CASE REPORT

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PHYSIOLOGICAL CORRELATES OF ALMOST LOSS OF CONSCIOUSNESS (A-LOC) DURING DYNAMIC FLIGHT SIMULATION (DFS) ON HUMAN CENTRIFUGE: A CASE REPORT

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Introduction: G-LOC is still a threat for aircrew of high performance aircrafts. It is evoked by a high level of +Gz acceleration causing a deficit of brain oxygenation. Although near-infrared spectroscopy (NIRS) was used to identify brain oxygenation decreases preceding G-LOC, it is not used regularly in aero-medicine research in Poland. Here, we report the physiological correlates of Almost Loss of Consciousness (A-LOC) that occurred during a research project.

Methods: During Dynamic Flight Simulation training on a human centrifuge one pilot experienced momentaneous confusion which was recorded on a camera. We post-hoc reviewed his vital signs, stroke volumes (SV), cardiac output (CO) obtained with bioimpedance rheography, and brain oxygenation (OX) measures with near-infrared spectroscopy on the forehead. Finally, we reviewed the recording of his eye movements obtained with video-oculography.

Results: SV and CO measures were confounded by artefacts induced by anti-G straining manoeuvres (AGSM). However, OX measures demonstrated decreased brain oxygenation that lasted several seconds after the incident. Following the incident, the pilot's pulse remained decreased for several seconds.

Figures: 4 • **References:** 24 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2020 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Discussion: NIRS methodology seems to be resistant to artefacts created by muscles during AGSM. NIRS systems with a probing rate of 0.1 second might help detect upcoming A-LOC or G-LOC.

Keywords: loss of consciousness, dynamic flight simulation, near-infrared spectroscopy, blood oxygenation monitoring, impedance rheography

INTRODUCTION

Military pilots are exposed daily to high accelerations routinely during training. Dynamic aerial manoeuvres involving high +Gz acceleration manoeuvres are physically challenging and leave little margin for error. Exposure to high levels of +Gz acceleration may result in G-force induced Loss Of Consciousness (G-LOC) or Almost Loss Of Consciousness (A-LOC).

The signs and symptoms of G-LOC were reported as early as 1918, but G-LOC incidence did not begin to be actively determined until 1982 [11]. A number of military air forces have surveyed the incidence of G-LOC and A-LOC in their aircrew over the last 20 years. Some studies have indicated that approximately 8–20% of military aircrew have experienced G-LOC [1,3,16] and 14–52% have experienced A-LOC [13,16] at some point in their career. The Royal Air Force (RAF) conducted two surveys of G-LOC within their military aircrew in 1987 [15] and 2005 [4] with 19.3% and 20.1% of aircrew, respectively, reporting such an event at some point in their career [19]. It is assumed that G-LOC is a protective mechanism that maximised the survivability of neurons deprived of an adequate supply of oxygen [17,22,23]. When the stress is at levels that are insufficient to cause G-LOC, deficits in motor, vision and cognitive performance still occur. Under these conditions aircrew exhibit an altered state of awareness. This insidious phenomenon was defined as an Almost Loss of Consciousness (A-LOC) by the U.S. Navy researchers in the late 1980s [17,18]. A-LOC has been described as causing a disconnection between the desire and the ability to act [13]. It is a syndrome that includes a wide variety of physiological, emotional, and cognitive signs and symptoms. Their features include sensory abnormalities, amnesia, confusion, euphoria, loss of short-term memory, paralysis, reduced auditory acuity, and motor abnormalities [18]. These symptoms are similar to the relative incapacitation phase of G-LOC and have led to the concept of a G-LOC syndrome with a broad spectrum of possible neurological manifestations [18] which can lead to serious motor and cognitive impairments in the high +Gz environment [19].

The narrowing of the visual field is a sign of decrement in retinal blood flow and decreasing blood saturation may precede the onset of G-LOC. It has been demonstrated that brain oxygen saturation may be monitored in flight [7] during AGSM (Anti-G Straining Manoeuvre) training [2,6,17] and that the drop in oxygen saturation precedes loss of consciousness. However, the drop in blood oxygenation preceded G-LOC by only a few seconds [17].

Near-infrared spectroscopy (NIRS) has been used for clinical monitoring of cerebral function and oxidative metabolism [20] https://www.sciencedirect.com/science/article/pii/S1350453304001213?via%3Dihub - BIB20. There are a variety of substances in human tissue whose absorption spectra at near-infrared (NIR) wavelengths are well defined. Compounds such as oxygenated haemoglobin (HbO2) and deoxyhaemoglobin (Hb) have concentrations in tissue which are strongly linked to tissue oxygenation and metabolism. The changes in the concentration of Hb and HbO2 can be used to calculate parameters such as cerebral blood flow and cerebral blood volume [21].

Here, we report a case of A-LOC (recorded on camera) that occurred during a task on Dynamic Flight Simulation (DFS). We retrospectively reviewed the recorded physiological signals that were measured in the experiment.

MATERIAL AND METHODS

This paper is a retrospective case study of one participant (26 years old, little flight experience) who took part in an experiment evaluating blood shifts in response to hypergravity [8,9]. The subject held a current fitness to fly certificate issued by the Aeromedical Board (i.e., he was declared healthy). The study protocol was approved in advance by the Bioethical Committee of the Military Institute of Aviation Medicine in Warsaw (Decision No. 04/2014). Like other participants, he provided a written informed consent before participating.

Of the available measures, we recorded the ECG, the heart rate, and Gz value to monitor blood

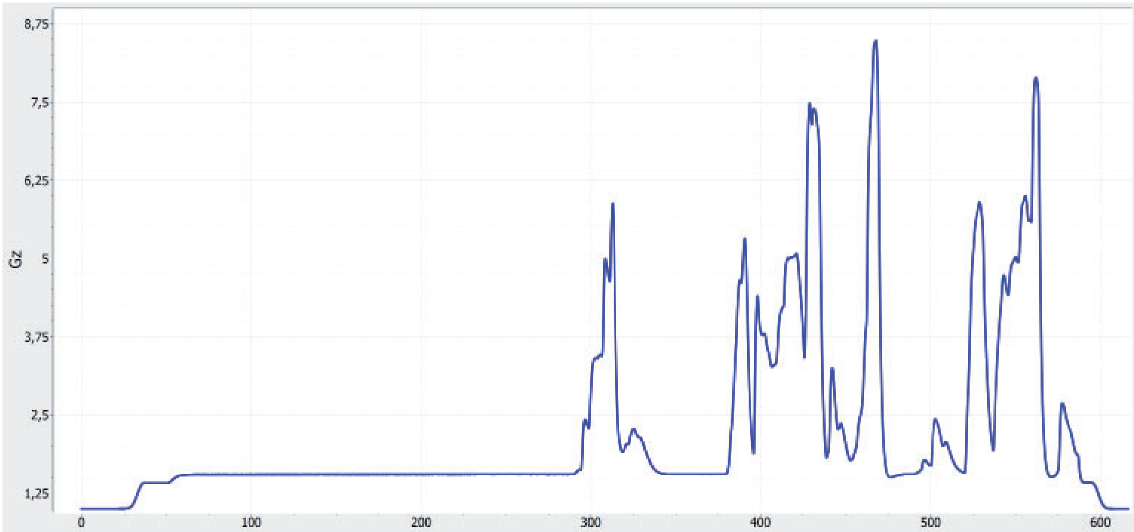

Fig.1. DSF +Gz profile (Dynamic Flight Simulation). Initially, the pilot flew without performing manoeuvres. In the figure, the pilot was flying in a straight line for 300s (Gz=1.4G) before the first manoeuvre and then performed commands from the instructor for the another 300s (Gz up to +9Gz).

mass-volume movements in military pilots while under sustained accelerations in Gz axis; the signals derived from bioimpedance were measured using electrical bioimpedance (ICG).

A 3-channel experimental module ReoWir (ITAM, Zabrze, Poland) was used to measure electrical bioimpedance simultaneously in the thorax and in the neck. The ReoWir module meets the safety requirements of European standard EN 60601-1 for medical equipment [9]. The metrological parameters of the module were verified by using a dedicated simulator of resistive parameters of the tissues – ReoTester [8,14]. The bioimpedance signal from the thorax is collected using a standard electrode arrangement, as in the Kubicek method [5], but the location of the electrodes on the head is an original arrangement.

The mean blood oxygenation of the frontal brain lobe (OX) was measured using near-infrared spectroscopy (NIRS; NellcorTM Pulse Oximetry, Covidien-Medtronic, Dublin, Ireland). OX was averaged in 4s intervals. The optoelectronic detector (optode) was attached to the right side of the pilot's forehead. Both NIRS and ReoWir were connected to the data system of the centrifuge, thus OX and bioimpedance signals were recorded synchronously with the ECG, the heart rate, Gz, and saved in the centrifuge's system. Then, all data were anonymised and exported for further processing on external computers. A human centrifuge HTC07 (AMST, Braunau, Austria) was used to simulate the Gz acceleration. It was previously studied and described in detail [9]. ECG and bioimpedance leads were connected, and the NIRS optode was attached to the forehead. Although the pilot, like the other participants of the study, was not dressed in anti-G trousers which are normally used in high +Gz to handle the heavy loads better, the Gz acceleration was limited to +9G.

Exposure profile

Dynamic Flight Simulation (DFS) was used, meaning that the flight profiles were not predefined and each pilot was free to apply as much acceleration as he/she felt proper for carrying out the task ordered by the instructor. The profile of the overloads generated by the pilot are shown in figure 1. During this flight, the pilots were additionally equipped with a portable eye tracker to objectively assess potential use for detecting impaired vision due to overload. The maximum overload in this profile was +9Gz and the maximum overload increase rate was +6Gz/s. The pilot, like the other participants of this study, was asked to provide feedback on possible blackouts, darkening/narrowing of the field of view during the acceleration. Regardless, this A-LOC was unreported.

RESULTS

Observation of physiological changes associated with A-LOC.

Note the decrease in the amplitude of the derivative neck signal before A-LOC (red stars, fourth line), and the decrease of cardiac rhythm after unconsciousness (green stars, first line). The HR decrease was most probably the result of the cessation of +Gz after the A-LOC episode (the centrifuge was stopped manually by the doctor

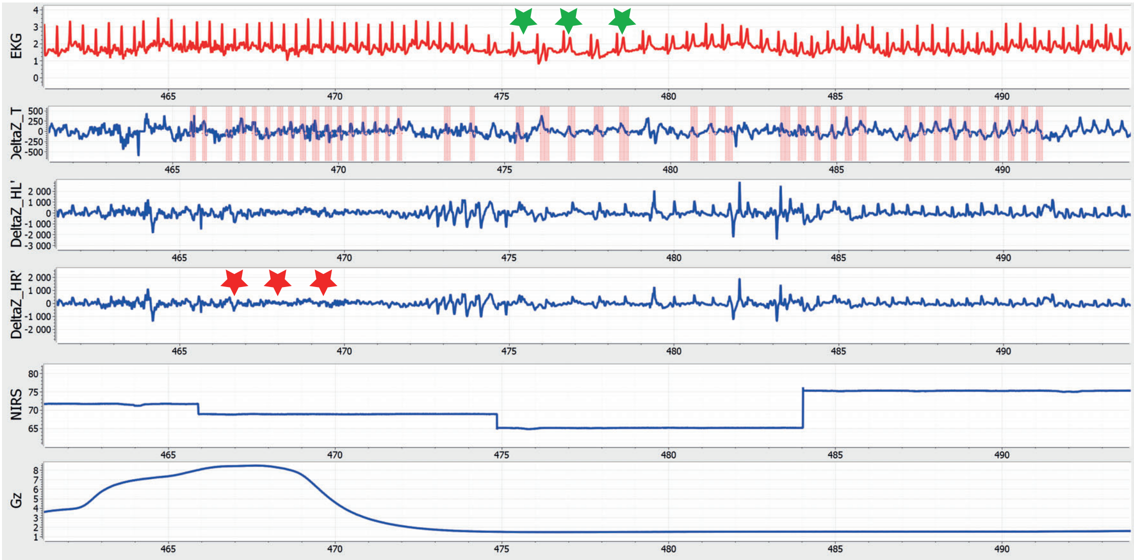

Fig. 2. Changes in the physiological parameters involved in A-LOC due to +Gz. NIRS signal is averaged over 4 seconds – it is the reason for the apparent delay.

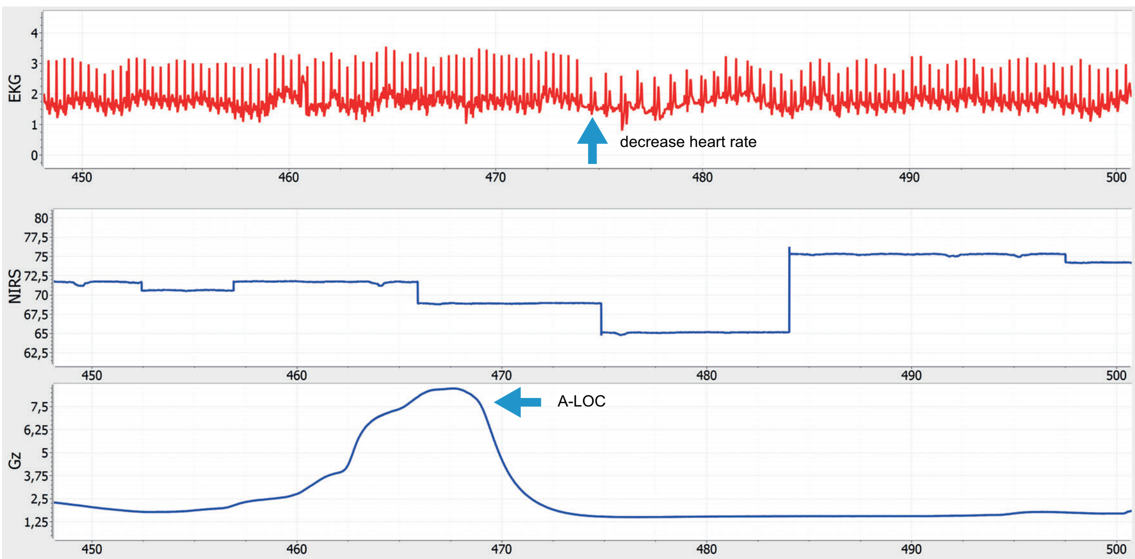

Fig. 3. Changes in the heart rate associated with A-LOC caused by high acceleration (first line). Note that the our NIRS system averages signals over 4s seconds, therefore, the NIRS measurements appear delayed in relation to the acceleration.

controlling the exposition). The loss of frontal lobe oxygenation (fifth line) occurs with a delay of four seconds due to the very large time constant of the NIRS system. This was due to the construction of NIRS apparatus used. During A-LOC, the pilot shut his eyes.

The fixed components of thorax resistance (second line) and neck resistance (third line) do not show changes during A-LOC. Artefacts from the bioimpedance signal did not identify significant changes. The pilot did not report a blackout or loss of peripheral vision, however, the recording from the eye-tracker and the recording of simulated flight parameters explicitly suggest that he was not in control of the aircraft at that time.

DISCUSSION

Several complementary methods such as an ECG, impedance cardiography, and NIRS have been used to observe A-LOC. The event was characterized by the decrease of heart rate after loss of control of the aircraft and reduced oxygenation in the brain frontal lobe measured by NIRS. A decrease in the derived amount of the bioimpedance signal variable component preceding loss of consciousness was also noted; however, the signal was of poor quality due to muscle contractions accompanying AGSM.

Taking into consideration all the recorded parameters, the NIRS signal looks most promising be-

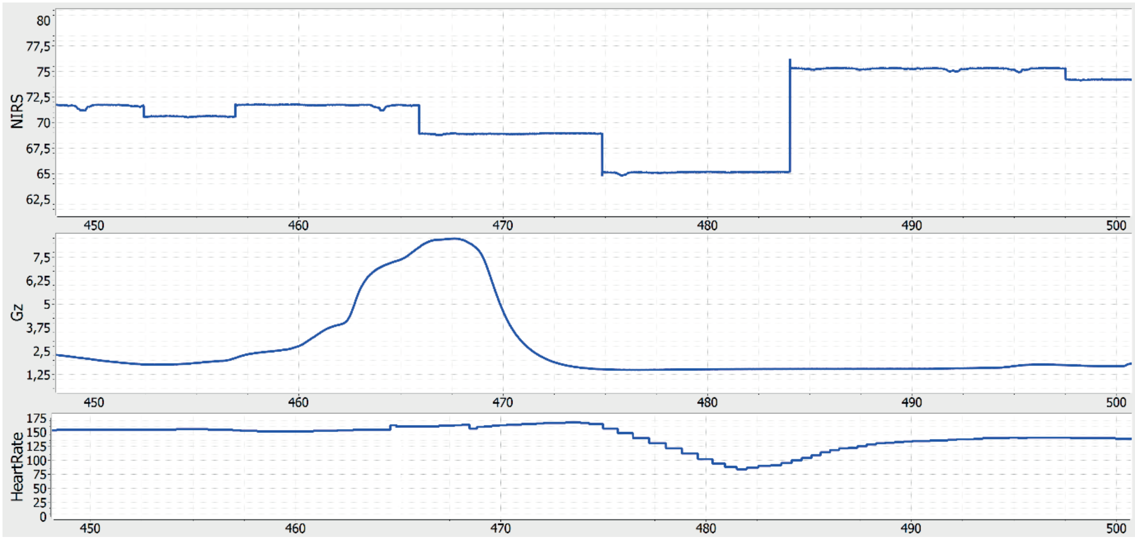

Fig. 4. Case of low oxygen saturation in the frontal brain lobe (NIRS; first line) related to the lower heart rate (third line) due to acceleration.

cause other registered signals did not change significantly or changed after the A-LOC episode, thus being unusable for prevention but rather confirmation of the situation. Further systematic studies are needed if we want an automated warning system of incoming G-LOC or a prevention system.

CONCLUSION

NIRS methods with short acquisition time might be helpful in predicting incoming A-LOC and G-LOC, therefore, giving the pilot some time to adjust the flight profile or switch to the automatic aircraft recovery system. Further research should be performed with short integration time of NIRS.

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AUTHORS' DECLARATION:

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REFERENCES

1. Alvim KM. Greyout, Blackout, and G-Loss of Consciousness in the Brazilian Air Force a 1991-92 Survey. Aviat Space Environ Med. 1995; 66(7):675-7.
2. Caiozzo VJ, Rose-Gottron C, Baldwin KM, Cooper D, Adams G, Hicks J, et al. Hemodynamic and Metabolic Responses to Hypergravity on a Human-Powered Centrifuge. Aviat Space Environ Med. 2004; 75(2):101-8.
3. Cao XS, Wang YC, Xu L, Yang CB, Wang B, Geng J, et al. Visual Symptoms and G-Induced Loss of Consciousness in 594 Chinese Air Force Aircrew-a Questionnaire Survey. Mil Med. 2012; 177(2):163-8.

4. Green NDC, Ford SA. G-Induced Loss of Consciousness: Retrospective Survey Results from 2259 Military Aircrew. Aviat Space Environ Med. 2006; 77(6):619-23.

5. Gujjar AR, Muralidhar K, Bhandopadhyaya A, Sathyaprabha TN, Janaki P, Mahalla BK, et al. Transthoracic Electrical Bioimpedence Cardiac Output: Comparison with Multigated Equillibrium Radionuclide Cardiography. J Clin Monit Comput. 2010 ; 24(2):155-9.

6. Kobayashi A, Kikukawa A, Kimura M, Inui T, Miyamoto Y. Cerebral near-Infrared Spectroscopy to Evaluate Anti-G Straining Maneuvers in Centrifuge Training. Aviat Space Environ Med. 2012; 83(8):790-4.

7. Kobayashi A, Tong A, Kikukawa A. Pilot Cerebral Oxygen Status During Air-to-Air Combat Maneuvering. Aviat Space Environ Med. 2002; 73(9):919-24.

8. Kowalczuk K, Puchalska L, Palonek H, Sobotnicki A, Janewicz M, Wyleżoł M, et al. Hemodynamic Parameters and Brain Oxygenation in Military Pilots as a Function of Acceleration's Duration at 4g and at 6g: A Preliminary Study. The Polish Journal of Aviation Medicine, Bioegineering and Psychology. 2017; 23(1):22-8.

9. Kowalczuk K, Puchalska L, Sobotnicki A, Czerw M, Janewicz M, Wylezol M, et al. Effects of Gradual Onset +Gz on Hemodynamic Parameters and Brain Oxygenation in Military Pilots: Preliminary Study. The Polish Journal of Aviation Medicine, Bioengineering and Psychology. 2016; 22(3):5-11.

10. Lin PC, Wang JH, Li SC. Subjective Stress Factors in Centrifuge Training for Military Aircrews. Appl Ergon. 2012; 43(4):658-63.

11. Lyons TJ, Harding R, Freeman J, Oakley C. G-Induced Loss of Consciousness Accidents - Usaf Experience 1982-1990. Aviat Space Environ Med. 1992; 63(1):60-6.

12. Metzler MM. G-Loc Due to the Push-Pull Effect in a Fatal F-16 Mishap. Aerospace Medicine and Human Performance. 2020; 91(1):51-5.

13. Morrissette KL, McGowan DG. Further Support for the Concept of a G-Loc Syndrome: A Survey of Military High-Performance Aviate. Aviat Space Environ Med. 2000; 71(5):496-500.

14. Piekar E, Sobotnicki A. The Simulator of Resistive Parameters of the Tissues for Bioimpedance Research. Measurement Automation and Monitoring. 2014; 60:1181-4.

15. Prior A. Questionnaire Survey to Investigate the Incidence of G Induced Loss of Consciousness in the Royal Air Force. London: Ministry of Defence, RAF Institute of Aviation Medicine1987 Contract No.: Report No: 650.

16. Rickards CA, Newman DG. G-Induced Visual and Cognitive Disturbances in a Survey of 65 Operational Fighter Pilots. Aviat Space Environ Med. 2005; 76(5):496-500.

17. Ryoo HC, Sun HH, Shender BS, Hrebien L. Consciousness Monitoring Using near-Infrared Spectroscopy (Nirs) During High Plus Gz Exposures. Med Eng Phys. 2004; 26(9):745-53.

18. Shender BS, Forster EM, Hrebien L, Ryoo HC, Cammarota JP. Acceleration-Induced near-Loss of Consciousness: The "a-Loc" Syndrome. Aviat Space Environ Med. 2003; 74(10):1021-8.

19. Slungaard E, McLeod J, Green NDC, Kiran A, Newham DJ, Harridge SDR. Incidence of G-Induced Loss of Consciousness and Almost Loss of Consciousness in the Royal Air Force. Aerospace Medicine and Human Performance. 2017; 88(6):550-5.

20. Tamura M, Tamura T. Noninvasive Monitoring of Brain Oxygen Sufficiency on Cardiopulmonary Bypass Patients by near-Infra--Red Laser Spectrophotometry. Med Biol Eng Comput. 1994; 32(4):S151-S6.

21. Ueno T, Yoshimoto S. Noninvasive and Continuous Estimation of Cerebral Blood Flow and Volume Using near Infrared Spectrophotometer. Chance B, Alfano RR, editors 1997.

22. Whinnery JE. Observations on the Neurophysiologic Theory of Acceleration (+Gz) Induced Loss of Consciousness. Aviat Space Environ Med. 1989; 60(6):589-93.

23. Whinnery JE. Theoretical-Analysis of Acceleration-Induced Central-Nervous-System Ischemia. IEEE Eng Med Biol Mag. 1991; 10(1):41-5.

24. Whinnery JE, Whinnery AM. Acceleration-Induced Loss of Consciousness - a Review of 500 Episodes. Arch Neurol. 1990; 47(7):764-76.

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