian flight (-9 h) and short layover (50 h) … across 4 d … We monitored 42 SAS aircrew for 9 d with activity monitors and diary before, during, and after flight … During the outbound day the wake span was 21.7 h and 90% of the aircrew adopted local bed times on layover. The readaptation to normal sleep/wake patterns were rapid on the return. Napping was common (93%), especially on-board and before the return. Sleep efficiency dropped below 90% during layover, being felt to be too short and disturbed by awakenings, and gradually returned to normal across four recovery days. Recovery sleep was characterized by difficulties waking up and feelings of not being refreshed from sleep. Sleepiness symptoms increased during layover and gradually decreased across recovery days, still being elevated on day 4 … In the present study we found that westward flights are associated with extended wake spans during layover, increased sleepiness, and slow recovery on return home. Strategic sleeping may counteract the effect somewhat, but individual differences are few.”[2]

JUNE 1973

Self-destructive pilots (Office of Aviation Medicine, Federal Aviation Administration, Washington, DC): “Often the relationship between the pilot and his aircraft is such that the aircraft may be thought of as an extension of the pilot himself during the act of flight …

“Most people live without a sense of imminent danger. They assume a myth of invulnerability in which it is felt that nothing seriously detrimental is going to happen to them. At times, this illusion has the useful function of protecting the individual from limiting his life activities and from living in a constant state of terror of the real dangers that life holds. Excessive awareness of a threatening danger can contribute to progressive psychosocial deterioration and maladaptation in the face of potentially stressful everyday situations.

“It follows that the more experience, training and competence an individual has to utilize in adapting to increased stress demand, the greater the likelihood of success in dealing with demanding flight situations. Instrument flying techniques, emergency landing, stall recovery, and other maneuvers are skills that help to keep the pilot alive.

“More important to the individual than this increased proficiency, however, is a deeper understanding of his own capabilities and limitations. He must develop a greater appreciation of the full reality of the world of risk and in the process, place less reliance on the myth of invulnerability. This understanding, of course assumes good common sense and emotional stability and does not necessarily result from flying experience. Even the technically ‘competent’ individual may fail in adaptation if a stress event overloads his total coping capacity. Self-destruction then can become almost inevitable.”[4]

JUNE 1948

Top three drugs (University of Pennsylvania School of Medicine, Philadelphia): “It is extremely difficult to obtain completely unbiased opinion as to the action of alcohol, nicotine and caffeine. Most physicians and scientists who have worked on the subject do not seem to be able to offer an opinion which is unspoiled by rationalization.

“Since, however, these three are by far the most frequently used of all drugs, especially by aviators, it seems expedient to state certain of their pharmacological properties, as seen in the recent literature.

“The medical literature should be unbiased. The commercial literature and advertisements are apt to be somewhat to the ‘left’ of center. And the literature from such organizations as the [Women’s Christian Temperance Union] and the Prohibition Party is certainly likely to be extremely conservative in any claims that might be made for the benefit of these drugs. An attempt will be made to be unbiased, referring to all three types of literature mentioned above, and admitting to the use of all three of the drugs under discussion–in moderation, of course.”[1]

Perception versus reality (University of Minnesota, Minneapolis, and Naval School of Aviation Medicine and Research, Pensacola, FL): “Nonvisual spatial orientation during flight is subject both to gross limitations and to illusions. The perception of turning and tilting to the right or left appears after a considerable lag from the actual onset of the maneuver. The direction of the bank and turn may be in error, and the estimates of the amount of bank are markedly depressed. Perceptions of both tilting and turning are transient, and disappear before the plane recovers from the turning attitude. The recovery from the turning attitude is accompanied by sensations of tilting and turning away from the direction of the preceding turn, which persist into the period of straight and level flight following a maneuver. The onset of turn and the turn proper are accompanied by sensations of tilting backward, which persist for the duration of the turn. Following recovery, the observer feels himself tilting forward after a brief period of feeling upright. The perceptions of g *per se* are strong and accurate.”[3]

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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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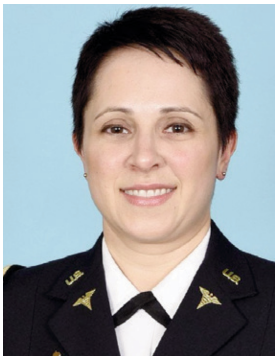
AsMA Constituent Organization Presidents for 2023–2024

Benincasa Heads Army Flight Surgeons



LTC Jennifer A. Benincasa is the incoming President for the Society of U.S. Army Flight Surgeons. She hails from the City of Brotherly Love, Philadelphia, PA, and graduated from LaSalle University with a dual Bachelor of Arts in Biology and Psychology with a Premedical Concentration. She was commissioned as an Army Officer through the Health Professions Scholarship Program as a Second Lieutenant and attended the Philadelphia College of Osteopathic Medicine, where she was awarded her Doctor of Osteopathy medical degree in 2009. She completed her Transitional Year Internship at Madigan Army Medical Center at Joint Base Lewis-McChord in 2010 and General Surgery Internship at Tripler Army Medical Center on the island of Oahu in 2011. Afterward, she served a General Medical Officer tour in an aviation unit, where she developed her interest in and passion for operational, aviation, and aerospace medicine.

LTC Benincasa then completed her Occupational Medicine residency training with the U.S. Army School of Aviation Medicine in 2016 and Aerospace Medicine residency training with the Naval Aerospace Medical Institute in 2017. During her residency training she earned both her Master of Science in Healthcare Administration from University of Maryland University College and her Master of Public Health from the University of West Florida in 2016. She is board certified in both Occupational and Aerospace Medicine with both the American Board of Preventive Medicine and American Osteopathic Board of Preventive Medicine. She is a member of many professional societies, including the American Osteopathic Society, American Association of Public Health Physicians, American Public Health Association, American Society of Aerospace Medicine Specialists, Space Medicine Association, Society of Critical Care Medicine, and the Society of Federal Health Professionals. She is also a member of the Aerospace Medical Association, where she serves on the Council, Nominating Committee, and Scientific Program Committee.

LTC Benincasa' s military experience includes serving as Battalion Flight Surgeon in Germany with the 412th Aviation Support Battalion in the 12th Combat Aviation Brigade from 2011–2014, Brigade Flight Surgeon in Hawaii with the 25th CAB in the 25th Infantry Division from 2017–2019, Command Surgeon for Army Sustainment Command at Rock Island Arsenal from 2019–2021, and deploying as a Battalion Flight Surgeon in Afghanistan in support of Operation Enduring Freedom from 2012–2013. She is currently stationed at Fort Rucker, AL, where she served as the Program Director of the Residency in Aerospace Medicine at the U.S. Army School of Aviation Medicine from 2021–2023 and currently serves as the Chief Aeromedical Reviewer/Flight Surgeon/Aerospace Medicine Specialist at U.S. Army Aeromedical Activity. Her awards include the NATO Medal, Overseas Service Ribbon, Humanitarian Service Medal, National Defense Service Medal, Army Achievement Medal, Army Commendation Medal, Air Medal, and the Meritorious Service Medal. She also holds a Bronze Medal, Order of St. Michael Award.

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Berry to Lead ASAMS

Dr. Daniel K. Berry is the incoming President for the American Society of Aerospace Medicine Specialists (ASAM). He is a graduate of Southern Adventist University in Collegedale, TN, with a Bachelor's degree with a Mathematic major and a Chemistry minor. He earned an M.Sc. in Biomathematics from Loma Linda University in California with his research in 3-D modeling of cardiac electrical activity using Aitoff projections, and a Ph.D. in Biomedical Engineering from the California Coastal University with his research in statistical analysis of cardiac disorders using the angiogram as the gold standard. He graduated from Kansas City University of Medicine and Biosciences and completed his postgraduate training at the Tulsa Regional Medical Center, which is now the Oklahoma State University Hospital. He completed the RAM requirements for a Master's of Public Health at the University of Oklahoma, School of Public Health, in Oklahoma City, OK. He is Board Certified in Aerospace Medicine by the American Osteopathic Board of Preventive Medicine and is Board Certified in Family Practice by the American Osteopathic Board of Family Practice.

Dr. Berry served in the U.S. Air Force for 28-½ years as a physician. He started his career as a Flight Surgeon at Tinker AFB in Oklahoma City, OK. Within 1 year he was promoted to the chair of the 10-physician department. His next assignment was at McGuire Air Force Base in New Jersey, where he was the Director of Preventive Health Services and directed the offices of Flight Medicine, Public Health, Bioengineering, Infectious Diseases, and the Immunizations Clinic. He was then assigned as the Aerospace Medicine Squadron Commander at Tyndall Air Force Base in Panama City, FL. Then he was selected to be the Command Chief of Aerospace Medicine, the Chief of Clinical Medicine, and the Medical Director of the Personnel Reliability Program for headquarters Space Command at Peterson Air Force Base in Colorado Springs, CO. He then became the Aerospace Medicine and Aeromedical Information Systems Director for the Human Systems Program Office at Brooks City-Base in San Antonio, TX, where he directed the departments for 17 medical device and information systems development. He went on to become the Human Systems Office Deputy Group Commander. His last assignment with the U.S. Department of Defense was as the Joint Project Manager for Biological Defense. He retired from the Air Force but continued to practice Aerospace Medicine in the Federal Aviation Administration first as the Deputy Regional Flight Surgeon, and then as the Regional Flight Surgeon for the Central Region of the United States. He is also the acting Senior Regional Flight Surgeon for the Federal Aviation Administration.

Dr. Berry has also been extensively involved in professional activities with the American Osteopathic Association. He has held nearly every office in the American Osteopathic College of Occupational and Preventive Medicine, including President of the College. He developed and founded the Osteopathic Specialty of Undersea and Hyperbaric Medicine and established the Undersea and Hyperbaric Medicine Conjoint Committee. He is currently the Chair of the American Osteopathic Board of Preventive Medicine, has served in this position for 14 years, and was just re-elected for a 15th year. He is a distinguished Fellow of the American Osteopathic College of Occupational and Preventive Medicine and a fellow of the Aerospace Medical Association.

Dr. Berry is one of the authors of the "Aerospace Medicine Board Essentials" text book. He is also a frequent lecturer on topics in Aerospace Medicine and has written articles on Aerospace Medicine.

He is a trained item writer for Board questions and is trained in Anghoff psychometric procedures. He developed the first Undersea and Hyperbaric Medicine Table of Specifications (TOS) and Joint Task Analysis (JTA), and has participated in updating the previous Aerospace Medicine TOS, and JTAs. He holds five medical patents and is the president and owner of Obtronics, Inc., which is a medical device development company.

Ruskin Is Incoming AsHFA President

Keith J. Ruskin, M.D., is the incoming President for the Aerospace Human Factors Association (AsHFA). He is a Professor of Anesthesia and Critical Care and Director of Aerospace Medicine at the University of Chicago. His clinical practice focuses on neurosurgical anesthesia. His major academic interests include neurosurgical anesthesia, human performance, and aerospace medicine. His career has focused on teaching these disciplines to practicing physicians. He has worked as part of a team to develop guidelines for screening morbidly obese pilots for obstructive sleep apnea and for the management of in-flight cardiac arrest. He has developed a fatigue risk management program for physicians who must work overnight shifts and participated in a NASA workshop on space torpor. Keith is also interested in the terrestrial applications for this work, writing articles on the role of automation in the operating room and how personal protective equipment affects human performance. His funded research involves developing guidance for the next generation of alarms, alerts, and warnings in Air Traffic Control.

Dr. Ruskin received a Bachelor of Science in Biology and Biotechnology from Worcester Polytechnic Institute. He then attended medical school at the University of Miami School of Medicine and completed his residency at New York University Medical Center. He spent 20 years on the faculty of Yale University before being recruited to the University of Chicago. He has had a lifelong interest in aviation and currently holds a Commercial Pilot certificate with Airplane Single-Engine Land and Sea, Multi-Engine Land, and Instrument Airplane ratings. He holds a Second in Command type rating for the DC-3. He currently flies a Cessna Skylane out of Chicago Executive Airport (KPWK), but would love to would fly a jet.

Dr. Ruskin has published original research, review articles, and textbooks on a variety of topics, including willingness to fly during the COVID-19 pandemic, management of critical events, and other topics related to safety and human performance. He also teaches two undergraduate classes at the University of Chicago: “Conquest of Pain,” which covers pain physiology, and “Physiology in Extreme Environments.” He serves on the American Society of Anesthesiologists’ Patient Safety Editorial Board and Committee on Patient Safety Education and is Chair of the Aerospace Medical Association’s Aerospace Human Performance Committee. He is a Fellow of the Aerospace Medical Association, the Royal Aeronautical Society, and the American Society of Anesthesiologists. He is also a senior member of the Institute of Electrical and Electronics Engineers.

Welsh to Lead AsPS

CDR Welsh is the incoming President for the Aerospace Physiology Society (AsPS). A native of Ambridge, PA, he earned a Bachelor of Science and Master of Science in Exercise Physiology from Slippery Rock State University, PA. He also graduated from George Washington University with a certificate in Medical Laboratory Technology and is a board certified Aerospace Physiologist.

CDR Welsh enlisted in the Army in May 2002, and attended Basic Combat Training at Ft. Benning Infantry Training Center, GA. He was promoted to Sergeant in April 2005 and commissioned through the Navy’s Direct Commissioning Program in September 2005. In 2006 he completed his initial Navy training at Naval Air Station (NAS), Pensacola, FL, and NAS Whiting Field, FL. His training included Officer Development School, Aviation Preflight Indoctrination, Primary Naval Flight Training, and the Naval Aerospace Physiology Course. As a Naval Officer, his past assignments include Division Officer, Aviation Survival Training Center (ASTC), NAS Patuxent River, MD; Aeromedical Safety Officer, Training Wing Six, NAS Pensacola, FL; Aeromedical Safety Officer, Marine Aircraft Group 26, Marine Corps Air Station, New River, NC; Assistant Professor, Uniformed Services University of the Health Sciences School of Medicine, Bethesda, MD; Director of Aeromedical Safety, 1st Marine Aircraft Wing, Camp Foster, Okinawa; and Director ASTC Pensacola, NAS Pensacola, FL. He is currently the Deputy Surgeon at the 2nd Marine Aircraft Wing, Cherry Point, NC.

CDR Welsh is authorized to wear the Fleet Marine Force Officer Warfare Device and his current personal awards include the Defense Meritorious Service Medal, Navy and Marine Corps Commendation Medal (4 awards), Army Commendation Medal, Navy and Marine Corps Achievement Medal, and Army Good Conduct Medal.

Feuillie Is Incoming IAMA President

Vincent Feuillie, M.D. is the incoming President of the International Airline Medical Association (IAMA). Since 2016, he has held the position of Air France Medical Advisor. He joined Air France in 1998 and served in a variety of positions such as Deputy Medical Director, Medical Officer in the Occupational Health Department, and served in Air France’s International Travel Clinic, Paris Invalides, until taking his current position. From 1989-1999, he was also Day Hospital Head at the Institute Pasteur in Paris, where he also served in the Infectious and Tropical Diseases Department.

Dr. Feuillie is a member of the International Air Transport Association Medical Advisory Group, an International Academy of Aviation and Space Medicine academician, President of the French speaking Society of Aerospace Medicine (SOFRAMAS), and Member of the Medical Council French Civil Aviation Authority (DGAC). He was chair of the Organization Committee for the International Conference of Aerospace Medicine in Paris in 2022. He has been a member of the Airlines Medical Directors Association

Future AsMA Annual Scientific 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

since 2009, and is a member of the European Society of Aerospace Medicine and Member at Large of their Executive Council and a member of IAMA. He is a European Union Aviation Safety Agency representative at the Flight Standards Technical Committee, and a member of the Aerospace Medical Association since 2009. Within AsMA, he is a member of the Air Transport Medicine Committee.

Bates Continues as IAMFSP President

Col. Christopher W. Bates is starting his second year as President of the International Association of Military Flight Surgeon Pilots. He is currently the sole tanker Pilot-Physician for the U.S. Air Force and is actively engaged in human system integration issues for the KC-46. As a KC-46 instructor pilot he works with 22nd Operations Group in the execution of KC-46 Initial Operational Test and Evaluation and training of KC-46 aircrew. Prior to this assignment, he was the Commander of the 22nd Operational Medical Readiness Squadron, 22d Medical Group, 22d Air Refueling Wing, McConnell AFB, KS.

In 2001, Col. Bates was commissioned through the U.S. Air Force Academy and earned his Doctor of Medicine in 2005 from the Uniformed Services University of the Health Sciences (USU). He is a Pilot-Physician with over 2000 pilot flight hours in the T-6, T-1, KC-135, and KC-46. He has deployed as a pilot, flight surgeon, and critical care air transport team (CCATT) physician in support of Operation Enduring Freedom and Operation Iraqi Freedom. He is also a board-certified emergency medicine physician and a Fellow of the American College of Emergency Physicians. A full bio is available in the October 2022 newsletter: https://www.asma.org/asma/media/AsMA/pdf-journal/pdf-news-2022/oct-2022_news_final.pdf.

Auñón-Chancellor Is NASA Flight Surgeons President

Dr. Auñón-Chancellor is the incoming President of the Society of NASA Flight Surgeons. She received a B.S. in Electrical Engineering from George Washington University, Washington, DC, in 1997 and an M.D. from the University of Texas Health Science Center in Houston in 2001. She completed a 3-year residency in internal medicine at the University of Texas Medical Branch (UTMB) in Galveston, TX, in 2004 and then completed an additional year as Chief Resident in the Internal Medicine Department in 2005. She also completed an aerospace medicine residency at UTMB and an M.P.H. in 2007.

Dr. Auñón-Chancellor was selected by the National Aeronautics and Space Administration (NASA) in 2009. Board certified in Internal and Aerospace Medicine, she recently served as Flight Engineer on the International Space Station (ISS) for Expeditions 56 and 57. During her time on orbit, the crews contributed to hundreds of experiments in biology, biotechnology, physical science, and Earth science aboard the International Space Station. Investigations were led into new cancer treatment methods and algae growth in space. The crew also installed a new Life Sciences Glovebox, a sealed work area for life science and technology investigations that can accommodate two astronauts. During Dr. Auñón-Chancellor's first flight, she logged in 197 d in space. She currently covers medical issues and on-orbit support in the Astronaut Office. In addition, she serves as the Program Director for UTMB's Aerospace Medicine Residency Program and as academic faculty for LSU Health's Internal Medicine Residency Program in Baton Rouge, LA.

Dr. Auñón-Chancellor's awards and honors include the U.S. Air Force Flight Surgeons' Julian Ward Award, an Outstanding UTMB Resident Award, the William K. Douglas Award, and the Thomas N. and Gleaves James Award for Excellent Performance by a third-Year Resident in Internal Medicine. She is a member of the American College of Physicians, the American College of Preventive medicine, and the National Engineering Honor Society, and is an Associate Fellow of the Aerospace Medical Association.

Suresh to Head Space Medicine Association

Dr. Rahul Suresh is the incoming President of the Space Medicine Association (SMA). He is an operational Flight Surgeon at the NASA Johnson Space Center (JSC). He has served as the deputy crew surgeon for Expeditions 61-62 and as the prime crew surgeon for Expeditions 66-67 (SpaceX Crew 3). He currently serves as the Program Medical Officer for NASA's Low Earth Orbit Commercial Destination Program. His duties in this role include providing physician leadership for the Agency in its development of future commercial LEO destinations and to serve as the prime physician interface to commercial providers building LEO stations. His other roles include supporting SpaceX Crew Dragon launches and landings as a certified SpaceX Hawthorne Mission Control Specialist and as the Co-Lead of the Exploration Medical Integrated Product Team where he helps identify and fund development of medical capabilities for future exploration missions. He is a longstanding SMA member and has been the chair of the SMA Awards Committee for the past 2 years.

Dr. Suresh earned his Bachelor of Arts degree in Biochemistry and Cell Biology from Rice University in Houston, TX. He returned to his hometown of Rochester, MN, where he received his Doctor of Medicine degree and a Master of Clinical and Translational Research degree from the Mayo Clinic College of Medicine and Science. He completed residency training at the University Texas Medical Branch (UTMB) in Galveston, TX, and earned a Master of Public Health degree. He is currently board certified in Internal Medicine and Aerospace Medicine. He is also a practicing hospitalist and sees patients at hospitals in Houston.

Incoming SUSAFFS President is Andrus

John R. Andrus, B.Sc., M.D., M.P.H., M.Sc., Brig. Gen., USAF, is the incoming President for the Society of U.S. Air Force Flight Surgeons. He is the Commander, 711th Human Performance Wing (HPW), Air Force Research Laboratory, Wright-Patterson Air Force Base, OH. He entered the Air Force in 1988 through the Uniformed Services University and earned his B.Sc. at the University of California, Irvine, CA, his M.D. at the Uniformed Services University, and completed a family practice residency in 1996. He graduated from the Aerospace Medicine Primary Course in 1997 and the Squadron Officer School Correspondence Program in 1998. He received his M.P.H. in 2002 from the University of California, Berkeley, and also completed the Air Command and Staff College Distance Learning Program. He served an Aerospace Medicine Residency in

2003 and a General Preventive Medicine Residency in 2004 at the U.S. Air Force School of Aerospace Medicine, Brooks City-Base, TX. He completed the Air War College Distance Learning Program in 2007 and earned a Master of Science in National Resource Strategy at the Eisenhower School of National Security and Resource Strategy, National Defense University, Fort McNair, Washington, DC. He also holds a Project Management Professional Certification.

Dr. Andrus was a Family Physician, 65th Medical Group, Lajes Field, Azores, from 1996-1998, when he became Flight Surgeon at the 86th Medical Group and then at the 37th Airlift Squadron, both at Ramstein AB, Germany. In 2001, he attended the Air Force Institute of Technology to study for his M.P.H. He became Chief of Aerospace Medicine, 62nd Medical Group and then Commander of the 62nd Medical Operations Squadron, both at McChord AFB, WA., in 2004. He was assigned as Commander, 62nd Medical Squadron, JBSA Lewis-McChord, WA, in 2008 and became Deputy Command Surgeon, HQ U.S. Africa Command, Kelley Barracks, Stuttgart, Germany, in 2009. From 2012-2015, he served as Commander, 59th Medical Operations Group, JBSA Lackland, TX, before attending the National Defense University to earn his Masters. From 2016-2021, he served as Command Surgeon, HQ Air Force Space Command, Peterson AFB, CO, and then Command Surgeon and Director, Global Patient Movement Operations at U.S. Transportation Command before taking his current position.

Dr. Andrus deployed to support Atlas Response airlift operations and was the lead flight surgeon in the evacuation of injured USS Cole sailors from Yemen. He is the recipient of the Emma L. Bockman Memorial Award for outstanding scholarly activity, the Mackay Trophy, the Malcolm C. Grow Award, and the Life Cycle Logistics Field Award. His other awards include the Nuclear Deterrence Operations Service Medal with two oak leaf clusters, Humanitarian Service Medal with one oak leaf cluster, Air Force Recognition Ribbon, Air Force Achievement Medal, Air force Commendation Medal, Meritorious Service Medal with one oak leaf cluster, Legion of Merit, and Defense Superior Service Medal with one oak leaf cluster.

Krause Is the New SUSNFS President

Robert J. Krause, M.D., M.P.H., CIME, is the incoming President for the Society of U.S. Naval Flight Surgeons (SUSNFS). He is a physician and Captain in the U.S. Navy, dual board-certified in Occupational Medicine and Aerospace Medicine. He obtained a Bachelor of Science in Biomedical Engineering from Rensselaer Polytechnic Institute in 1996, his M.D. from the Uniformed Services University of the Health Sciences in 2008, and his Master of Public Health from the University of West Florida in 2014. Between 2012 and 2014, he served and Aerospace Medicine Residency at the Naval Aerospace Medical Institute in Pensacola, FL.

Dr. Krause began as a Student Naval Flight Officer at Aviation Training Command and CTW-6, Pensacola. FL, in 1996. From 1997-1998, he was a Naval Flight Officer at Sea Control Squadron Four One, San Diego, CA, and then Sea Control Squadron Two Four, Jacksonville, FL. He then became Officer in Charge, NROTC Unit, at the University of North Carolina, Chapel Hill. After he earned his M.D., he served in a variety of positions, including General Surgery Intern, Battalion Medical Officer, and Flight Surgeon, before becoming a Resident in Aerospace Medicine in 2012. Following his residency, he was assigned as Senior Medical Officer on the USS Theodore Roosevelt (CVN 71) and the USS George Washington (CVN 73). Starting in 2017, he was a Senior Regional Flight Surgeon at Branch Health Clinic Oceana in Virginia Beach, VA, and then was an Independent Contractor from 2018-2022 for American Analytical Medical Services, San Diego, CA; Maximus, McLean, VA; and MLS Group, Southfield, MI. He then became the Department Head of Operational and Aerospace Medicine, Branch Health Clinic Oceana, in 2018. That year, he also became Medical Director/Senior Medical Officer at Oceana Triad in Virginia Beach. In 2020, he left those positions to serve as an Aeromedical Analyst, Code 14 Branch Head, at Naval Safety Center, Norfolk, VA, a position he holds today. Additionally, from 2019-2022, he was Navy Specialty Leader, Aerospace Medicine and Flight Surgery, Bureau of Medicine and Surgery, in Falls Church, VA.

Dr. Krause is a member of the American College of Occupational and Environmental Medicine, and a member, previous Secretary, and past Vice President of the Society of U.S. Naval Flight Surgeons. He is an Associate Fellow of the Aerospace Medical Association (AsMA). His honors include the Air Medal (First Strike/Flight Award), Navy Achievement Medal, Navy Commendation Medal (three awards), Army Commendation Medal, and the Meritorious Service Medal (two awards). He is an author or co-author on six publications and presentations, and is a Certified Independent Medical Examiner (CIME) of the American Board of Independent Medical Examiners.

Sobel Continues as ANAHPS President

Annette L. Sobel, M.D., M.S., FAAFP, FAsMA, FAAN, is beginning her second year as president of the Aerospace Nursing and Allied Health Professionals Society. Dr. Sobel is currently Adjunct Professor, School of Nursing, at Texas Tech School of Health Sciences, and Adjunct Professor, Electrical and Computer Engineering, Texas Tech. She received her Bachelor of Science degree in Chemistry and Computer Science from Rutgers University in 1979 and her M.D. from Case Western Reserve in 1983. She did her Family Medicine Internship and Residency at Duke University. She received a Master of Science degree in Aerospace Medicine/Human Factors Engineering from Wright State University. She also attended Ari Command and General Staff Collee, Air War College, the NASA Flight Surgeon Course, the U.S. Navy Hyperbaric Medicine course, and the JFK school of Government National Security Program at Harvard University.

Dr. Sobel is a former President of the Space Medicine Association and the Aerospace Human Factors Association, recipient of the AsMA Julian E. Ward and AsHFA Henry F. Taylor Awards, and the Anti-Defamation League's Award for Superior Public Service. During her military career, and a civilian career as a Distinguished Member of the Technical Staff at Sandia National Laboratories, NM, she served during 9/11 and Hurricane Katrina responses, and worked on a number of forward-leaning partnerships for peace and non-proliferation. She led DoD development of public health/counter WMD initiatives in Thailand, Vietnam, Qatar, and across the CENTCOM (pre-AFRICOM) areas of responsibility for the Office of the Secretary of Defense. She worked for USAID/NGOs in Africa on medical education and training and developed an interprofessional pre-hospital care and innovation initiative in Lubbock for medical, nursing, business, and engineering students. A full biography is available in the June 2022 journal [AMHP 2022; 93(6): 540-541 and in the newsletter [June 2022:N22].

Did you know? FAA seminar info can be found at: https://www.asma.org/scientific-meetings/other-meetings.

Lee to Head LSBEB

Peter H. U. Lee, M.D., Ph.D., M.P.H., M.S., FACS, FACC, FAsMA, Lt.Col., USANG, is the incoming President of the Life Sciences and Biomedical Engineering Branch (LSBEB). He is an Assistant Professor of Pathology and Laboratory Medicine at Brown University and a cardiothoracic surgeon at Southcoast Health in Massachusetts. He received a B.S. in neuroscience, Ph.D. in pathobiology, and M.D. degrees, all from Brown University. He received an M.S. in Space Studies from the International Space University in France and an M.P.H. from Harvard University. He completed his surgical training at Tufts University, UCLA, and Stanford University.

Dr. Lee is board certified in both general surgery and thoracic surgery and is a Fellow of the American College of Surgeons (FACS), a Fellow of the American College of Cardiology (FACC), and a Fellow of the Aerospace Medical Association (FAsMA). He was also a heart and lung transplant surgeon while on faculty at The Ohio State University. His research interests span the range of clinic, outcomes, translational, and basic science research. He has over 100 scientific publications, abstracts, and book chapters. He has his own basic science laboratory focusing on skeletal and cardiac muscle tissue engineering, gene therapy, and the use of stem cells. He has an interest in applying tissue-engineering technologies for use in regenerative medicine, as replacement tissue, as a biological pump, and an organ-on-a-chip type in vitro experimental model. He also has an interest in aerospace medical and space life sciences research. He has flown multiple microgravity and spaceflight experiments, including in parabolic zero gravity flights, aboard the space shuttle, and on the International Space Station (ISS).

Dr. Lee is a recipient of the Young Investigator's Award by the American Society for Gravitational and Space Research (ASGSR) as well as a Faculty Research Fellowship by the American College of Surgeons (ACS). He is an elected Academician of the International Academy of Aviation and Space Medicine (IAASM), and the International Academy of Astronautics, an Executive Council member of AsMA, a member of LSBEB, the past President of the Space Surgery Association (SSA), and former Governing Board member of the ASGSR. He is also a member of the User Advisory Committee for the International Space Station National Laboratory. He serves as a Lt. Colonel in the U.S. Air National Guard, where he serves as a general surgeon and flight surgeon and was the Chief of Clinical Services for the 179th Medical Group. He is also the co-founder and Chief Executive Officer of the innovative medical device company Spiritus Medical, Inc., which has a license to manufacture and sell the NASA/JPL-designed VITAL ventilator. He has served as the medical officer on a 1-month Mars simulation mission in the Canadian Arctic as part of the Flashline Mars Arctic Research Station crew and was a finalist for the 2016 Canadian astronaut selection campaign. On a personal note, he is a seventh degree grandmaster in taekwondo, a certified master scuba diver, and a private pilot.

2023 Associate Fellows Announced

The following members of the Aerospace Medical Association have achieved Associate Fellow status and were approved by the Executive Committee: Jeffrey Althoff, Chris Bates, Quen Shaw (Thomas) Chong, Joseph Connolly, Daniel Danczyk, Ari Epstein, Erik Frijters, Patrice Guillemautot, Candice Nicole Hatcher-Solis, Any Kreykes, Charles G. Mahakian, Carlos Navarro, Nina Purvis, Michael Schmidt, Philip Strawbridge, and Frank Villamaria.

In Memoriam: James T. Webb, Ph.D.

AsMA Home Office staff were deeply saddened to hear of the death of James T. Webb, Ph.D. He was a Fellow of the Aerospace Medical Association and served as the AsMA Vice President of Education and Research. He also served as the AsMA President (2013-2014) and was honored with the 2018 Louis H. Bauer Founders award.

Dr. Webb entered the U.S. Air Force (USAF) in 1965. Following receipt of his pilot wings in 1966, he became an F-4D Aircraft Commander and terminated active duty in 1970, after a tour in Vietnam, to pursue graduate degrees from the University of Washington in Seattle. For his efforts in Vietnam, he received the Distinguished Flying Cross and the Air Medal with eight oak leaf clusters. During graduate work for his Ph.D. in Fisheries (Biochemical Ecology) at the University of Washington in Seattle, he flew C-141A heavy transport jets as a pilot and aircraft commander with the 97th MAS, USAF Reserve (ASSOC), at McChord AFB, WA. After completing graduate work and 2800 hours of C-141A flying time, he resumed extended active duty with the USAF in the Department of Biology faculty, USAF Academy, Colorado Springs, CO, in 1979. He taught biology, aerospace physiology, and comparative animal physiology and served as Director of Research. In 1984, he was assigned to the USAF School of Aerospace Medicine (USAFSAM) at Brooks AFB, TX, as a research physiologist.

At USAFSAM, Dr. Webb worked with crewmembers of Space Shuttle mission 51C in an attempt to quantify fluid shifts during Space Shuttle launch and early phases of adaptation to weightlessness. He served as one of the subjects in a protocol on the USAFSAM human centrifuge during this research project. In 1987, he joined KRUG Life Sciences as a senior research scientist on contract with USAFSAM. For his 1991 article in Aviation, Space, and Environmental Medicine (now Aerospace Medicine and Human Performance), "Unpredictability of fighter pilot G tolerance using anthropometric and physiologic variables" (ASEM 1991; 62:128-35), he received the 1992 Harold V. Ellingson Literary Award from the Associate Fellows Group of the Aerospace Medical Association (AsMA). His later research on DCS led to receipt of the Sidney D. Leverett, Jr., Environmental Science Award in 1999 for his article in the blue journal, "An abrupt zero-preoxygenation altitude threshold for decompression sickness symptoms" (ASEM 1998; 69:335-40).

One of Dr. Webb's research projects demonstrated increased efficiency of preoxygenation by employing exercise to enhance perfusion and ventilation. This research led to receipt of the Fred A. Hitchcock Award for Excellence in Aerospace Physiology from the Aerospace Physiology Society (AsPS) in 1996. The exercise during prebreathe technique was incorporated with NASA findings to enhance denitrogenation prior to the extravehicular activity beginning in 2001. He received the Silver Snoopy award from the NASA astronauts in 2002 for this work. In 2003, he received the Paul Bert Award for Physiologic Research from AsPS and the Professional Excellence Award from the Life Science and Biomedical Engineering Branch (LSBEB) in 2004.

After retirement from the USAF, Dr. Webb continued aerospace physiology research as a scientist with Wyle Laboratories. In 2006, he began employment with Eagle Applied Sciences, LLC, in a curriculum development role aimed at compiling a "Handbook of Aerospace and Operational Physiology" to replace a 1976 Air Force Pamphlet on the same subject. He coordinated the efforts of 28 USAF subject matter experts who contributed to its completion. As part of that effort, he reviewed the decompression sickness research at Brooks AFB from 1960–2010, published in May 2011 as a supplement to the journal. Throughout his 26 years of altitude and acceleration physiology research at Brooks, he published 20 first-author, peer-reviewed research papers in ASEM and co-authored 15 more. He was the winner of the 2011 John Ernsting Award for all his work in physiology.

Dr. Webb was a member of the International Association of Aviation and Space Medicine, Sigma Xi (The Scientific Research Society), and a life member of the Order of Daedalians (The National Fraternity of Military Pilots). He was board certified in Aerospace Physiology by the AsMA and held an Airline Transport Pilot certificate from the Federal Aviation Administration. After retirement, he continued efforts to investigate DCS risk and consulted with the USAF via his consulting firm, Scientific Aerospace Research Consulting (SARC), LLC.

Dr. Webb was instrumental in implementing and growing the AsMA Aerospace Physiology Certification Program. He served on the AsMA Executive Committee and Council, and served as Chair of the Aerospace Physiology Certification Board and on the editorial board of the AsMA journal. In 2010, he received the President's Award for his efforts as Chair of the Editor-in-Chief Selection Committee. He was a member of the Space Medicine Association and the Life Sciences and Biomedical Engineering Branch (President 1995–1996) He served on numerous AsMA committees, including the Resolutions Committee, Bylaws Committee, Aerospace Human Factors Committee, History and Archives Committee, Awards Committee, Science and Technology, and many more.

Scholarship Winners

AsMA International Aerospace Medicine Scholarship

Sophie Levasseur is a third-year medical student at McGill University in Montreal, Canada. She holds a bachelor's degree in Honours Behavioral Neuroscience from Concordia University. She began as a Research Assistant at the McGill Centre for Studies in Aging in Verdun, Quebec, Canada. She then became a Research Assistant at the Neurobiology of Learning Lab at Concordia University, Montreal, Quebec. She went on to become a Medical Scribe for Jewish General Hospital's Emergency Department in Montreal. She is currently a vaccinator with the Quebec COVID-19 Vaccination Campaign. She is the founder and co-president of McGill University's first Space Medicine Interest Group (SMIG), a Co-President of the McGill Student Surgical Society, and a CSTARS CSAM Medical Student Representative.

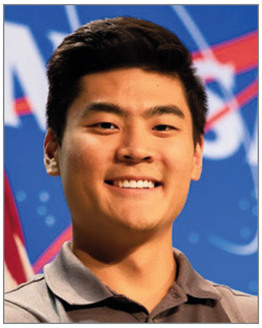
Anita Mantri, Ph.D., Memorial Travel Scholarship

Samuel Stephenson, M.D., is a recent graduate of Eastern Virginia Medical School (EVMS). He is from Culpeper, VA, and completed his undergrad in 2019 at the University of Virginia with a major in kinesiology. He then moved to Norfolk, VA, for medical school at Eastern Virginia Medical School, from where he will graduate in May 2023 with an M.D. During the COVID-19 pandemic, he was on a team that used 3-D printers to make respirators which were used by the Children's Hospital for the King's Daughters during the early pandemic and he volunteered at numerous vaccine clinics helping administer COVID-19 vaccines to the local community. He also led exercise classes and nutrition discussions at the Salvation Army Adult Rehabilitation Center, working with the Portsmouth Diabetes Prevention Program, and serving as a running pacer at local half marathons. He developed a novel touchscreen switch task and completed and published his first study titled, "Simulated Space Radiation Exposure Effects on Switch Task Performance in Rats" in *Aerospace Medicine and Human Performance*. He completed the NASA Aerospace Medicine Clerkship last October. He will begin his residency training in June 2023 at UTMB in the combined Internal Medicine/Aerospace Medicine program.

Stanley R. Mohler, M.D., Aerospace Medicine Endowed Scholarship

Cyril Mani is a final-year aerospace engineering student at McGill University, Montreal, Canada, completing—with a parabolic flight campaign—his ESA-funded thesis investigating spacecraft propulsion in microgravity. From 2019-2022, he led 25 engineering students to build and launch the first Canadian experimental student rocket, while also working on Canada's very first commercial launch capacity. His was invited to present at IAC 2022 in Paris and CI/CS 2022 in Ottawa. He then pivoted his career to aerospace medicine and joined the Space Medicine and Astronaut Health division of the Canadian Space Agency (CSA). He contributes to the flagship Connected Care Medical Modules program and pursues aerospace medicine research. He wishes to obtain a Ph.D. in biomedical engineering and clinical experience through an M.D.

Jeffrey R. Davis, M.D., Aerospace Medicine Endowed Scholarship



Alex Suh is an M2 medical student originally from Omaha, NE, studying at Tulane University School of Medicine in New Orleans, LA. He began his education studying physics at the University of Nebraska at Omaha and then was part of an exchange program at Yonsei University, Seoul, Korea, studying microbiology and taking a Korean Intensive Language Program before attending Tulane University. He started as a Research Intern at the University of Nebraska Medical Center in the Departments of Pharmacology and Experimental Neuroscience and Ophthalmology and Visual Sciences. He then designed a prototype of an aircraft wing at the Tulane University Novel Tech Challenge. Later he became a videographer and editor at Suh-Hermsen Omni Glasses. Last summer, he conducted research in the Cardiovascular and Vision Laboratory at NASA's Johnson Space Center as a University Space Research Association Intern. He is President of the Tulane University Aerospace Medicine Student and Resident Organization and is serving as Communications and Logistics Chair in the Tulane University Social Contexts in Medicine Program. He is also a volunteer at Luke's House Eye Clinic in New Orleans. He is author or co-author on over 15 publications.

Full biographies for the scholarship winners can be found in the April 2023 newsletter [https://www.asma.org/asma/media/AsMA/pdf-journal/pdf-news-2023/april-2023_news3.pdf].

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