Multiple E-2D Hawkeye Aircrew with Neurocognitive Symptoms During a Single Over-Pressurization Episode

Samuel Y. Ko; George M. Rice

BACKGROUND: Increased frequencies of physiological episodes have been a significant concern for Naval Aviation for the last several years. These include several aircraft platforms, but no previously documented E-2D Hawkeye events. This report documents an episode in an E-2D, with multiple aircrew affected at the same time.

CASE REPORT: While deployed aboard a U.S. aircraft carrier, five E-2D Hawkeyes aircrew were simultaneously exposed to the same over-pressurization during a routine sortie. Out of the five aircrew, four immediately reported hypoxic-like neurocognitive symptoms of "mental slowing", difficulty concentrating, and headache. They were evaluated and treated using standard protocol according to the Physiologic Event Clinical Practice Guidelines set by the Naval Safety Center. All aircrew were treated with 100% ground level oxygen with resolution of symptoms.

DISCUSSION: Although rare, physiological events may occur in multipassenger platforms such as the E-2D Hawkeye. Utilizing and strictly adhering to standard clinical practice guidelines provided an efficient process of evaluation by different flight surgeons concurrently that avoided a possible delay in treatment. After, eliminating other potential etiology for the crew's symptoms, a pressure-related mechanism of injury appears to be the most probable cause.

KEYWORDS: physiological episode, pressure fluctuation, neurological, cognitive deficit.

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Physiological events[6] have been a significant issue for naval aviation since 2010.[7] The most recent published data accounts for 571 separate events.[7] The U.S. Navy defines a physiological event as an occurrence of abnormal or unexpected physiological response in the setting of an aircraft system malfunction.[6] These physiological events have often occurred in the setting of a malfunctioning On-Board Oxygen Generator System (OBOGS) or Environmental Control System, which are installed on tactical aircraft such as the Navy's F/A-18, T-45, E/A-18G, and T-6 platforms. These two systems are responsible for providing the life support functions for aircrew comfort and safety by supplying adequate oxygen, pressurization, and temperature.[4,5] There is currently no accepted cause that exists to explain the underlying mechanisms for the various types of subjective symptoms; it is believed to be multifactorial.[4,7] Recently, these events have been characterized into three environmentally plausible classifications; human factors, hypoxia-like, or pressure-related disorders.[7] Since these cases have been limited to the tactical jet communities, at most two aircrew have been affected during any single occurrence. The isolated and varied nature of previous reports has posed challenges to the aeromedical community when developing and proposing hypotheses as to the underlying mechanisms and pathophysiology. This case report offers a unique exposure to several aircrew of an E-2 Hawkeye, who experienced a simultaneous over-pressurization resulting in various degrees of neurocognitive symptoms.

CASE REPORTS

Aircrew consisted of a total of five individuals, two pilots and three flight officers. The pilots sit in the forward cockpit and directly control the aircraft in a side-by-side configuration. The

From the U.S. Navy, Virginia Beach and Norfolk, VA, USA.

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Address correspondence to: Samuel Ko, M.D., Flight Surgeon, U.S. Department of the Navy, 1760 Tomcat Blvd., Rm. 1640, Virginia Beach, VA 43260, USA; samuel.y.ko@gmail.com.

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flight officers operate sensor and communication equipment in the aft cabin. During takeoff and landing they face forward; in flight the seats swivel 90° to the left so they are arranged in a row facing workstation consoles to the left. The two areas are connected by a narrow passageway that has the main hatch and contains the outflow valve. While there are doors separating the passage in flight, the entire cabin is continuous in that it is pressurized as a single unit. During the flight they are able to communicate to each other through an inter-communication system that is set to "ON." Aircrew are equipped with harnesses and survival vests. The harness is attached to the parachute pack, which interfaces with the seat and simultaneously acts as a cushion. Flight helmets are worn for their communication devices, but on longer flights aircrew may opt to use an aviation headset for communication. Oxygen masks are tested for OBOGS functions during start-up and they remain connected to the system and secured in a pouch, not attached to the helmet. They are not routinely used during a flight and are not required to be.

The flight was a routine maritime operation event providing the usual role as an airborne early warning and command and control aircraft. It originated from aboard a U.S. Nimitz-class aircraft carrier. It was a daytime flight that occurred in May 2019, with a launch time midmorning (t = 0:00). No issues were noticed prior to flight, including standard briefing, crew walk, preflight, and taxi to catapult. Launch via catapult, fly away, and climb were also without incident. At t = 11:00 min the aircraft was operating at cruising altitude at approximately 19.0k ft (5791 m), with a cabin pressure of 4584 ft (1397 m), which is within tolerances for expected scheduling of 5000 ft (1524 m). At t = 17:00 min, the crew noticed a rapid, but not instantaneous, increase in cabin pressure. In response the pilot decreased altitude to 9.7k ft (2957 m), with a max cabin pressure of −6086 ft (−1856 m), which would be effectively below sea level. Master Caution lit up with "OBOGS Lo Purity" and "OBOGS Degrade." At the time no aircrew were wearing masks. To aid in troubleshooting, the flight officer in the forward seat went forward to check the cabin outflow valve, which has been known to get stuck. When tapping on the housing it was indeed not in the proper position. At time t = 18:00 min the cabin pressure dump valve was actuated by the pilot, which allowed the pressure to equalize with ambient air pressure. The pilot descended in altitude at time t = 22:00 min; as the aircraft passed 6.5k ft (1981 m), the cabin altitude corresponded with ambient pressure according to expected scheduling. Discussion among the aircrew included the subjective feeling of acute hypoxia-like symptoms that coincided with the sudden increase in pressure. The aircrew attempted to resume normal flight at t = 27:00, resetting the pressure dump, and testing the pressurization by returning to 10.8k ft (3292 m). The system failed to appropriately pressurize and instead corresponded with changing ambient pressure. A decision was made by aircrew to abort the mission. The pilot in command navigated the aircraft back to the carrier for an emergency landing. The aircraft recovered at time t = 56:00 min with an otherwise unremarkable arrested landing back aboard the carrier.

All aircrew were evaluated immediately postflight. After a quick debrief with medical personnel, survival equipment was removed while in the flight deck battle dress station. Evaluation followed standardized protocol using the Physiologic Events Clinical Practice Guidelines (**Fig. 1**)[6] by three active duty designated naval flight surgeons. Evaluation includes review of past medical history, active waivers, and daily activities within the last 72 h. None of the aircrew had prior physiological episodes. None of the aircrew reported any extraordinary human factors other than the normal stressors of being deployed aboard a carrier. Physical exam consisted of a complete head to toe evaluation with a detailed neurological exam, including mental status, cranial nerves, muscle strength, reflexes, coordination, sensory function, and gait. A basic cognitive screen was accomplished using the Montreal Cognitive Assessment (MoCA). It is a bedside test that evaluates domains of executive function, naming, short-term memory, attention, language fluency, abstractions and delayed recall, and orientation. A maximum score is 30; normal is 26 or greater for a high-school graduate. While a score of 26–29 is "normal," in a high functioning population such as aviators, who have gone through a screening process, this range is concerning for impairment from expected baseline by navy aeromedical community informal consensus. Consultation via telephone was performed for all crewmembers with an on-call undersea medical officer, located at the Naval Aerospace Medicine Institute, in Pensacola, FL. The aircrew were then treated according to current Physiologic Events Clinical Practice Guidelines.[6]

Pilot 1 is a 34-yr-old man with about 2300 h in the E-2 Hawkeye with no medical waivers. Symptoms started after the initial over-pressurization, with tingling and numbness in the extremities and overall fatigue. These symptoms were consistent with his hypoxia recognition symptoms. Subjectively, he felt it took more than the usual concentration to make usual communications and control the aircraft. Symptoms had modest improvement with the use of emergency oxygen during recovery aboard the ship. He reported having mild upper respiratory illness in the 48 h prior to the flight, but not taking any medications. Exam revealed a BP of 144/90, but otherwise normal vitals. MoCA was 29/30. Since he was symptomatic, he was treated with 2 h of 100% oxygen by nonrebreather or ground level oxygen (GLO). Symptoms improved during the course of treatment. Repeat exam demonstrated improvement on MoCA, with 30/30. Pilot 1, upon follow-up at 24 and 48 h, remained asymptomatic and was returned to flight status.

Pilot 2 is a 27-yr-old man with 300 h in the E-2. He has a waiver for hypothyroidism post-thyroidectomy for Graves' disease. He reported no abnormal symptoms. He did have a sensation of increased pressure and a popping sensation in the ears. Emergency oxygen was used during recovery, with no subjective change. He was asymptomatic upon evaluation. Exam showed a BP of 140/86, with the remainder of vitals being normal. Exam revealed no significant abnormalities. There was no change in his status during the evaluation. Pilot 2 was asymptomatic but was provided 100% oxygen as a precaution. Within no change in status he was released to full flight status. No formal follow-up

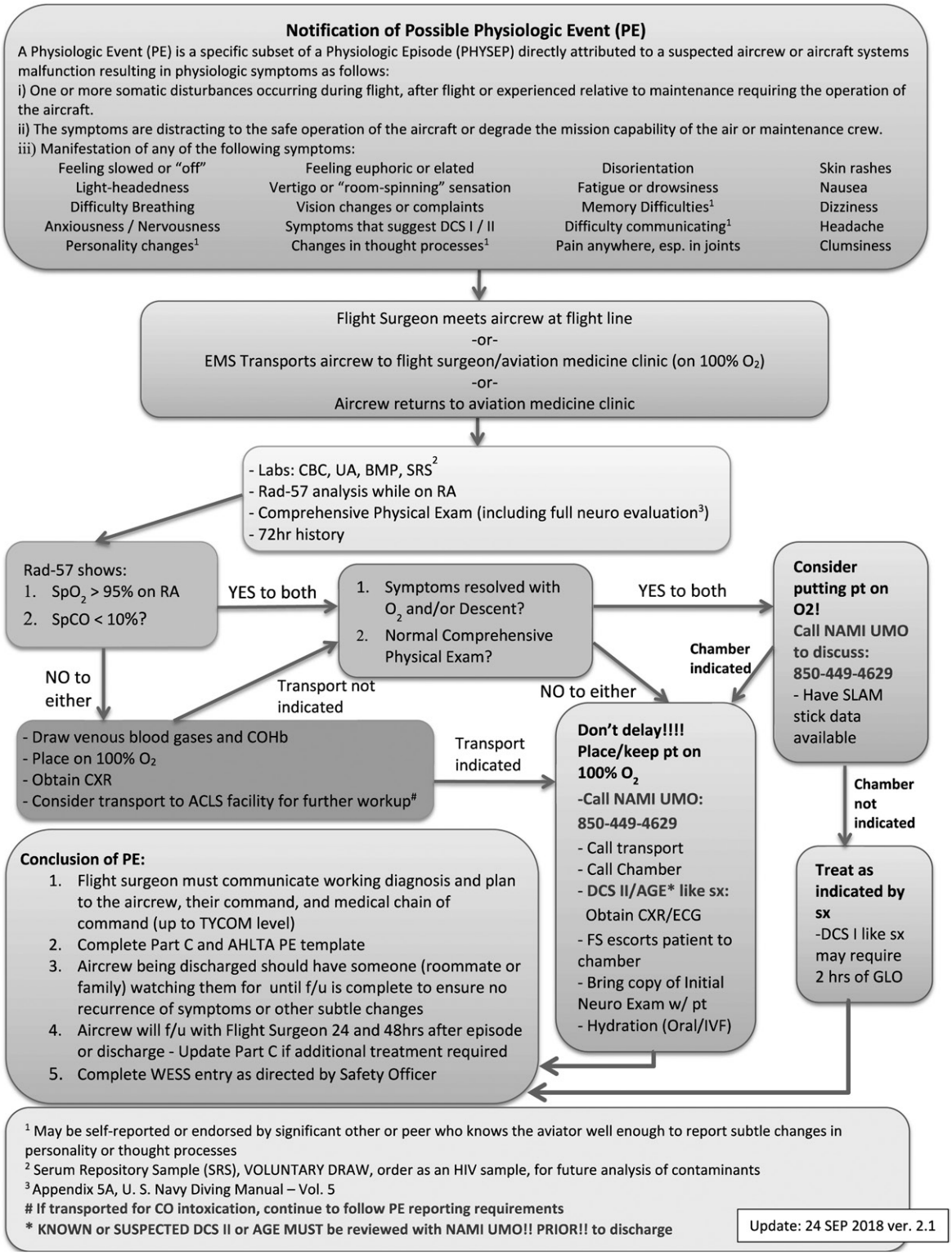

Fig. 1. Clinical practice guidelines for physiological events.

was conducted on Pilot 2, but he remained asymptomatic and flew the next day without issues.

Flight Officer 1 is a 33-yr-old man with 250 h in the E-2 and no waivers. He reported numbness, tingling, and lethargy, with tunnel vision and confusion during flight. He felt worse upon initiating emergency oxygen during recovery. He was noted to be "slow," with some stuttering, by fellow aircrew. Vitals signs were normal; however, his neurological exam was abnormal. It was readily apparent that he was having difficulty recounting specific details about the flight. During the MoCA, he struggled

with the visuospatial exercise, copying of the cube, and drawing a clock face. After scoring a 21/30, he was placed on GLO. The remainder of the neurological exam was completed during the first few minutes on GLO. He exhibited other objective neurological deficits, including left lower extremity weakness 4+/5, lateral nystagmus with leftward gaze, fine tremors bilaterally during finger-nose-finger testing, but was still able to perform relatively well, and ataxia demonstrated by body swaying with closed eyes during Romberg's Test. Flight Officer 1 completed treatment with 2 h of GLO. Part of the neurological exam was completed while treatment was initiated but was nonetheless still abnormal. His prognosis was guarded at first, but after an hour showed improvement and, by the end of the 2 h, was subjectively and objectively normal for him. Flight Officer 1, upon 24 and 48 h follow-up, remained asymptomatic and was returned to flight status.

Flight Officer 2 is a 26-yr-old woman with 600 h in the E-2 and a waiver for atypical squamous cells of undetermined significance, though pending discontinuation of waiver as recent PAPs were normal. She reported symptoms of left leg and foot tingling, dizziness, "cloudy mind," and nausea. The nausea was severe enough she felt uncomfortable putting on the oxygen mask and, in fact, did not initiate emergency oxygen. Her left hand felt shaky in flight and she was noted to be "less talkative" by crewmates during the flight. During clinical evaluation she noted a mild headache. Her vitals were normal. Her neurological exam was likewise normal. She scored a 27/30 on MoCA, with difficulty copying a cube and difficulty during delayed recall, even with a category cue. Her abstraction between two words of similar category yielded an answer that was not incorrect, but concrete in that a watch and ruler "both have numbers" instead of both being tools for measurement. Flight Officer 2 was symptomatic and per protocol started on 2 h of GLO. Repeat neurological exam was normal, with improved cognitive testing. More subtle difficulties were improved, she scored 28/30, still with difficulty recalling words, however, with quick recall on category cue. Flight Officer 2, upon follow-up at 24 h, reported a mild headache overnight, but otherwise no recurrence of other symptoms experienced in flight. At 48 h she remained asymptomatic and was returned to flight status.

Flight Officer 3 is a 33-yr-old man with 1200 h in the E-2 Hawkeye and on waiver for anemia. He reported symptoms in flight as being "slowed" and taking "concerted effort" to concentrate on required tasks. He did not go on emergency oxygen in an effort to conserve supply in case others in a more critical role required it. On exam his vitals were normal, except for a BP of 144/91. His exam was normal, MoCA was 28/30 with difficulty copying a cube and delayed recall. Hemoglobin/hematocrit was 13.3/38.7, consistent with waivered borderline anemia; the remainder of the labs were unremarkable. Flight Officer 3 was symptomatic and per protocol started on 2 h of GLO. Repeat neurological exam was normal. He reported a mild headache upon leaving medical, but it resolved after sleeping for the night. Flight Officer 3, upon follow-up at 24 and 48 h, was asymptomatic and returned to flight status.

DISCUSSION

Physiological events previously have been described primarily to occur in tactical platforms and to at most two aircrew at one time. This case represents, to our knowledge, the first event to occur in in an E-2 Hawkeye and to several aircrew at the same time, with four of five aircrew having various symptoms suggestive of a syndrome with a similar mechanism. None of the aviators had previously experienced physiological episodes; further, it is unlikely they all shared an underlying medical susceptibility from undiagnosed disease or environmental exposure. Their social history, including diet, exercise, and supplement or substance use revealed no remarkable pattern. The nonspecific symptoms, often without clear objective findings, made diagnosis challenging.

Another challenging aspect to this physiological event was the number of immediate evaluations that needed to be performed for the aircrew. Fortunately, aboard a deployed aircraft carrier, there are at least three flight surgeons on the ship when fully manned. We used all available qualified providers to perform history and physical exams on the crew. Using multiple evaluating providers may be a source of variability with regards to evaluation and clinical determination of treatment. However, each exam component was performed strictly using existing clinical practice guidelines that also required the concurrence with a single on call undersea medical officer for hyperbaric disposition. This sets a standard on initial diagnosis and treatment; however, subsequent evaluation and management, particularly involving individuals with recurrent or persistent symptoms, would benefit from further study and eventual standardization. Strategies such as serial cognitive exams, specialty referral, or even repeat hyperbaric treatments are considered on an individual case-by-case basis, driven by the treating flight surgeon's clinical judgement.

The evaluation of impaired pilots using current clinical practice guidelines covers three main differential diagnoses. Possible human factors are reviewed as part of the history and exam. The two main categories are hypoxia and pressure-related syndromes. Hypoxic hypoxemia is ruled out in the absence of depressurization. This remains unlikely even with intended depressurization below 10k ft (3048 m) aircraft altitude and subsequently corresponding cabin altitude. In the absence of presenting toxidromes histotoxic hypoxia is ruled out; similarly, otherwise healthy individuals would not simultaneously develop hypemic hypoxia. Toxins and exposures are considered, but have been determined in previous cases not to be a factor.[7] A short duration of flight with a previously functioning Environmental Control System also rules out stagnate hypoxia. One hypothesis, as a result of naval root cause analysis, posits relative hypoxia caused by vasoconstriction. Further, this hypothesis proposes preoxygenation as a cause of susceptibility, as studied in high performance tactical aircraft.[6] This case would not follow this model as the cabin of the E-2 is not supplied with 100% oxygen or pressurized to a level to cause higher than normal partial pressure of oxygen. Aircrews have oxygen available, but it is not routinely used; in this case oxygen was not used by

all individuals nor was it used continuously. Hypocarbia has been proposed as a possible pathophysiology, but does not sufficiently explain duration of symptomology or resolution with use of ground level oxygen.

The persistent challenge to better explore these hypotheses is the lack of physiological data, particularly real-time. Issues of oxygenation or ventilation are difficult to elucidate using pulse oximetry or even a RAD-57 (Masimo, Irvine, CA, USA) after the pilot has landed and egressed from the aircraft. While venous blood gas studies may provide more robust and precise data, it is still prone to error for dynamic physiological changes. In-flight use of emergency oxygenation or delayed collection of samples due to aircraft operations would confound such post-event data. In-flight data collection improvements, such as cabin pressure gauges or oxygen sensors, focus on environmental factors; they look at the machine and neglect the human, where the symptoms and pathology is occurring. While issuance of heart rate monitors to aviators has been a step toward real-time biometric data, more robust systems to measure oxygenation, breathing rate, and effort would be valuable. Similarly, cognitive testing needs improvement. The Montreal Cognitive Assessment was pressed into use, but is intended for assessing for delirium and dementia. Use of a Military Acute Concussion Exam was used informally in other cases, but is not yet validated for this purpose. Like the MoCA, it is limited in the ability to assess mild deficit and ceiling effects may exist when administered on high functioning individuals. While more formalized neurocognitive testing is available, it is not readily accessible for bedside use at the initial assessment. The ideal scenario would include real-time biometric data that measures cognitive functioning, particularly that of executive and attention domains, in addition to the other physiological markers of dysfunction in the aviator.

Pressure-related illnesses have been a focus of attention for naval aviation. In airframes such as the F/A-18, pressure fluctuations have produced a similar nonspecific presentation. Clinically these individuals appear to have suffered a concussion, but pressure changes have not been demonstrated to have the amplitude or rate to replicate a pressure wave from a concussive explosion; thus, traumatic brain injury is not likely. The aircrew in this case lacked the more focal deficits seen in arterial gas embolism or decompression sickness. Models evaluating similar pressure profiles for past physiological events have also shown decompression sickness to be unlikely.[7] It remains, however, that the onset of symptoms is most closely correlated to the fluctuations in cabin pressure experienced by the aircrew. Fluctuations in ambient pressure have been associated previously with exacerbating or inducing several neurological conditions such as Meniere's Disease, migraines, and subarachnoid hemorrhage.[2,3,8] Low-frequency atmospheric pressure oscillations have also been experimentally associated with changes in mental activity.[1] Interestingly, subjects in that study reported vague cognitive deficits when exposed to stochastic low-frequency fluctuations.[1] Such vague symptoms of "cognitive slowing," "difficulty focusing," and "feeling behind the jet" are commonly reported by affected aircrew and was reported by all the affected aircrew in this case. It is plausible, therefore, that because all aircrew were exposed to the same exposure, this rapid fluctuation resulted in the varied neurological symptoms of dizziness, headache, and mental slowness experienced by our aircrew. The exact pathophysiological pathway for these varied symptoms still remains unclear, but given the significant risk to safety and completion of a mission, further studies are warranted.

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Authors and affiliations: Samuel Y. Ko, M.D., U.S. Navy, Virginia Beach, VA, USA, and George M. Rice, D.O., M.P.H., U.S. Navy, Norfolk, VA, USA.

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