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ORIGINAL ARTICLE

EFFECTS OF GRADUAL ONSET +GZ ON HEMODYNAMIC PARAMETERS AND BRAIN OXYGENATION IN MILITARY PILOTS: PRELIMINARY STUDY

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Introduction: Sustained acceleration in +Gz axis may lead to blood mass-volume displacement. Currently, during centrifuge training, this displacement is not assessed directly, but the focus is on its functional correlates, such as the narrowing of the visual field and a decrease in blood oxygenation in the pilot's brain. These are very crude measures that say little about the physiological processes taking place in the pilot's body. Thus, the aim was to evaluate more detailed measures of the cardiovascular system: stroke volume (SV) and cardiac output (CO) and their changes with gradual onset +Gz, as well as changes in frontal brain oxygenation (OX) in relation to Gz, SV, and CO.

Methods: Eight military pilots (six active with different amounts of flight experience) performed the gradual onset rate profile of Gz, Delta Gz = 0.1G/s, till 6G. Their SV, CO were evaluated with bioimpedance cardiography, while their OX with near infrared spectroscopy. ECG was constantly monitored.

Results: Increase in Gz led to linear decreases in SV, while CO remained statistically unchanged; however, in most cases, OX decreased linearly with increasing Gz.

Discussion: Linear increase in +Gz load on human centrifuge results in decreases in cardiac output. Increased heart rate compensates for changes in stroke volume. Nonetheless, brain oxygenation decreases with Gz, likely due to decreased lung gas exchange capacity in hypergravity. Thus, measuring blood oxygenation at the level of the brain may be a better method of monitoring pilots during centrifuge training than bioimpedance cardiography.

Keywords: hemodynamics, cardiac output, stroke volume, head-foot acceleration, +Gz, monitoring, bioimpedance cardiography

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INTRODUCTION

Assessment of compensational reflexes during training in high-sustained G is of great diagnostic importance. Currently, ECG (and ECG-derived heart rate), blood saturation and blood pulsation at the earlobe, as well as the narrowing field of vision are used to assess the blood mass-volume displacement under acceleration in +Gz axis (head-foot direction). 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 (G –force induced loss of consciousness). It has been demonstrated that brain oxygen saturation may be monitored in flight [9] during AGSM (Anti-G straining Manoeuvre) training [4,8,19] 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 [19].

Impedance cardiography (ICG) is a noninvasive technology measuring total electrical conductivity of the thorax and its changes in time to process continuously a number of cardiodynamic parameters, such as Stroke Volume, SV, Heart Rate, HR, Cardiac Output, CO, Ventricular Ejection Time (VET), etc. It is used to detect the impedance changes caused by a high-frequency, low-value current flowing through the thorax or another organ such as the neck or limb. ICG is also known as electrical impedance plethysmography (EIP) or Thoracic Electrical Bioimpedance (TEB).

ICG was extensively validated against other established methods. Electrical bioimpedance methods were often used to monitor cardiac output (CO) and stroke volume (SV) [14] and were validated against other methods , such as Doppler ultrasound (Echo Doppler) [2,5,21], multigated radionuclide cardiography [6]. Additionally, in animal models, ICG was validated against thermodilution and Doppler ultrasound across a wide range of blood flow parameters [5], as well as against stroke volumes obtained with dye dilution and electromagnetic flowmeters in dogs [15]. Finally, ICG methods were used to demonstrate vascular vasoconstriction in humans during exercise [12]. In humans, electrical bioimpedance methods were used to non-invasively and simultaneously measure cardiac and peripheral (limb) blood flow [21].

Given the proven reliability of the ICG method, we evaluated its potential use to monitor blood mass-volume movements in military pilots while under sustained accelerations in Gz axis. Here, we focus on the Gradual Onset Rate (GOR) profile that is generally used in aviation medicine diagnostics.

METHODS

Subjects

Eight male military pilots (age: 34.8±8.2 years; 24-47 years; five in active duty; two working mostly in the office, and one retired, currently piloting civilian aircraft), with different amounts of flight experience, participated in the study. All subjects had current fitness to fly certificates issued by the Aeromedical Board (i.e. they were healthy). They all had normal or corrected-to-normal vision. The study protocol was approved in advance by the Bioethical Committee of the Military Institute of Aviation Medicine in Warsaw. Each subject provided written informed consent before participating and they were paid for taking part in the experiment.

Equipment

A human centrifuge HTC07 (AMST, Braunau, Austria) was used to produce Gz. It is a flight simulator giving opportunities for using it in operational, training and diagnostic profiles. It permits intensive pilot training providing enhanced performance of anti-G maneuvers and familiarization of aircrews with the effects of high accelerations and push-pull phenomena. Moreover, the centrifuge provides a safe alternative to raise awareness of aircrews in the case of occurrences of unwanted effects of accelerations, such as G-LOC loss of consciousness or spatial disorientation. The gondola of the centrifuge is assembled on an 8-meter-long arm and allows to achieve Z-axis accelerations in the range from –3Gz to +16Gz with the maximal onset of accelerations over 14.5 G/s. Additionally, gyroscopic suspension of the gondola allows to achieve X-axis and Y-axis accelerations respectively in the range of the values ± 10G and ± 6G. Interchangeable parts of the centrifuge gondola facilitate functional projection cockpit equipment of the Polish Air Forces basic multi-purpose aircraft i.e. F-16 Block 52+ and MiG-29. The centrifuge is equipped with multiple devices to monitor the physiological effects elicited by the accelerations on the pilot. Of the available measures, we recorded ECG, heart rate, and Gz value. Mean blood oxygenation (both oxygenated and de-oxygenated blood) of the frontal lobe of the brain (OX) was measured using near infrared spectroscopy (NIRS; NelcorTM Pulse Oximetry, Covidien-Medtronic, Dublin, Ireland). OX was averaged in 4s intervals. The optode was attached to the forehead of the pilot.

Stroke volume (SV) and cardiac output (CO) were measured using electrical bioimpedance. A 3-channel experimental module ReoWir (ITAM, Zabrze, Poland) was used to measure electrical bioimpedance simultaneously in the thorax and in the neck. The module allows to register the signal component of variable impedance ΔZ or its first derivative dZ/dt and measure the base impedance Z0 in three channels. The measurement of electrical impedance is implemented using the constant current tetrapolar method. A high frequency (40 kHz) of the current of a small constant amplitude (1 mA_{RMS}) flowing through the body results in a voltage drop across the impedance of the tissues. This voltage signal is amplified, demodulated, and digitized with 24-bit resolution. The firmware implements the separation of base impedance Z0 from the variables component ΔZ.

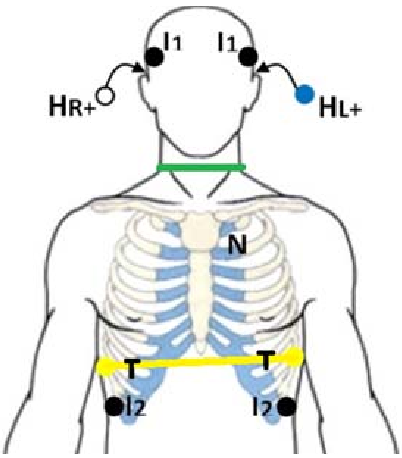

Fig. 1. Location of electrodes: Current electrodes: I1 placed on temples (gel electrodes), I2 placed on the thorax (spring electrode), receiver electrodes Hl+ and HR+ - behind the ears (gel electrode), N placed on the bottom of the neck (spring electrode).

ReoWir module meets the safety requirements of European standard EN 60601-1 for medical equipment confirmed by a report from an accredited laboratory. Metrological parameters of the module were verified by using a dedicated simulator of resistive parameters of the tissues – Reo-Tester [16].

The location of electrodes on the pilot is depicted in Fig. 1. Bioimpedance signal from the thorax is collected using a standard electrode arrangement, as in the Kubicek method [6], but the location of the electrodes on the head is an original arrangement. Both NIRS and ReoWir were connected to the system of the centrifuge, thus OX and bioimpedance signals were recorded synchronously with ECG, heart rate, Gz and saved in the centrifuge's system. Then, all data were anonymized and exported for further processing on external computers.

Procedure

The subjects were briefed on the study and its aims. Then ECG and bioimpedance leads were connected, and the NIRS optode was attached to the forehead. The Gradual Onset Rate (GOR) profile was selected, as it is the most common profile used in aviation medicine diagnostics. It is characterized by a linear increase in Gz at 0.1G/s rate, until 6G is reached. Then the centrifuge is decelerated at - 0.5G/s (see Fig. 2)

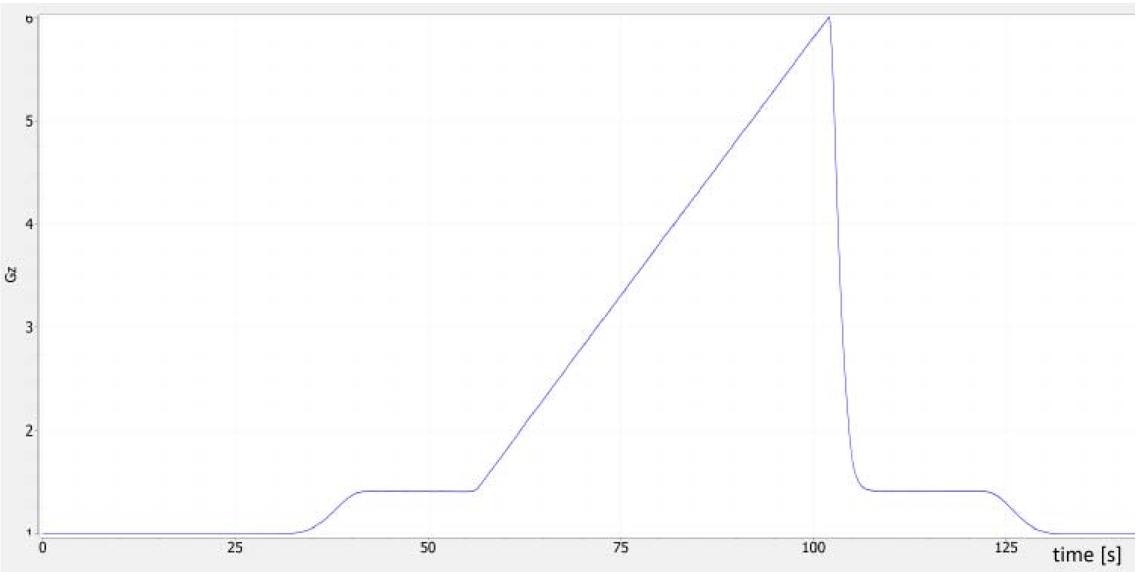

Fig. 2. Gz acceleration as a function of time in the GOR profile. After initial centrifuge startup procedure (increase up to 1.4Gz), Gz increased linearly with time, until +6Gz was reached.

Calculation of stroke volume

Stroke volume (SV) of the heart was calculated based on the Kubicek formula [20],

$$SV = \text{constant}\left(\frac{1}{Z_0}\right)^2\left[LVET\left(\frac{d_z}{d_t}\right)_{\max}\right]$$

where Z_0 is the base impedance measured directly during the experiment. Z_0 values measured at the beginning of LVET were taken for calculations. Left-ventricular ejection time (LVET) and (dZ/dt) max were traced manually by two independent raters, trained and supervised by LP, who has extensive expertise in bioimpedance methods. The method is depicted in Fig.3. In short, onsets and ends of the ejection phase were marked manually by the raters, thus the left ventricle ejection times (LVET) were established. Within these intervals, respective maxima and minima were automatically detected by our purpose-written software, thus (dZ/dt)max were established. Identified artifacts were excluded from analyses. SV and CO were calculated.

For the neck, only (dZ/dt)max was marked; it can be interpreted as the flow index in the carotid arteries [7,22].

Statistical Analysis

Percentage changes of all measures of interest were scaled by means of average respective values at 1G. The normality of distributions was evaluated automatically with appropriate tests. Linear regressions were used to evaluate relationships between normalized values of SV, CO, brain blood oxygenation, heart rate, and Gz, for individual pilots. We acknowledge that the bioimpedance signals were affected by artifacts created by the subject's breathing; however, these artifacts were statistically 'averaged out' by the regression procedure, similarly to signal averaging applied in commercially available equipment. Additionally, relationships between normalized values of SV, CO and blood oxygenation were evaluated using linear regression. All tests were performed using Statistica 13.1 software (Dell, Round Rock, TX, USA).

RESULTS

Analyses of individual data demonstrated nonlinearity in the relationships between NIRS, heart rate, and Gz.

For thorax, the base impedances, compared to respective impedances at 1G, were lower of the order of 0.4±0.5Ω at low accelerations (range 0 ÷ -1.8Ω), while they generally increased on average by 0.35±0.64Ω at higher accelerations (range -0.8 ÷ +1.2 Ω), likely reflecting blood mass displacements out of the thorax due to hypergravity (AGSM; anti-gravity straining manoeuvres). However, for the neck and compared to respective impedances at 1G, the impedances increased on average by 0.64±0.69Ω and 0.47±0.90Ω for low and high G-loads, respectively. The respective ranges were (-0.41 ÷ -2.04Ω) and (-1.22 ÷ +1.63Ω).

The slopes in linear regressions of the individual relationships between SV and Gz were generally significantly negative, attesting that SV decreases with increasing Gz. Fig. 4 depicts exemplary data. CO demonstrated a different relationship: in the

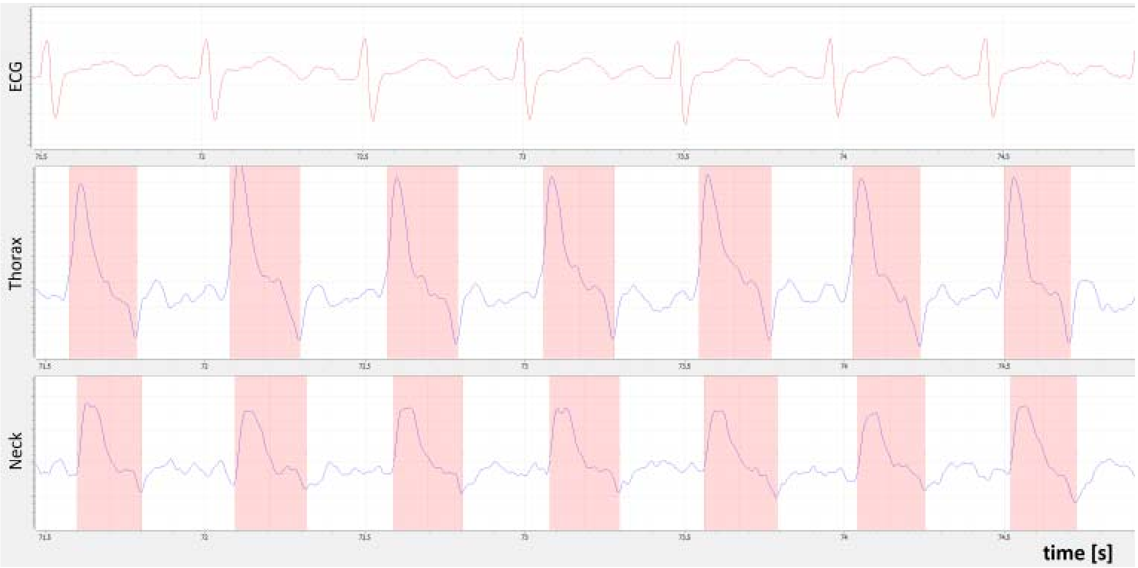

Fig. 3. ECG signal and derivatives of thorax and neck bioimpedance signals. The red areas depict the left ventricle ejection time (LVET).

majority of pilots, an initial increase in CO was observed, which was followed by a decrease in CO at higher Gz accelerations. However, in two participants, the CO decreased linearly with Gz, and in another two it increased. Nonetheless, OX generally linearly decreased with increasing Gz load, as exemplified in Fig. 5.

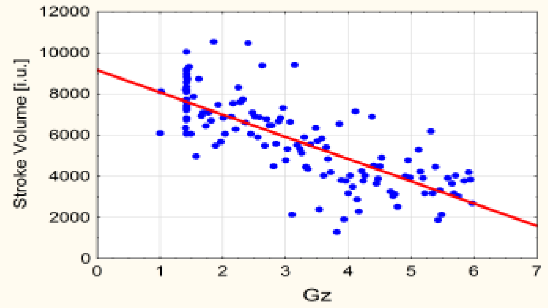

Fig. 4. Changes in stroke volume (SV) as a function of Gz (aggregated data from all pilots).

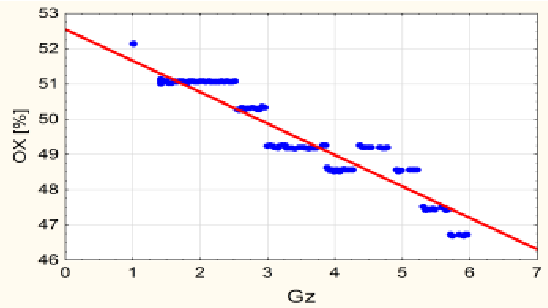

Fig. 5. Brain blood oxygenation at prefrontal lobe as a function of Gz (representative figure).

We did not find any significant correlations between flow index in the carotid arteries and Gz, SV, or CO. OX was generally significantly related to CV (mean slope: +0.024±0.029) but not to CO (mean slope: +0.003±0.029).

DISCUSSION

In this study, we demonstrated that linear increase in +Gz acceleration led to linear decreases in stroke volume. These changes were compensated by increased heart rate, which resulted in unchanged cardiac output in the range up to 6G. However, larger G loads resulted in statistically significant decreases of brain frontal lobe oxygenation, most likely due to the redistribution of the blood in the thorax; i.e. less blood ended up in the brain due to the larger gravitational field in the centrifuge. An additional Gz effect that must be taken into consideration is air-blood mismatch in lungs under Gz [3,11,24].

All examined pilots were neither instructed to perform or withdraw from performing AGSM. However, they performed a muscular component of AGSM without breathing component. The breathing component of AGSM relies on the intermittent increase of airway pressure which can at least partially alleviate Gz effects in the lungs. Surprisingly, brain oxygenation was more strongly related to cardiac volume than to cardiac output.

Our results are not in line with a previous study by Rohdin et al. [17], who reported 30-40% smaller CO in healthy volunteers at 5G, compared with 1G. We invited military pilots, who are a selected population and trained to resist the effects of hypergravity. They perform muscular tensioning under Gz as a habit emerging from flight experience. Thus, the differences in the results likely reflect the two different cohorts participating in both studies. This conclusion is further supported by several studies [1,13,23], which did not find significant changes in CA of young participants at +Gz below 2G. However, they reported decreases in SV at those accelerations, which is consistent with our results.

Rohdin et al. [17] also demonstrated decreased lung diffusion capacity in hypergravity. On the other hand, increases in base impedance of the neck with increasing Gz, could be interpreted as a decrease of the blood volume in the neck. However, cranium acts as a rigid container of the brain, cerebro-spinal fluid, and blood, which are virtually incompressible [18], thus the amount of blood in the brain is likely constant during +Gz accelerations used in our study. Moreover, cerebral autoregulation maintains relatively constant cerebral blood flow within the range of arterial blood pressure from about 60 to 150 mmHg [10,18]. In our experience, arterial blood pressure may decrease below 60 mmHg at +6G, thus smaller cerebral blood flow may contribute to decreases of OX with increasing +Gz.

The above-mentioned phenomena could be responsible for decreases in OX in our pilots, despite no apparent changes in cardiac output. Given our relationship between brain oxygenation and stroke volume, but not cardiac output, we believe that further research into lung gas exchange capacity in hypergravity is warranted.

We did not evaluate changes in arterial pressure and its relationship to the measured parameters. As it is known that Z0 increases with bleeding induced hypotension in pigs [25], it is likely that changes in blood pressure would explain some variance in SV, CO, and OX.

Our results may help understand physiological adaptations to hypergravity in commercial space flights. Although the G loads in these voyages are not expected to surpass 4G, one should remember that military pilots are selected based on endurance and fitness. Thus, the physiological processes described in our study may take place at much lower accelerations in the general population. The non-zero resistance of the current electrodes applied in our study lead to some limitations in the results, as it caused a slight overestimation of baseline impedances, but, it resulted in slight underestimation of the reported changes in SV and CO. Similarly, the breathing artifacts had detrimental effects on fitting quality; however, it is unlikely it biased the regression results.

The conclusions are limited by the fact that the pilots performed straining at various times of the training; some of them at the very beginning of the profile, once stopping at higher Gz accelerations. These maneuvers could have caused variability in the measured relationship between stroke volume, cardiac output, and Gz. Nonetheless, brain oxygenation decreased in all pilots with increasing Gz.

CONCLUSIONS

In conclusion, a linear increase in G load on human centrifuge results in decreases in stroke volume. Increased heart rate compensates for changes in cardiac output, although there are limitations to this mechanism. Nonetheless, brain oxygenation decreases with Gz, possibly due to decreased lung diffusion capacity in hypergravity. Thus, measuring blood oxygenation at the level of the brain may be a better method of monitoring pilots during centrifuge training than bioimpedance cardiography.

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AUTHORS' DECLARATION:

Study Design: Krzysztof Kowalczuk, Liana Puchalska, Michał Janewicz, Stefan P. Gaździński; **Data Collection:** Krzysztof Kowalczuk, Liana Puchalska, Aleksander Sobotnicki, Marek Czerw, Michał Janewicz, Stefan P. Gaździński; **Manuscript Preparation:** Krzysztof Kowalczuk, Aleksander Sobotnicki, Mariusz Wyleżoł, Stefan P. Gaździński; **Funds Collection:** Mariusz Wyleżoł. The Authors declare that there is no conflict of interest.

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ASSESSMENT OF KNOWLEDGE ABOUT THE ENERGY VALUE OF SELECTED MEALS BY THE HELICOPTER EMERGENCY MEDICAL SERVICE (HEMS) TEAM

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Introduction: Introduction: An appropriate level of nutrition knowledge resulting in proper eating is one of the components of health behaviours. The profession of both paramedics and pilots should involve taking greater care of one's health. The aim of this study was to assess the Polish Medical Air Rescue paramedics and pilots' nutrition knowledge with respect to the energy value of selected meals present in the daily diet.

Methods: The assessment of the energy value of selected foods was carried out among all Polish Helicopter Emergency Medical Service (HEMS) pilots and paramedics (66 pilots, 65 paramedics) aged 27-59. Their nutritional status was assessed based on the results of anthropometric tests. The HEMS team's knowledge about the energy value of selected foods was assessed based on the author's photographs of meals. The meals energy value was calculated using the applicable Polish tables of foods' nutritional value and content.

Results: The assessed group was characterized by a high share of overweight and obese persons. According to BMI, 34.6% of the tested persons had normal range body mass, 44.9% were overweight, and 20.5% were obese. An analysis of the respondents' answers showed that on average they overestimated energy value of six out of the seven presented meals. The overestimation concerned mainly the energy value of supper (over 215 kcal) and snack I (over 283 kcal). Those were meals including fast food, sweets and stimulants.

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Conclusions: The HEMS team's knowledge about the energy value of meals was unsatisfactory. The level of nutrition knowledge was independent of a person's profession, education, sex, and BMI. Nutrition education and healthy lifestyle programs should be implemented in the examined group.

Keywords: knowledge about energy value, Polish Medical Air Rescue, overweight, obesity

INTRODUCTION

An appropriate level of knowledge about nutrition, and the resulting proper diet is one of the components in health-promoting behaviors [9,17]. The profession of both paramedics and pilots should involve taking greater care of one's health. Both occupations require high mental and physical fitness in order to be able to act efficiently in stressful conditions. The fitness depends on numerous factors, one being proper nutrition. A well-balanced diet ensures wellness, facilitates recovery processes, provides protection against illnesses and improves the performance of the organism [4,5,16]. A condition of a well-balanced diet, apart from a proper supply of nutrients is a proper supply of calories. In order to maintain the body's energy balance, the quantity of the energy supplied to the organism must be equal to the spent energy [6]. Illnesses related to disorders of energy balance are a serious health problem. More than 1 billion adults and 100 million children in the world suffer from obesity or overweight [2]. Limiting calorie intake in the daily food ration, and thus generating a negative body's energy balance, is one of the crucial components of body weight reduction. Persons with excessive body weight are particularly encouraged to pay attention to the energy value of individual products and meals as well as to estimate the daily calorie intake [3]. Therefore, increasing the level of knowledge about nutrition is an important tool for stimulating proper eating behaviors, which prevent overweight and obesity [7]. However, as numerous studies prove, knowledge about nutrition does not always translate into eating habits and behaviors [17,5,15]. For instance, despite high social awareness and introduction of a variety of nutrition programs in Great Britain, its obesity rates continue to grow [10].

It is assumed in the study below that HEMS paramedics and pilots should be characterized by a high level of knowledge about nutrition due to their profession.

The aim of this study is to assess the Polish Medical Air Rescue paramedics and pilots' knowledge about nutrition with respect to the energy value of selected meals present in the daily diet.

MATERIAL AND METHODS

The assessment of the energy value of the selected meals was carried out among all Polish Helicopter Emergency Medical Service (HEMS) pilots and paramedics (66 pilots, 65 paramedics) at the age of 27-59. The majority of the respondents were men, while women constituted 3.8% (they were present only among paramedics).

Their nutritional status was assessed based on the results of anthropometric tests. Height and body weight were measured, which was the ground for calculating the height- and weight-based Body Mass Index (BMI), which was then interpreted according to the WHO classification [21].

The HEMS team's knowledge about the energy value of the selected meals was assessed based on the authors' photographs of meals: breakfast, lunch, dinner, high tea, supper and two snacks. The composition and energy value of the presented meals are included in Tab. 2.

The energy value of the meals was calculated based on the applicable Polish food composition and nutrition tables [8]. In order to analyze the results more precisely, the answers obtained from the HEMS team were divided into three categories: answer within the standard, answer below the standard and answer above the standard. An answer within the standard was considered one constituting ± 10% of the correct value. Answers below the standard were below this range, while answers above the standard were above this range. Four questionnaires were not subject to statistical analysis due to incomplete answers.

The STATISTICA 10.0 PL program was used for statistical analyses; the value of the statistical significance was assumed at the level of $p<0.05$. Average values, standard deviation, median, minimum and maximum values were calculated. Normal distribution was examined using the Shapiro-Wilk test, while the U Mann-Whitney and Kruskal-Wallis non-parametric tests were applied for comparing the energy value of meals depending on the profession, education, and BMI. Relations between the analysis of answers by categories (a correct answer, an answer below the standard and above the standard) and the above variables were checked with the chi-square test.

Tab. 1. Description of the examined group.

Variable		Results	
Age [in years]	X ± SD	42.8 ± 9.6	
	(min – max)	27.0 – 59.0	
Body weight [in kg]	X ± SD	86.2 ± 14.7	
	(min – max)	59.9 – 140.1	
Height [in cm]	X ± SD	178.1 ± 5.8	
	(min – max)	164.0 – 195.0	
BMI	X ± SD	27.1 ± 4.2	
	(min – max)	19.7 – 42.9	
Sex:	(%); n		
women		3.14	4
men		96.85	123
Profession:	(%); n		
pilot		53.5	68
paramedic		46.5	59
Education:	(%); n		
higher		70.9	90
secondary		29.1	37
Place of residence:	(%); n		
town/city		81.9	104
village		18.1	23

X – average value; SD – standard deviation; % – percentage of respondents; n – number of respondents

RESULTS

The examined population was composed of 127 employees of the Helicopter Emergency Medical Service, 53.5% of whom were pilots and 46.5% were paramedics. The group under assessment was characterized by a high share of overweight and obese persons. BMI was proper in the case of only 34.6% of the tested persons, while 44.9% of them were overweight, and 20.5% were obese. Overweight and obesity were more common among pilots (60.2%) than among paramedics (38.5%). The majority of the respondents had higher education and came from towns/cities. A detailed description of the group in terms of somatic and demographic characteristics is presented in Tab. 1.

In analyzing the average values of the answers provided by the respondents when estimating the energy value of meals, it was found that they overestimated the energy value of six out of the seven presented sets (Tab. 2). The average answer below the correct value was provided only in the case of lunch. The respondents' most significant overestimations concerned the average energy value of supper (by over 215 kcal) and snack I (by over 283 kcal), that is meals consisting of fast food, sweets and stimulants. The respondents estimated the energy value of breakfast with the highest accuracy. The ranges presented in Tab. 2. (min - max) prove, however, a considerable diversity of the answers given by the respondents.

Tab. 2. Assessment of the calorific value of individual meals.

Presented meals	Correct answer [kcal]	Average answer provided by the respondents (X ± SD) (n=127)	Median	Range (min - max)	
Breakfast (2 slices of brown bread with butter, a poultry cabanos sausage, an egg, a tomato)	473	507.6 ± 341.7	450.0	30.0	2 000.0
Lunch (a bilberry bun, an apple)	444	352.1 ± 208.5	300.0	30.0	1 200.0
Dinner (a minced poultry cutlet, potatoes, beetroots, apple juice)	675	800.3 ± 703.3	700.0	150.0	7 000.0
High tea (3 pancakes with cottage cheese)	472	557.3 ± 490.3	450.0	60.0	4 500.0
Supper (pizza, beer)	1,045	1 260.6 ± 1,362.6	950.0	115.0	14 000.0
Snack I (5 chocolate covered marshmallows, coffee with a teaspoon of sugar)	284	567.8 ± 984.1	350.0	40.0	10 500.0
Snack II (3 Jaffa cakes)	168	261.9 ± 458.3	150.0	15.0	4 500.0
Total	3 560	4 307.7 ± 4156.6	3 390.0	510.0	43 150.0

X – average value; SD – standard deviation; n – number of respondents; min – minimum; max – maximum

The analysis of answers in individual categories (answers within the standard, answers below the standard, answers above the standard) showed that the answers within the standard were given by the smallest percentage of the respondents (from 13% to 24.4% depending on the presented meal). Nearly half of the respondents underestimated the energy value of breakfast, high tea, and supper (Tab. 3). The majority of the respondents (64.6%) underestimated the energy value of lunch, too. Snack I (coffee with a teaspoon of sugar and 5 chocolate covered marshmallows) turned out to be the meal the energy value of which was most frequently overestimated (62.2%). The overestimated values of snack I arose from the fact that the majority of the respondents did not know that the energy value of coffee is very low (9 kcal/100g – Kunachowicz et al.), which resulted in a significant overestimation of the energy value of the whole presented meal.

Tab. 3. Estimation of the calorific value of individual meals by answers within the standard, answers below the standard and answers above the standard (N=127).

Presented meal	Answers within the standard	Answers below the standard	Answers above the standard
Breakfast (473 kcal)			
N	28	62	37
Percent	22	48.8	29.1
X ± SD	488.6±20.9	275.6±95.3	910.8±364.4
(min – max)	450 – 500	30 – 400	550 – 2,000
Lunch (444 kcal)			
N	17	82	28
Percent	13.4	64.6	22
X ± SD	425.9±29.2	231.4±91.1	660.7±176.0
(min – max)	400 – 480	30 – 380	500 – 1,200
Dinner (675 kcal)			
N	27	49	51
Percent	21.3	38.6	40.2
X ± SD	668.5±50.3	385.5±113.5	1 268.6±911.6
(min – max)	600 – 750	150 – 550	800 – 7,000
High tea (472 kcal)			
N	21	62	44
Percent	16.5	48.8	34.6
X ± SD	481.0±24.9	302.9±95.5	952.3±659.9
(min – max)	450 – 500	60 – 400	550 – 4,500
Supper (1,045 kcal)			
N	21	62	44
Percent	16.5	48.8	34.6
X ± SD	1 033.3±63.9	663.6±206.7	2 210.2±1 978.9
(min – max)	950 – 1,150	115 – 900	1,200 – 14,000
Snack I (284 kcal)			
N	16	32	79
Percent	12.6	25.2	62.2
X ± SD	286.9±15.4	179.0±51.8	782.2±1 199.4
(min – max)	260 – 300	40 – 250	320 – 10 500
Snack II (168 kcal)			
N	31	43	53
Percent	24.4	33.9	41.7
X ± SD	150.0±0.0	87.6±25.7	468.9±657.3
(min – max)	150 – 150	15 – 120	200 – 4 500

X – average value; SD – standard deviation; n – number of respondents; min – minimum; max – maximum

No relation between indications of the energy value of meals as well as answers in the categories (answers within the standard, answers below the standard, answers above the standard) and profession, education and state of nutritional status as per BMI ($p>0.05$) was observed.

DISCUSSION

Maintaining a good psychophysical condition by the HEMS team is indispensable for pursuing this profession. Undertaking health-promoting behaviors, including compliance with appropriate dietary recommendations, prevents absence from work due to illnesses, reduces health care costs, and increases the operating efficiency of individuals and entire organizations [12].

The Polish Medical Air Rescue population is characterized by a low knowledge about the energy value of meals. Merely one in four examined persons provided an answer within the standard. It is particularly worrying as excessive body weight was found in more than 65% of the tested persons from the group under analysis. It was proved in the Polish National Multi-Centre Health Survey (Wieloośrodkowe Ogólnopolskie Badanie Stanu Zdrowia Ludności) (2010) that Poles' knowledge about nutrition is at a very low level, which is consistent with the obtained results of the authors' research. It was expected that paramedics, due to their medical education, would be characterized by better knowledge about nutrition than pilots. However, no statistically significant differences as to the level of knowledge between the groups were found ($p>0.05$). The authors' results are confirmed by other researchers, who proved that health behaviors, including eating behaviors, of paramedics do not differ from health behaviors in the control group in a statistically significant manner [11]. A low level of knowledge about nutrition was also recorded in other groups, such as military volunteers [4], athletes [18], so persons who should take care of proper nutrition and have knowledge in this respect. In contrast, the study by Kayapinar and Savas [5] found that the level of knowledge about nutrition among police officers was satisfying although it did not translate into eating behaviors in that group. In the authors' research, education of the respondents did not determine their level of knowledge about the energy value of the presented meals either. Similar results were obtained in the study by Bleich and Pollack [1], which was conducted on 663 adults in the United States of America.

Like in the authors' research, no significant differences between the level of knowledge about nutrition and the BMI value were stated in the study by O'Brien and Davies [10] as well as Bleich and Pollack [1]. O'Brien and Davies [10] imply also that the deficit of knowledge about nutrition is not the most important factor in overweight and obesity prevention. Yet it was proved in the study by Shimokawa [14] that a higher level of knowledge about nutrition contributed to reducing calorie intake, which directly prevents excessive body weight gains. Additionally, the researcher proved that the level of such knowledge differs among overweight persons and those with proper body weight. Like in the study by Shimokawa [14], a relationship between the respondents' BMI and their knowledge about nutrition was proved in the study by Shah at al. [13]. The higher the BMI of the examined persons, the more commonly they overestimated the size of the food portions presented in the study, with the relationship being statistically significant (p within the range from 0.1 to 0.3 depending on the meal).

Sex can be also one of the factors determining the level of knowledge about nutrition. It was stated in the study by York-Crowe et al. [22] that women were characterized by a higher level of knowledge about nutrition in comparison to men. Hence, the low level of knowledge about nutrition in the analyzed group can be explained by the fact that the vast majority of the examined HEMS team were men.

CONCLUSIONS

1. The HEMS team's knowledge about the energy value of meals was unsatisfactory.
2. The level of knowledge about nutrition was independent of a person's profession, education, sex, and BMI.
3. It is worth implementing nutrition education and healthy lifestyle programs in the examined group.

AUTHORS' DECLARATION:

Study Design: Agata Gaździńska, Mariusz Wyleżoł; **Data Collection:** Agata Gaździńska, Paweł Jagielski, Robert Gałązkowski; **Manuscript Preparation:** Agata Gaździńska, Mariusz Wyleżoł, Paweł Jagielski; *Funds Collection:* Robert Gałązkowski. The Authors declare that there is no conflict of interest.

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REVIEW ARTICLE

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PHYSIOLOGICAL EFFECTS AND OPERATIONAL USE OF POSITIVE PRESSURE BREATHING FOR G-PROTECTION

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Abstract: In preparation for a study, a MedLine search was conducted to review the status quo of positive pressure breathing for G protection (PPG). Aside from protective clothing, positive pressure breathing is one of the central building blocks of today's anti-G measures. PPG has been covered by quite a few reviews. Since a definite review by Fong and Fan in 1997, a number of articles have been published. The topics covered reflect the effects of the new capabilities of 4th and higher generation fighter aircraft, such as the high onset-rates and the high sustained Gz-loads, and the need for further anti-G protection concepts. Furthermore, an old anti-G suit concept has been revived and emerged in recent publications. Positive pressure breathing for Gz protection is reviewed in comparison with anti-G-straining maneuvers (AGSM) with regard to pressure schedules and with respect to the composition of the inspired gas mixture. In addition, operational considerations are reviewed, covering aspects that contribute to the successful deployment of anti-G gear. Particular focus was put on the reduction of unwanted side effects of anti-G suits and PPG. The work available on this topic and new technology anti-G suits suggest more work to be done, in particular in the field of undesirable side effects on the health of the pilots.

Keywords: positive pressure breathing for G protection, PPG, Anti-G suits, Anti-G straining maneuvers

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INTRODUCTION

Pilots require means that allow them to match or at least come close to matching the performance envelope of their aircraft. The point where the unassisted and unprotected pilot can be expected to do so has long since passed: fourth and higher generation fighter aircraft bring a new quality of exposure to acceleration forces to aircrews. Gz forces can be sustained much longer, and the onset and offset of these forces can be much brisker than in prior fighter aircraft. In an effort to ensure both short and long-term operational readiness of aircrews, an intensive search for new techniques capable of further increasing the G-tolerance began when the 4th generation of aircraft appeared in the 80ies. In this context, positive pressure breathing for G protection came more and more into focus.

Just as the name suggests, the term PPG describes a breathing process with externally controlled, continuous positive pressure used to protect the pilots against G-forces. The positive pressure is applied through a facemask continuously throughout the respiratory cycle. The applied positive breathing pressure is transmitted to the arterial system in the same manner as the pressure generated during an anti-G straining maneuver. The striking difference is the minimal voluntary effort required by the individual when positive pressure is applied.

PPG is accompanied by a number of additional measures like anti-G suits/trousers, usually a counterpressure vest, waistcoat or jerkin (in that case PPG is called "assisted or balanced PPG"), and occasionally surgical hoses or functionally equivalent gear covering the upper and lower arms [14,32,55,69]. The anti-G gear and procedures interact; they are usually employed in combination.

Initially, positive pressure breathing (PPB) was introduced into service in 1944 [44] to further increase the oxygen ceiling of aircrews and protect them from the effects of reduced O2 partial pressure of higher altitudes and, in the case of the potentially catastrophic, sudden failure of cabin pressurization at high altitudes. For fighter pilots in World War II, this was meant to be a tactical altitude advantage hence it was called pressure breathing for altitude protection (PBA).

Later on, this method (PPB) was also discovered to be capable of increasing the G tolerance of airmen. Most likely the first experimental proof of this concept was provided by Lambert in 1944 [67,98]. Although historically introduced to increase the oxygen partial pressure at high altitudes, the use of positive pressure breathing has been extended to counteract the fatigue issue while performing the AGSM. PPG increases intrathoracic pressure through external pressure applied through the breathing mask.

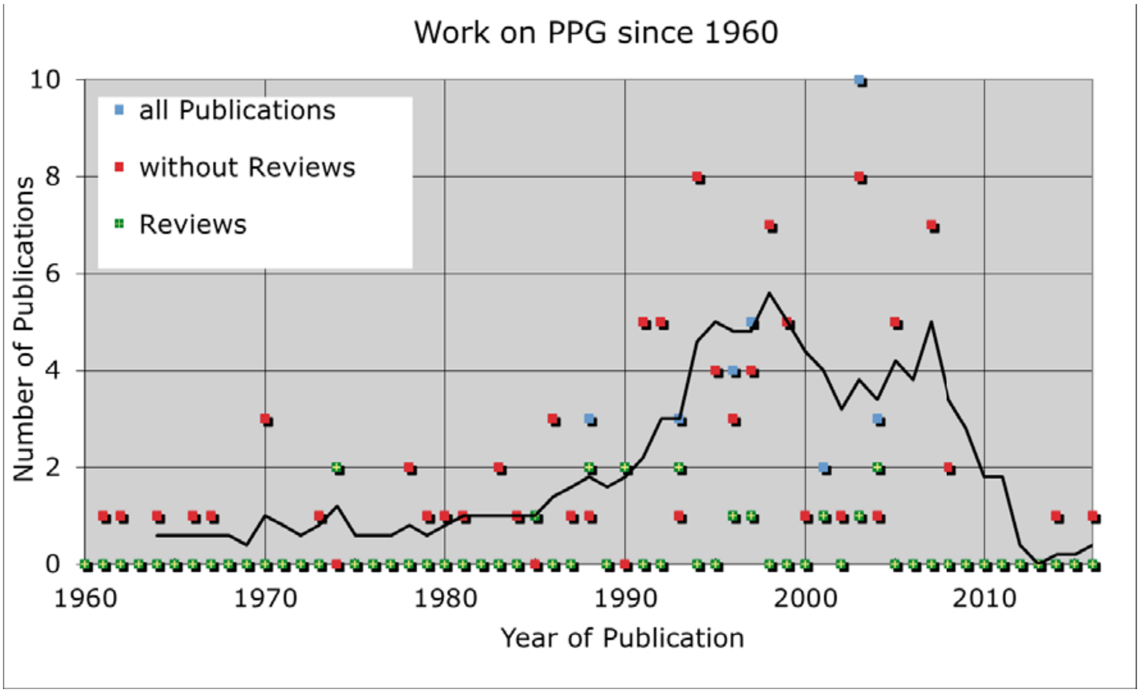

Fig. 1. Shows the distribution of frequency of the appearance of papers dealing with PPG over the years since the 1960s. A noticeable increase can be attributed to the introduction of 4th generation aircraft into service.

Today PPG is used in most nations to meet the demands of modern fighter aircraft. Fundamental investigations of the physiological consequences/effects of positive pressure breathing on the circulatory and respiratory systems go back to the forties of the last century. At that time, they focused on the action of positive pressure breathing for altitude protection [12,29,44]. Therefore, only moderate levels of airway pressure were a subject matter of subject in those studies (4 inches of water to 12 inches of water (30 cmH2O = 23 mmHg)). The high sustained Gz capabilities of current highly maneuverable fighter aircraft require much higher airway pressures to the order ranging from 8.0 kPa (= 60 mmHg) to 10.7 kPa (= 80 mmHg). So the question arises whether the knowledge of the side effects of former times is still true today.

PPG is one of the key building blocks of today's anti-G measures. Since the appearance of two of the last reviews [41,67], a noticeable number of papers have been published.

The objective of this paper was to review, summarize and describe the results of the world literature search on PPG. By doing so, an overview of the recent work covering various aspects, including the fringe effects of positive pressure breathing will be presented.

For systematic reasons, this publication will first summarize the manifold aspects of PPG used alone or in combination with anti-G straining maneuvers (AGSM). In addition, the various PPG schedules used will be discussed and. last but not least, operational and health aspects will be reviewed.

SOURCES

A Medline search was conducted using a combination of terms, i.e. "Gz and Positive Pressure Breathing" (38 hits + 1 hit in Chinese), "Gz and Atelectasis" (9 hits) and "Positive Pressure Breathing and G-Protection" (21 hits with few articles not found by the previous search term combinations). The search covered dates up to and including December 2016. Neither language nor date restrictions were set. A total of 51 different articles were found.

In addition, a search of the ASMA CD # 2007 was conducted using the same search terms (17 hits). Abstracts for posters and presentations were omitted. Furthermore, a manual search of the AGARD and RTO archive was conducted. Review articles emerging from the search were screened for further publications. This revealed a number of additional hits that were directly or indirectly linked with this topic, ending up with a total of 100 different articles covering this topic and cited in this review.

The articles were divided into different groups. The criteria applied included the max. Gz-load, max. Gz-duration, applied PPG pressure, type of anti-G suit and measured parameters. The review shows the different approaches to PPG under high Gz loads.

All the articles found were considered; however, not all the articles found contributed to the particular focus of this review. These articles are hence not cited.

PRINCIPAL FINDINGS

Enhancement of Gz Tolerance through PPG

Increasing G-duration tolerance (G-endurance tolerance) (G-time tolerance) with PPG

Improved flight performance of aircraft has prompted the development of improved G-ensembles. The ability to increase G-endurance tolerance has been shown for many anti-G suits (COMBined Advanced Technology Enhanced Designed G-Ensemble (Combat EDGE), US Air Force Advanced Tactical Anti-G System (ATAGS), US Navy Enhanced Anti-G Lower Ensemble (EAGLE), Tactical Life Support System (TLSS), Swedish Anti-G Ensemble 39 (AGE-39), Extended-Coverage anti-G Suit (ECGS) of the Finnish Air Force, etc.). All of them use PPG.

Although controversially described by some authors [71], it is predominantly agreed that PPG, assisted or not, increases the G-endurance of pilots [2,35,40,58,62,81]. A striking result was presented by Burns and Balldin [19]; assisted by PPG pressures of 50 mmHg and 70 mmHg, the endurance of the pilots in simulated aerial combat maneuvers (SACM) just about doubled in comparison to the reference group wearing anti-G suits and performing AGSM.

These results were confirmed in another experiment [31]; durations of over 2 ½ minutes in SACM were achieved with PPG compared to less than 1 ½ minutes without PPG. It is interesting to note that higher pressure did not lead to better endurance.

One team [66] reported a case of up to 12 ½ minutes of SACM and 3 cases with over 9 minutes of SACM continuously using extended anti-G suits and PPG.

Experimental data supports the position stated in earlier publications: G-tolerance time increases with PPG in comparison to AGSM. Earlier pilot fatigue with AGSM is the common explanation for the differences [2,19,62].

In addition to the increase of head level arterial blood pressure, G-time tolerance is improved by PPG due to its effect on the respiratory system. It reduces inspiratory resistance and increases overall lung breathing volume. Due to this, the gas exchange is improved and the fall in arterial oxygen saturation normally seen at accelerations of more than +4 Gz is reduced. Also, arterial oxygenation increases and the necessary effort to be generated by the aircrew is reduced [62]. However, in experiments aimed to further improve oxygenation by the administration of PPG together with increased O2 fractions, it was observed that higher O2 fractions do not necessarily lead to better oxygenation but to a higher degree of atelectasis [36,41,61,89,90].

Furthermore, it could be shown that G endurance is diminished when the pressure in extended coverage trousers was reduced [65,66], whereas no change in the G-endurance could be observed when no chest counterpressure was used [58,95,97].

In addition, Balldin and Siegborn [7] found no deterioration of G-endurance in their heat stress experiments when using PPG.

Increasing relaxed G-level tolerance (relaxed +Gz-intensity tolerance) with PPG

PPG has been compared in various settings and using different benchmarks. One approach to show the effect of PPG is to measure the relaxed +Gz tolerance of individuals, with or without assistance. and with different anti-G suits. Burns [18] reported an average increase in relaxed G tolerance of up to 0.7 Gz, depending on the pressure schedule, for assisted PPG. This is less than he expected based on theoretical considerations. Also, Domaszuk [34,35] found PPG to improve the G tolerance, to different degrees, for all groups of test subjects. He reported increases of up to 2.2 Gz for one of the groups. Shaffstall and Burton [81] evaluated different anti-G suits. They reported increases of relaxed G tolerance from below 3 Gz to well over 6 Gz for all set-ups. A noticeable increase in relaxed G tolerance with PPG was also confirmed by Shubrooks [83] and Pecaric et al. [76]. In addition, it was found that G-level tolerance was not diminished when no chest counterpressure was used [10,58].

Sharma [82] observed an increase in relaxed gradual onset run tolerance when PPG was administered, whereas the mean straining gradual onset run tolerance was not different when either PPG or no PPG was administered.

Comparison of AGSM with PPG

AGSM and PPG were found to be similar in that they both produce intrathoracic pressures of comparable degree which augment cardiovascular pressure, most importantly head-level blood pressure for brain perfusion. Regardless of whether PPG was used or the pilot executed a maximal AGSM, intrathoracic pressures reached up to 70 to 100 mmHg [16,70]. According to Burns [21], the basic difference between these two pressure sources is that the AGSM is an active, fatiguing process which pressurizes the lung parenchyma from without, by respiratory muscle activity, whereas PPG is a passive process which pressurizes the lung parenchyma from within through the face mask and the trachea.

When executing an AGSM, pilot fatigue occurs faster [40,83]. Surprisingly little pilot fatigue was reported with a novel concept of an anti-G suit that does not rely on PPG [96].

The +Gz-intensity tolerance results of straining and PPG combined and a maximal AGSM alone were found to be comparable [16,32,83]. Consequently, the arterial blood pressures were comparable and the +Gz-intensity tolerance with PPG was shown to be not superior to the +Gz-intensity tolerance with a properly executed maximal AGSM.

With respect to G-time tolerance, an increased endurance during simulated aerial combat maneuvers (SACM) was reported by Sharma when using AGSM and PBG simultaneously compared to using AGSM alone [82].

Comparison of PPG alone with PPG in combination with AGSM

A lot of work on this topic was done in the Swedish Air Force. They found out that PPG contributes to the arterial blood pressure response only to a tiny degree in the presence of a strong AGSM [37], that intrathoracic pressure did not add for AGSM and PPG [15,16,38] and that G-level tolerance was not increased by the combination of PPG and AGSM, whereas G-protective properties of an anti-G suit are further enhanced by pressure breathing [38]. Furthermore, inflation of the counterpressure vest did not seem to reduce “work of breathing” (WoB) at high Gz loads compared to AGSM [59]. In addition, several indications of inadequate support from thoracic counterpressure could be found [16,59]. Contradictory results were presented by Balldin et al. [10].

In their experiments, the combination of PPG and an AGSM enhanced G tolerance and comfort of their subjects when compared to AGSM alone.

Also, Clere et al. [32] found hints of an additional benefit when AGSM and PPG were combined. Sharma described PPG as a useful assistance adjunct to AGSM. It makes inspiration effortless and thereby reduces fatigue [82].

PPG Schedules

PPG schedule per se

In order to compare PPG schedules, it is necessary to differentiate between the PPG onset pressure and rate or PPG start- and endpoints but also between the respective parameters for the anti-G suit. The ratio between PPG pressure and suit pressures, as well as the torso coverage of the jerkin providing the chest counterpressure, (i.e. assisted PPG) are other important parameters describing the system. All these factors influence the outcome that the use of PPG will have on the pilot.

As an example, the data of the COMBAT EDGE and of the AEA used in the Eurofighter are given below:

- COMBAT EDGE: The system is automatically activated at + 4 Gz. Breathing pressure increases by 1,6 kPa (= 12 mmHg) with each +1 Gz increase, up to a design maximum of 8.0 kPa (= 60 mmHg) at 9 Gz. Chest counterpressure is applied at the same level as mask pressure.
- AEA: Like the COMBAT EDGE, this system also initiates PPG at 4 Gz. The mask cavity pressure increases by 1.5 kPa/Gz, reaching 8 kPa (60 mmHg) at 9 Gz. PPG is balanced as well.

What is also comparable to the COMBAT EDGE is the pressurization of the suit itself. Pressurization starts at 2 Gz and ends at 9 Gz with a pressure of 70 kPa (about 525 mmHg). This translates into a rate of 10 kPa/Gz.

Most studies have reported PPG values of 30-60 mmHg; however, there are studies that used lower values (25 mmHg) [12,14,30,76,83], or higher values (up to 80 mmHg) [1,6,19,28,42,45,48,76]. When pressures higher than 60 mmHg are used, the discomfort caused to the aircrew usually outweighs the positive effects of PPG [1,42,48].

A variety of studies investigated the ideal PBG pressure/G schedule and the G level for PPG to cut in and out [14,33,76].

Several authors demonstrated Gz-protection to be improved with increasing PPG pressure [45,76]. Depending on the aircraft type, the onset for the application of PPG pressure was reported to be between 3 Gz [76,77] and 4 Gz [37,66].

Also, the ratio of mask-to-pants/anti-G suit pressure was shown to influence the overall effectiveness [28,33,62,74]. Ratios between one [74,91] and all the way up to four [1,48,51,81] were systematically studied. In the Aircrew Equipment Assembly (AEA BAeS), it is about 8.75 at 9 Gz. The best level of protection was provided by a ratio of G-suit pressure to breathing pressure of about 4:1 [1,50,62].

In an earlier study [77], a pressure of up to 470 mmHg was applied to the anti-G pants. Up to 60 mmHg were used for PPG. This study, as well as others (e.g. [30]), showed a correlation between PPG pressure and arterial blood pressure.

ACKLES et al. [1] as well as Shaffstall and Burton [81] compared British, Swedish and Canadian systems. The system that provided the best protection against the adverse physiological effects of positive pressure breathing was a jerkin providing the torso coverage of the RAF jerkin and with the G suit inflated to 3.2 times breathing pressure.

Response time of the anti-G gear and work of breathing

Clère et al. [32] cited a study of Burton investigating delays in the application of appropriate breathing pressure. Delays of up to one second after reaching a G plateau were stated as acceptable for pilots when executing a mandatory proper AGSM in addition to PPG to compensate for this. He concluded that PPG does not directly protect subjects against the risk of G-LOC.

In today's fighter aircraft capable of high G-onset rates, the known delays can amount to a noticeable fraction of time spent in SACM. Also, the experienced delays account for the increased differential pressure and work of breathing (WoB) causing more-than-necessary pilot fatigue and increased risk of G-LOC because of the required compensating AGSM.

Since the last reviews, the question of the response time and WoB has been explicitly addressed in a technical paper [13]. Modern, electronically controlled regulators reduce the WoB significantly; however, they still have room for improvement.

Krock et al. [66] reported that, in an effort to reduce physiologically undesired effects, reduced pressure schedules were tested on different extended coverage anti-G suits. The experienced reduction in G-protection was well below operational requirements and likely not significant for operations.

Grönkvist et al. [59] presented data showing that a reduction and even an elimination of chest counterpressure did not increase WoB at any G load. Likewise, neither G tolerance nor G-endurance was reduced in any practical way.

Operational Considerations

The best of concepts for G-protection do not succeed in service if unwanted or adverse side effects of the anti-G equipment render its use undesirable. Hence, operational considerations must also be taken into account.

Leaks

In the context of anti-G protection gear as used in this paper, the term "leaks" refers to leaks between the mask and the pilot's face. When the mask shifts for whatever reason, air may be leaking out. Depending on the type of controller used in a specific set-up, this could lead to a drop in applied pressure, which in turn translates into reduced G-protection [78].

Also, the air may be leaking out towards the eyes of the pilot [78]. This is perceived as very uncomfortable [72]. Leaking air may also cause additional noise [78], making audio communication more difficult.

Voice communication

The search process described above did not reveal any systematic work related to voice communication and PPG. It should, however, be noted that increased respiratory pressure (PPG) does seem to decrease the ability for clear voice communication [72]. This too was one result of a comparative study performed in the German Air Force between optimized variants of the Libelle G Multiplus® and the Aircrew Equipment Assembly [86]. Decreased communication capability can be perceived as a risk to the safe conduct of the mission.

Thermal Stress

With advancing anti-G suits, reports of thermal stress for the pilot came up. Increasing coverage by the anti-G suit's tight fabric restricts the body's ability to regulate the temperature.

Balldin et al. [7,9] reported that, in a controlled environment, heat stress was comparable for the Combat Edge and a standard US Air-Force anti-G ensemble (without a counterpressure vest). Relaxed G tolerance, determined in a gradual onset run, decreased after exposure when heat stress, quantified by the body core temperature, increased. Values dropped from 7.6 Gz to 7.1 Gz for the Combat Edge and 7.1 Gz to 6.3 Gz for the standard ensemble. However, PPG did increase G tolerance, even after some dehydration due to heat stress.

Physical training

One of the benefits of PPG is the reduction of fatigue of the pilot due to AGSM. To prove this, the heart rate recovery quantified with the help of the "Erholungspulssumme EPS" (the sum of all heart beats over the resting level during the recovery period) was determined after G exposure to +6 and +8 Gz in a group performing an M-1 maneuver or PPG respectively [23,24]. It could be shown that the fatigue developed by persons using PPG at +8 Gz was comparable to the fatigue developed by a group performing an M-1 AGSM at + 6 Gz [23,24].

Pilots performing better in aerobic endurance and anaerobic power are less in need of the supportive PPG or advanced anti-G suits. Already in 1974, Burton et al. [23,24] pointed out the increasing importance of physical training as one of the anti-G measures. Russia was reported to successfully take the route of very specific physical training and evaluation [25].

It became obvious during a study the authors were involved in that, aside from developing the appropriate physical strength and endurance, it is of great importance that the proper AGSM required for different anti-G ensembles and/or working principles – pneumatic vs. hydraulic – are practiced to the point where they become second nature.

Cognitive Performance

Modern anti-G suits protect well against sustained acceleration and enable better G-endurance. They use PPG as well as higher body coverage. Albery and Chelette in 1998 [2] studied the cognitive performance of subjects using five different configurations of anti-G suits. Six subjects performed simulated flying tasks consisting of a primary target tracking task and a secondary task, which was a choice reaction time task called "RAPCOM = Rapid Communication". As a result, it could be shown that subjects wearing anti-G suits using PPG and providing higher coverage were able to perform more efficiently.

Health considerations

The ultimate objective of all research on G tolerance and anti-G suit design is to increase both the G-level and the G-endurance tolerance of the pilots to values at least matching, if not exceeding the capabilities of the aircraft flown. As of today, a G tolerance of up to 9 Gz in operational settings can be achieved through a number of different anti-G suits (e.g. AEA, COMBAT EDGE, ATAGS, the Swedish TFCS (Swedish Tactical Flight Combat

Suit), ECGS of the Finnish Air Force, the French ARZ 825 AGT system and so on).

However, a number of phenomena with potentially adverse immediate as well as long-term effects on pilot performance and pilots' health has generally been reported as "side effects" so far. Only a few publications pointed out these "side effects" as an objective for further investigation [14,42,72,78,85]. It may be worth an attempt to group and review those effects.

Effects on the cardiovascular system

The increase of intrathoracic and the resultant corresponding rise of systolic, diastolic, and systemic mean arterial blood pressures is one of the key effects of PPG. And this was indeed consistently shown in the literature beginning in 1946 [1,6,20,21,48,50,51,63,83,98,100]. Shubrooks [83] measured eye-level systemic arterial blood pressure (Psa) and demonstrated the effectiveness of PPG in maintaining an elevation of Psa during +Gz. Despite the significant increase in the heart rate and total peripheral resistance due to PPG, a reduction in stroke volume and cardiac output, as well as venous return to the heart, was observed [1,6]. All these effects seen were directly related to the level of PPG [1,6]. Simultaneous counterpressure did not reveal further hemodynamic effects [6].

Data presented by Goodman et al. [50] demonstrated that cardiovascular responses to PPG are determined not only by the absolute level of PPG but also by G-suit coverage: The higher the PPG level and the coverage of the anti-G suit used, the higher the systolic, diastolic and mean arterial blood pressure reactions to PPG. This was explained by the preservation of the left ventricular preload with extended coverage anti-G suits during PPG. When investigating cardiovascular responses to +1 Gz PPG under different aspects, Goodmann et al. [48,51] also found that an extended coverage as it is provided by the Tactical Life Support System (TLSS) minimizes cardiovascular function decay observed in other PPG ensembles [48] and permits the use of higher levels of PPG [49]. This has been thought to be due to the augmented venous return and stroke volume resulting from the larger and more uniform application of pressure in the leg G-suit bladders.

In addition, they could demonstrate that, at least for the ATAGS anti-G suit, even reduced suit pressures sufficed to compensate for the adverse cardiac effects of PPG and that a suit pressure being too high may cause an unwanted reduction of the heart rate [51]. However, one also has to take into account that greater coverage of anti-G suits may suppress the cardiovascular reflexes normally triggered by the fall in stroke volume and thus prevent any compensatory increase in the heart rate [42].

Njemanze et al. [74] studied the effects of PPG on the perfusion of the visual cortex and demonstrated that the mean cerebral blood flow velocity (MCBFV) increased in direct proportion to the increase in +Gz acceleration with PPG.

Siitonen et al. [84] found that up to +6 Gz total as well as local cerebral blood flow, although about one-third below the baseline, determined before the onset of acceleration, is maintained sufficiently high by both extended coverage G-suits with PPG and AGSM.

It was reported that, when switched from zero to 1 Gz conditions, the collapse of the internal jugular vein can be avoided by the application of PPB of 30 mmHg or higher. Hence circulation is re-established; the change in posture is compensated [30].

The question whether or not chronic exposure to high-G plus PPG with transient, i.e. repeated and short-term increases of cardiac preload and afterload, would result in right or left ventricular distention or hypertrophy or other long-term adverse effects on the heart has not been exclusively answered yet. Experimental data gained from instrumented animal models did not support these assumptions [64,92]. Albery et al. [3,4] conducted a longitudinal study on 18 subjects without a previous history of high +Gz exposure and did echocardiography to look for cumulative long-term effects of Gz exposure times. He described no significant differences for any of the 16 echocardiographic parameters, including right and left ventricular dimensions and wall thickness, aortic and left atrial dimensions and tricuspid and mitral valve inflow velocities after exposure durations described as equivalent to 3 years of F-16 flying. Further, he described no differences between male and female subjects [3].

Balldin et al. [8] tried to answer the question whether PPG in combination with extended coverage anti-G suits would increase the risk for premature ventricular contractions. No signs of premature ventricular contractions occurring more often during the +Gz plus PPG condition were found in any of the 14 volunteers of their study [8].

Effects on the respiratory system

Even without any additional Gz load (Gz = 1), there already exists a ventilation-perfusion mismatch in the lung. Upper regions of the lung are better ventilated and less well perfused; basal regions are well perfused and experience lesser ventilation. It is in part for this mismatch that the gas exchange in the lung is not ideal. High Gz loads stretching the hydrostatic column dramatically increase this preexisting mismatch between ventilation and perfusion in the lung tissue and the vertical non-uniformity of blood flow [23,24,41]. This mismatch together with concomitant mechanical distortion and organ displacement results in an increase in the respiratory dead space in the lung, an overall reduced capability for gas exchange and a reduced SaO2. Ultimately, this limits the performance of the pilot [23,24,41,46,47].

In the basal regions of the lung, poor ventilation and high perfusion along with increased PPG-induced O2 partial pressure increase the likelihood of the occurrence of atelectasis on a regular basis. This effect becomes more pronounced with increasing FiO2, resulting in a further increased O2 partial pressure [61,89,90,91]. Reports about dry cough were found in the literature [91]. Atelectasis was shown to be reduced by a dilution of the inspired oxygen concentration by argon or nitrogen, using unassisted positive pressure breathing of 30 mmHg or AGSM [89]. In experiments performed by Haswell et al. [61], no reduction of atelectasis could be found when argon (5%) was added to pure oxygen. However, a reduction of atelectasis was observed in subjects performing a simulated aerial combat maneuver and breathing 100% oxygen when PPG of 30 mmHg was used.

The lung seems to be the weakest part of the organism with respect to its reactions to high accelerations in z-direction [88]. Wood et al. therefore called it the "Achilles heel" [99]. Without a doubt, positive pressure breathing puts additional stress on the respiratory system and, as a result, safety concerns have been raised about lung over-distension and subsequent lung pathology. In an attempt to address some of these concerns, Green [55] investigated changes in lung volume subdivisions under high Gz acceleration and PPG with and without full coverage anti-G trousers and varying areas of chest counterpressure coverage. The profound reduction of vital capacity found to occur despite the presence of PPG (65 mmHg at +9 Gz) and variation of chest counterpressure coverage with increasing +Gz acceleration were most striking. The unchanged expiratory reserve volume (ERV) to vital capacity (VC) (ERV/VC) ratio at +9 Gz compared to +1 Gz was used to argue against lung over-distension under these experimental conditions.

In a non-PPG environment, inspiration is an active process, whereas exhalation is passive. The application of PPG reverses this and creates a new respiratory pattern [44]. The pilot has to make an effort to exhale. This, in relation to the level of PPG, was reported to be burdensome, getting more and more difficult, and to be responsible for the fatigue observed due to PPG. It takes some getting used to and training by the pilot [1,12,44,87].

In unassisted pressure breathing, the midposition of the chest (the point at the end of a normal expiration), as well as the minute ventilation and tidal volume, were reported to be much higher than when assisted positive pressure breathing was used [12,87]. A concomitant increase of functional residual air possibly indicates a relatively inefficient mixing of gases in the lungs.

The so-called "assisted or balanced" positive pressure breathing method using an additional counterpressure provided to the chest via a jerkin or a counterpressure vest was introduced to counter-balance any increased pressure in the lungs. It should limit lung expansion and, by doing so, prevent over-distension [12] and was shown to assist expiration, improve comfort and reduce the fatigue involved in unassisted pressure breathing due to the enhanced effort required to exhale against continuous PPG [14,62,81]. For a long time, balanced PPG was also thought to reduce the risk of lung disruption due to high breathing pressures. However, Grönkvist et al. [58] found the chest bladder to be incapable of countering the overall expansion of the lung during PPG and also found the risk of lung parenchyma disruption not being increased when no chest counterpressure was used [58]. In this paper, they were unable to exclude the possibility of balanced PPG being capable of preventing regional over-distension of alveoli located in the apical parts of the lung [58]. Later on [59], Grönkvist's group could show that transpulmonary pressure at the upper portion of the lung was unaffected by pressurization of the chest bladder and concluded that the bladder in the jerkin is not capable of preventing regional over-distension of alveoli located in the apical parts of the lung and does not seem to reduce the risk of lung rupture.

Due to the fact that high PPG pressure is applied in combination with and to compensate the adverse effects of high Gz accelerations, it is not unexpected for the two effects, high Gz accelerations and PPG, to partially cancel each other out. Borges et al. [27] applied an imaging technique to subjects under G load. Despite the limitations of the electrical impedance tomography (EIT) method, he describes evidence for atelectasis at G loads not exceeding 3.5 G. The extent of atelectasis varied with the fraction of inspired oxygen. Since pressurization of anti-G suits could be shown to provoke augmented intraregional ventilation inhomogeneity, in particular within the lung bases [60], automated inflation of the anti-G suit may have influenced the results.

Data from the literature was found emphasizing that not only the absolute values of PPG but also the anti-G suit design are important for the maintenance of pulmonary function. Comparing the effect PPG had to preserve lung volumes under various anti-G suit pressures and coverages, Tripp and Larssen [93] found out that especially the size of the abdominal bladder is crucial for the G protection provided by the suit. Therefore, they recommended the use of pulmonary function testing as a useful means of designing and evaluating the next generation of anti-G suits.

Even though PPG set-ups differ in various anti-G suits over some range, newer anti-G systems typically cause relatively high pressures to be applied to the lung (up to 60 to 80 mmHg). These pressures exceed the commonly accepted standards for clinical ventilation (30 to 35 cmH2O; equivalent to about 22 to 26 mmHg) as they can be found in standard textbooks. The same holds true for home ventilation devices (Constant Positive Airway Pressure or CPAP) used to treat sleep apnea (20 mmHg). The standard for mobile ventilation equipment (DIN EN 794-3) defines a stringent upper limit of 60 cmH2O +10% (equivalent to about 45 mmHg +10%) which a ventilator must not exceed under any circumstances. These standards reason with the risk of barotraumas.

Although positive pressure breathing for +Gz protection in the flying community is applied for much shorter times than positive pressure breathing in the clinical setting, the high onset rates and in particular the absolute values of the pressures used give cause for concern [43,55,88,100]. High onset rates can generate significant shear forces in the lung tissue. Both high onset rates and high absolute pressures can result in alveolar ruptures, with bulla formation, potentially leading to pneumothorax, pulmonary interstitial emphysema (PIE) or pneumomediastinum. This indeed happens and has been reported in the literature. There have repeatedly been case reports of sudden, not really satisfactorily explainable pneumothorax events in fighter pilots [11,43,68,79,94,100] or in subjects of positive pressure breathing experiments [52,53,100]. Already in 1946, Carr and Essex [29] applied continuous positive pressure respiration of 20 cm of water to dogs for three hours and found numerous emphysematous blebs beneath the pleura scattered diffusely over both lungs. Krock [64] reported the failure of unprotected lungs in animal models to be between 60-100 mmHg (range of 40-100 mmHg] "due to alveoli "stretching away" from the inelastic pulmonary vascular sheath".

Even if some authors state that studies on miniature swines could show that medical concerns about elevated transmural and differential pressures in the heart and lung with PBG are without any physiologic basis [26], the reported findings would, in our opinion, give reasons to assume adverse long-term effects of PPG on the lung. Apparently, long-term adverse effects have attracted little investigation so far. Few publications [88] were found regarding long-term effects of high-Gz load on the respiratory system. No publications were found regarding long-term effects of PPG on the respiratory system. There is still a lack of knowledge regarding this topic [85] and systematic studies using sensitive technology such as low-dose CT scanning to address the potential concern regarding pulmonary function have not been done so far [52]. Bang et al. [11] answered the question whether we would be able to detect potential pulmonary pathologies such as emphysema at an early stage by using those methods routinely and commonly applied in today's diagnostics during annual flight medicals. The answer was negative. In their paper, all eight subjects with emphysema and two subjects with lungs cysts detected in the low-dose chest computed tomography were cleared because they revealed normal pulmonary function.

Pain

The hydrostatic pressure caused by the acceleration forces leads to pain sensations in the dependent regions of the body. Since the arms are actually unprotected in pneumatic anti-G suits, the most known pain is arm pain. There are a number of publications addressing arm pain [37,56,57,72,75,91] for pneumatic anti-G suits. They unanimously described arm pain as an issue.

Travis described arm pain as not limiting in the operational environment for F15 and F16 aircraft. Paul dedicated his work to abdominal and foot pain. He concludes that inflation limiters and foot bladders are needed to eliminate or at least attenuate the pain experienced. There are correlations between forearm venous pressure (FVP), G load and duration and arm pain experienced [56] with venous pressures beginning from 160 to

200 mmHg. PPG directly raises venous pressure; raising the arm closer to heart level is an option to lower venous pressure [37].

Arm cuffs raise a number of operational issues, which are to be considered carefully. Green 2007 presented a detailed view of the origin of arm pain. He attributed arm pain to forearm venous resistance (FVR) rather than to FVP. PPG was reported to add to arm pain only when arm pain already occurs; when the arm was not close to the hydrostatical height of the heart, its reference position, PPG did increase arm pain.

Welsch et al. covered a novel anti-G suit concept, which is based on hydrostatic rather than pneumatic pressure [96]. It was stated that, with these anti-G suits tested up to G loads in excess of 10 Gz, arm pain does not occur at all, likely because the arms are protected as well.

Further effects

Intraocular pressure was reported to rise with increased arterial blood pressure. This, along with the already positive intraocular pressure compared to the blood pressure of the retinal vessels, helped to protect the retina from rising arterial pressure caused by PPG. Up to PPG pressures of 60 mmHg, no intraocular hemorrhage was observed [54]. Ryles et al. stated in 1996 that it is unlikely that increased intraocular pressure is of medical concern [80].

CONCLUSIONS

PPG is an integral part of today's anti-G measures. It supports the pilot in tolerating high G loads for longer periods of time. Generally, nations having 4th and higher generation fighter aircraft in service also have anti-G assemblies that successfully assist the pilot in reaching the desired performance.

The primary goal of reaching G tolerance levels sufficient to match high-performance aircraft can be considered achieved. That said, it seems logical and sensible to turn towards what has so far been dismissed in the context of G tolerance in general and PPG in particular.

The focus of more recent as well as future work has to shift to the undesired side effects of PPG. These side effects are to be addressed and reduced; pilot mobility, comfort, and operational effectiveness are to be considered key values of future anti-G system development. Long-term health-related combat readiness shall be considered an asset. Chances are that some issues are not accessible by short-term experimental procedures. They should be identified through an extended annual flight medical using established clinical health screening procedures. Systematic studies using sensitive, low-impact technology, such as low-dose chest CT scanning, should address the potential concern regarding pulmonary function. That anti-G assemblies ought to be designed with the reduction of side effects in mind has already been stated by Ackles et al. in 1978 [1].

One path towards minimizing the undesired side effects of PPG may lead to fundamentally different anti-G suits. These need to be evaluated thoroughly. A first approach resulting in the development of the liquid-filled hydrostatic Libelle G Multiplus® anti-G suit, which does not rely on PPG, failed to pass the final evaluation process after the transfer to a commercial product had been completed. The published and confirmed benchmarking data, however, was rather encouraging, in particular since some of the most nagging side effects (arm pain, impairment of communication, G-measles, PPG) did not seem to show with this system.

There have been further steps in this direction with the introduction of an anti-G system called G-RAFFE. It was tested at an early stage of its development. Initial results are promising.

AUTHORS' DECLARATION:

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REVIEW ARTICLE

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MODELLING MOTION SICKNESS

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Introduction: Motion sickness is an undesirable phenomenon and continues to be an unresolved problem. Therefore, research is conducted aiming to understand the etiology of this disease better, as well as to anticipate its symptoms. This research is increasingly supported by numerical calculations, for the needs of which models of severity of motion sickness symptoms are developed. The aim of this paper is to review and characterize the models of severity of motion sickness symptoms available in the literature, as well as examples of the use of these models in research.

Methods: Systematic review.

Results: The first part describes the four most commonly used models of severity of motion sickness symptoms. A graphic representation of models and mathematical relationships were presented, based on which severity of the disease is determined. Finally, several examples of the use of these models in research are listed.

Conclusions: Taking into account the limitations of using certain models, the most prospective model for predicting severity of motion sickness symptoms was presented. The specific advantages of this model were described, as well as the conditions under which the study using this model should be conducted, in order to ensure reliable results.

Keywords: motion sickness, mathematical model, sensory conflict, subjective vertical

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INTRODUCTION

Motion sickness, also known as kinetosis or travel sickness, is a term used to describe discomfort caused by actual or apparent movement. Usually, a person does not feel the symptoms associated with this disease while traveling independently. This disease can occur when traveling by such means of transport as e.g. a car, aircraft, ship, as well as during exposition in e.g. flight simulators [2,8]. For this reason, the following terms are interchangeably used to describe this disease: car sickness, air sickness, seasickness and simulator sickness. Due to the fact that motion sickness is an undesirable phenomenon and continues to be an unresolved problem, research is conducted in order to understand its etiology better and to predict its occurrence [17,21,24,26–28,31,57,59]. This research is also carried out in the area of computer simulations for the needs of which models of severity of motion sickness symptoms are developed [3,8,9,13,22,35,37,46,47,50,54,58].

Numerical studies on severity of motion sickness symptoms are conducted in two directions. In the first direction, attempts are made to understand and model basic physiological mechanisms responsible for the development of disease symptoms [2,4,10,48]. The second direction of action focuses on the development of models, which enable to predict the occurrence of disease symptoms in different movement environments [32,37,45]. Two approaches are used in the modeling of motion sickness: empirical and theoretical. In the empirical approach, the model is based on the results obtained from the measurement of motion sickness symptoms experienced by people exposed to various types of movement. Models that belong to the second, theoretical, approach, aim to explain the causes of motion sickness. The empirical approach, although it has not thus far yielded the expected results, is the most popular and most widely used in the research on this phenomenon. This approach is limited to finding interactions between movement and motion sickness, assuming that this is the main cause of the disease. The theoretical approach currently employs two theories: "Sensory Conflict theory" (SC) and "Subjective Vertical Conflict theory" (SVC). SC theory is based on the work of Reason and Brand [50,51], expanded by Oman [47,49], who developed the final form of the mathematical description of this theory. Its essence is that all situations that cause motion sickness are determined by the state of the so-called sensory rearrangement [51]. In this state there is a sensory conflict not only between signals from the organ of vision, vestibular organ and other motion sensitive receptors. This conflict also applies to signals expected by the central nervous system (CNS), based on prior experience. According to the author, the difference in these signals is the cause of motion sickness. The SC theory in motion sickness modeling was also described by Benson [2]. His model of motion sickness is presented in fig. 1.

An essential component of this model (fig. 1) is a comparator that compares the sensed motions with motions that are expected by the CNS.

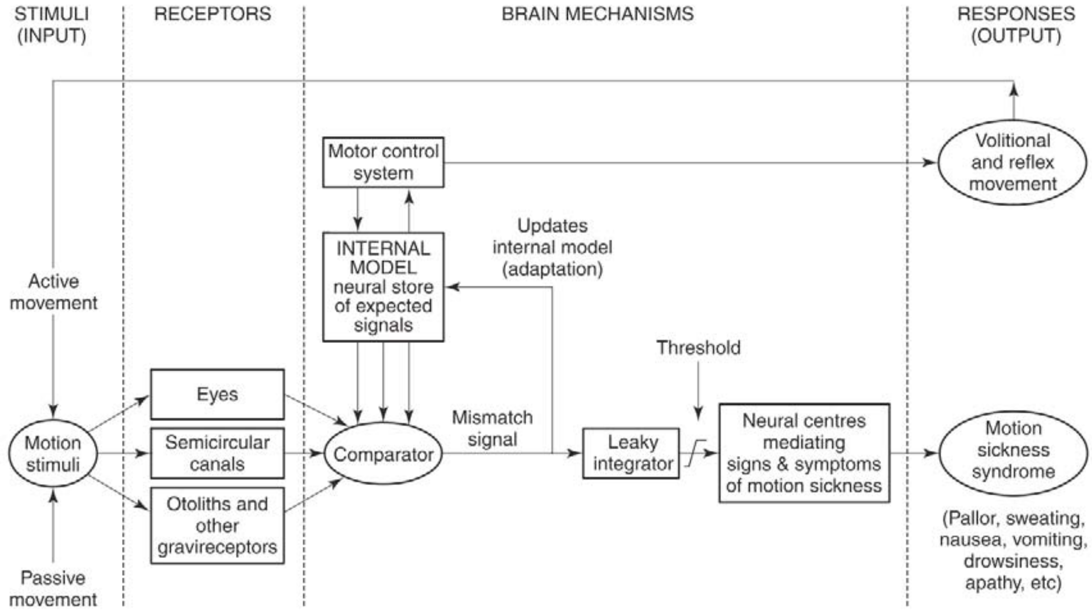

Fig. 1. The model of motion sickness according to the sensory conflict theory [2].

If these signals do not match, the comparator sends the so-called mismatch signal. This signal is used by the CNS to correct movement and position of the body. However, if the mismatch signal has a high value and is present over a longer period of time (e.g. in a boat moving up and down the waves), one of two reactions may occur [2]:

- adaptation to existing motions - internal model (CNS model), based on the mismatch signal, adjusts its motion expectations,
- motion sickness symptoms - cumulative sensory conflict.

The SVC theory, used in the second theoretical approach, was described by Bose and Bles [8]. It is a redefinition of the theory of sensory rearrangement [51]. The authors of this theory assumed that all situations that provoke the onset of motion sickness are characterized by the state in which the sensed vertical is contrary to the subjective vertical (SV) expected on the basis of previous experience [9]. Determination of SV takes place in the CNS on the basis of integrated signals from the organ of vision, vestibular organ and proprioceptors. The internal representation of the sensed vertical (SV), determined in the CNS, is a simplification of the classical theory of sensory rearrangement.

So far, scientists have made many attempts to develop models of severity of motion sickness symptoms [9,13,20,37,47,50,58]. These models describe mainly the mechanisms involved in the development of motion sickness, and also enable to determine the severity of its symptoms.

The aim this paper is to review and characterize the models of severity of motion sickness symptoms available in the literature, as well as examples of the use of these models in research.

As a result of a review of the available literature on motion sickness modeling, four of the most commonly used models of the severity of its symptoms are presented below.

Model Human Factors Research

As a result of numerous experiments conducted in Human Factors Research (HFR) Inc. California, USA [37,45], a model was developed that predicted the Motion Sickness Incidence (MSI) depending on the value, frequency and duration of vertical acceleration [37]. The authors of these studies have found that the results of measurements of the number and severity of motion sickness symptoms during its onset are variable and unique, while the symptom of vomiting is an observable marker of behavior. For this reason, the authors of this study have introduced the MSI index into the HFR model, which identifies the percentage of people who experienced vomiting under the influence of stimulating motion to the onset of the disease. HFR model [37] is described by the standardized normal distribution function for two variables: vertical harmonic oscillation with an amplitude z_a in the form of root mean square (RMS) and variable z'_t describing the vertical frequency f during exposure t. This model is described by the following equation:

$$MSI = 100 \cdot \Phi(z_a) \cdot \Phi(z'_t) \qquad (1)$$

where:

$\Phi(z)$- is a normal distribution function of the variable z, determined by the relation:

$$\Phi(z) = \frac{1}{2\pi} \int_{-\infty}^{z} e^{-\frac{1}{2}x^2} dx \qquad (2)$$

variables z_a and z'_t are defined as follows:

$$z_a = 2,128 \log_{10}(a) - 9,277 \log_{10}(f) - 5,809 \log_{10}^2(f) - 1,851$$

$$z'_t = 1,13\, z_a + 1,989 \log_{10}(t) - 2,904 \qquad (3)$$

in which:

a - root mean square of vertical acceleration component [g],

f - frequency of vertical acceleration component [Hz],

t - time of exposition to acceleration [min].

A graphic, three-dimensional representation of the HFR model is presented in fig. 2. It shows that with the increase of the root mean square (RMS) of the amplitude of acceleration, the level of motion sickness symptoms increases.

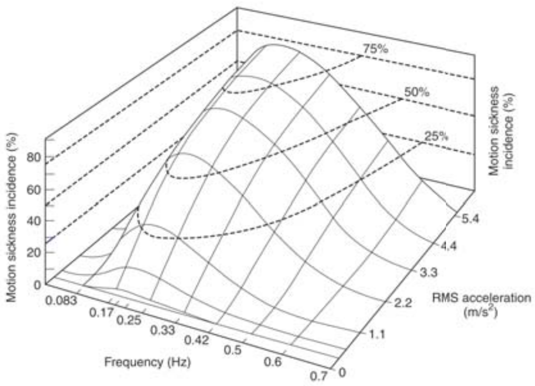

Fig. 2. Incidence of motion sickness as a function of frequency and acceleration, evoked by two-hour exposure to vertical (z-body axis) sinusoidal oscillation [2].

The highest saturation value of the disease symptoms occurs for the stimulus in the form of acceleration with the frequency of 0.16 Hz. In fig. 2, sections (25, 50 and 75%) were marked with horizontal plane, which correspond to the percentage of severity of disease symptoms. This model as-

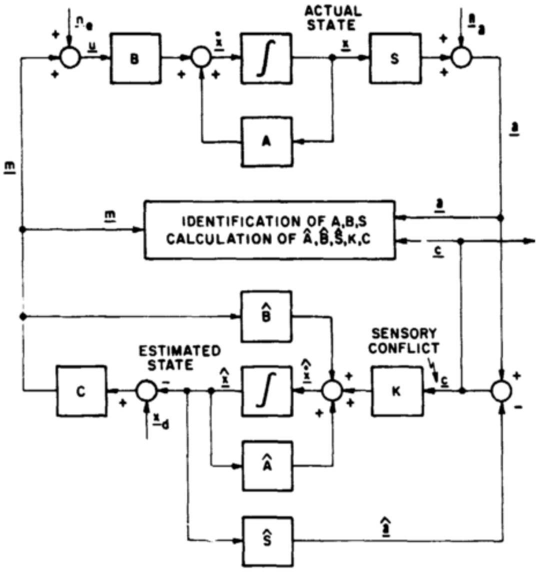

Fig. 3. Model for sensory conflict and movement control based on observer theory [47].

sumes that the maximum achievable level of disease symptoms amounts to 85%.

The disadvantage of using the HFR model is its rather complicated form and the fact that it is limited to vertical accelerations. For this reason, this model has been replaced by the concept of motion sickness dose as described by the Lawther and Griffin's model [32]. The model of motion sickness dose is currently the international standard used to predict the effect of vertical accelerations on the onset of motion sickness symptoms [16,56].

Oman's model

Oman [47,49] proposed a heuristic model of the dynamics of sensory conflict and locomotive motion assessment. This model made it possible to estimate subjective discomfort of a person, in the form of two motion sickness symptoms. The first symptom was the moment of occurrence of subjective complaints, while the second symptom was discomfort described by nonlinear function. The author has developed the model according to the SC concept [50], basing its structure on the optimal estimator model from the work of Borah et al. [6,7]. Fig. 3 presents the first of the two parts of Oman's model. This part is a model of sensory conflict and motion control, based on the state observer theory. Oman has distinguished sensor-level processing (upper part of the scheme) and processing in the CNS (the lower part, called the internal model). He determined the sensory conflict vector c (denotation $\underline{c}$ on fig. 3) from the difference of the vectors of the sensed state $\underline{a}$ and expected state $\underline{\hat{a}}$. These vectors represent information from all available sensors (among others, semicircular canals, otolith organs, organ of vision, proprioceptors). The increase in the value of the sensory conflict vector c indicates the increase of motion sickness symptoms. Fig. 4 presents the second part of Oman's model, which is a model of motion sickness. The input signal of this model is weighed sensory conflict h(*t*) It is processed through two parallel paths with fast and slow dynamics. Signals from both paths are added and then filtered with a fixed threshold. Thus the function R(t) is determined, which describes the severity of human discomfort.

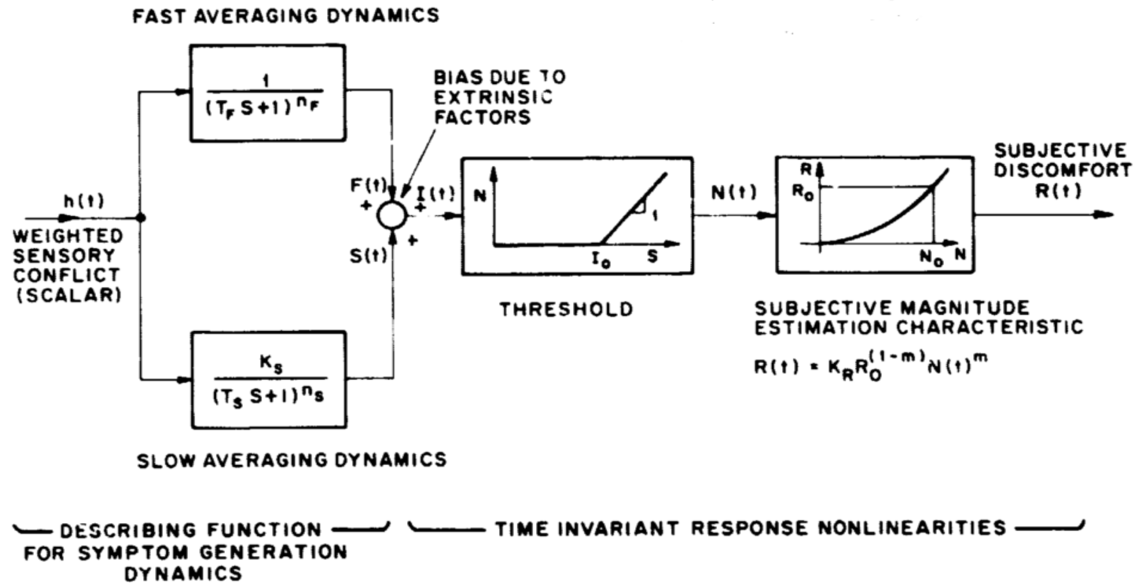

Fig. 4. Oman's model of subjective discomfort - motion sickness [47].

The susceptibility to motion sickness determined in this way depends not only on the degree of sensory conflict but also on the adopted amplitude of the signal processed in two paths, time constants and the threshold of nausea [49].

Oman has combined the sensory conflict model (fig. 3) with the motion sickness model (fig. 4), determining an intermediate signal h(*t*) - weighted sensory conflict. This signal is determined by the dependence:

$$\mathbf{h}(t) = \mathbf{c}^{\mathbf{T}}\mathbf{T}\mathbf{c} \tag{4}$$

where:

c – is the sensory conflict vector determined from the difference of the vector of the sensed state and the expected state vector (estimated in the CNS),

T – symmetrical matrix, whose coefficients describe the individual's sensitivity to the sensory conflict signal.

Oman estimated the orientation of the vertical by using optimum control technology. For this purpose, he assumed that the CNS uses a similar strategy in position and motion estimation. Thus, based on prior experience, the CNS estimates the orientation of the vertical using the responses of physical sensors (otolith organs) and the signals from the organ of vision. Oman's model [49] has some limitations. The model is linear and describes processing in the CNS using the state observer, although some sensory information is probably estimated in a nonlinear manner. In addition, this model does not take into account the process of adaptation to stimuli that cause motion sickness. A detailed description of the model can be found in the paper [47].

Bos and Bles's model

Bos and Bles's model [8,10,11] is an extension of Oman's model of motion sickness [47]. The main assumption underlying the theoretical construction of this model is the redefinition of the theory of sensory rearrangement [38]. The authors have assumed that motion sickness is primarily triggered in situations where the sensed vertical is not consistent (does not coincide) with the expected vertical determined in the CNS, based on prior experience. Bos and Bles formulated the SVC theory in this way. The researchers, when expanding Oman's model of motion sickness [47], included in its structure additional modules for determining the sensed vertical (response from the physical sensor of the otolith organ) and the expected vertical (response from the CNS). Fig. 5 Presents part of Oman's model of motion sickness [47] (thin lines) along with the modules added by Bos and Bles [4] (thick line).

The desirable state of the human body in fig. 5 is represented by the vector x_d. This vector is defined as follows. A person (matrix C) generates motor commands m that affect the model of body dynamics (matrix B). In this way he determines his position x . This signal together with external actuations n_e (e.g. from aircraft movement), is detected by human sense organs (matrix S). They are receptors of vision, vestibular organ and proprioceptors. In this way a signal is generated *a,* representing the sensed state of the body. In the blocks $\hat{\mathbf{B}}$ and $\hat{\mathbf{S}}$ the state of matrix B (motor activities) and matrix S (models of physical receptors) are recorded respectively. These are blocks representing processing at the CNS level. Similarly as in Oman's model [47], sensory conflict c is determined from the difference of the sensed state of the body *a* and expected state â, which is the output signal of the internal model (OUN model). Bos and Bles, using the fact that gravitational acceleration is constant, and the translational acceleration of the human body is usually short-lived, as suggested by Mayne [36], separated from gravitational-inertia acceleration *f=g-a* [42] sensed v_{sens} and expected

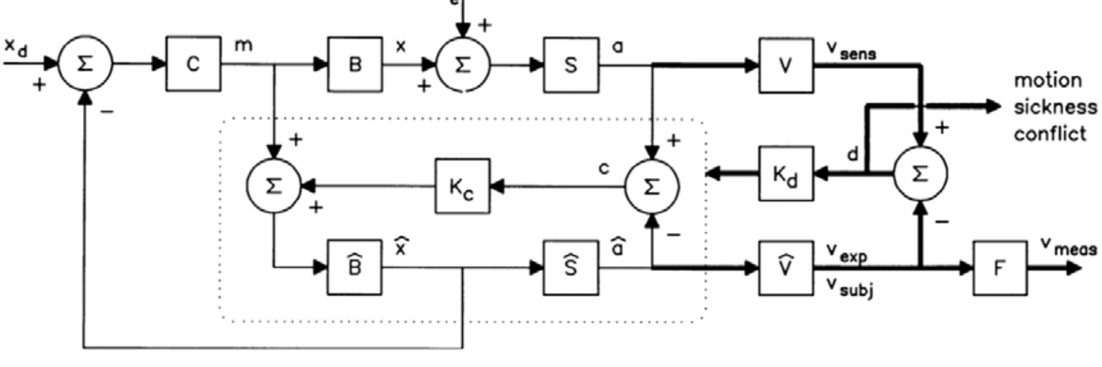

Fig. 5. Oman's model of motion sickness [47] (thin lines) extended by modules for determining the SVC (thick lines) [4].

v_{exp} vertical. For this purpose they used a low-pass (LP) filter described in the Laplace operator:

$$\mathbf{v}=\frac{1}{\tau s+1}\mathbf{f} \quad (5)$$

where: f - represents the response of the otolith organ to gravitational-inertia acceleration, τ - filter time constant, s - Laplace operator.

Equation (5) was used in blocks and $\hat{\mathbf{V}}$ (fig. 5), thus determining respectively sensed vertical v_{sens} and expected vertical. From the difference of vectors v_{sens} and v_{exp} a sensory conflict vector is created d, which is used in the next calculation step to update the vector v_{exp}. This updated vector v_{exp} is called a subjective vertical vector $v_{sub\,j}$ (fig. 5). In order to obtain the correct results, the sensed and expected vertical is determined in the Earth-fixed coordinate system. Then, vectors v_{sens} and v_{exp} determined by the dependence (5) are subject to a reverse transformation U^{-1}. As a result, vectors described in the head-fixed coordinate system are obtained. The principle presented above was presented in fig. 6 and described in detail in the paper [11].

Bos and Bles [9] indicate that the correct result of calculating the subjective vertical can be obtained using the following dependence:

$$\frac{d\mathbf{v}}{dt}=\frac{\mathbf{f}-\mathbf{v}}{\tau}-\omega\times\mathbf{v} \quad (6)$$

where:

ω - is the vector of angle velocity of the head, while

$\frac{dv}{dt}$ - derivative of the subjective vertical with respect to time in the inertial system.

Fig. 7 presents a complete Bos and Bles's model of motion sickness, which was developed according to the SVC theory for vertical motion.

The left side of this model (fig. 7), from which the sensory conflict vector is determined d, is the same as the extended structure of the Oman's model marked in fig. 5 with thick line. The sensory conflict vector is determined by the authors as follows (fig. 6 and 7):

$$\mathbf{d}=\mathbf{v}_{sens}-\hat{\mathbf{v}}_{exp} \quad (7)$$

In order to determine the MSI index, the sensory conflict vector d is nonlinearly transformed into a normalized parameter h and transformed using a second order function (fig. 7). A function

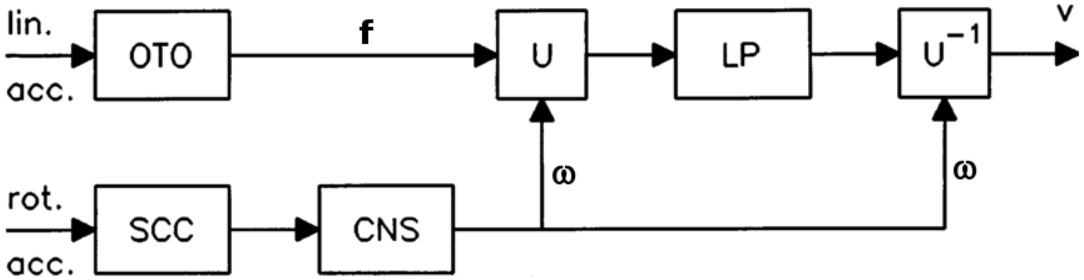

Fig. 6. Conflict model [9]. OTO - otolith organ, SCC - semicircular canal, CNS - central nervous system.

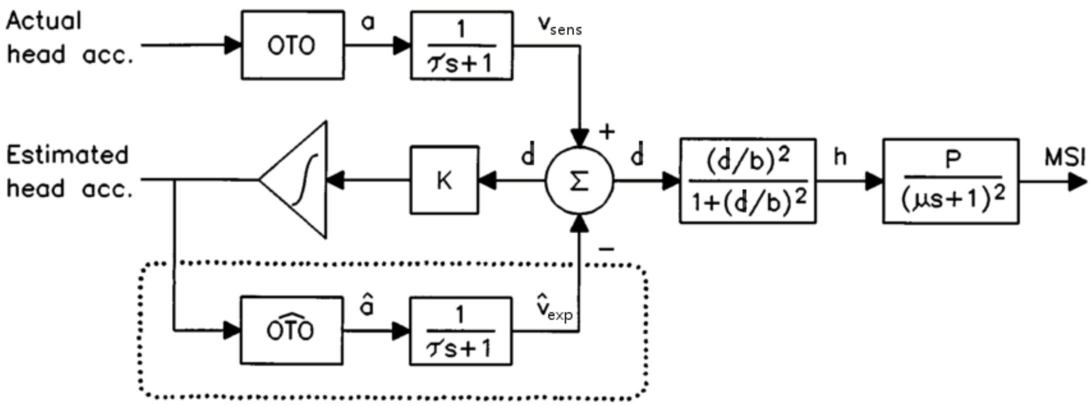

Fig. 7. Model of motion sickness based on the SVC for vertical motion [8].

that assumes a logarithmic or exponential form is used to describe the sensory conflict from mild to strong. For this purpose, the Hill function was used as follows [8]:

$$h=\frac{(\mathbf{d}/b)^n}{1+(\mathbf{d}/b)^n} \quad (8)$$

where:
d - sensory conflict vector, determined from equation (7),
b - parameter whose value is selected in the procedure of fitting the model quantitatively to the experimental data,
n - defines the inclination of the function h. The value of this parameter is in the range of n = 1 to n = ∞. For n = 2 and small sensory conflicts, the function h is exponentially increasing, while for larger conflicts it takes the form of a logarithmic function.

The second order filter was used to determine the severity of motion sickness symptoms, which reaches its maximum asymptotically and returns to zero after the sensory conflict has subsided. Its form is roughly described by the transmittance [8]:

$$MSI=\frac{P}{(\mu s+1)^2}h \quad (9)$$

where:
P - determines the maximum percentage of people who have had signs of motion sickness,
μ – time constant,
s - Laplace operator.

According to the SVC theory, only one conflict of signals is necessary, obtained from the difference of the response of the physical organs (otolith organs) and the SV - signal expected in the CNS, in order to determine the severity of motion sickness symptoms. As a result, stimuli do not need to be classified into different types of conflict, as is the case with the sensory regrouping theory. Although there are some examples of sensory conflicts that can cause motion sickness, according to Bles et al. [3] and Bos and Bles [8] , the internal representation of gravitational acceleration in the CNS is the basis of the SVC theory.

Lawther and Griffin's model

Lawther and Griffin [32,33] developed a motion sickness model, described in British Standard BS 6841 [16]. It is an international standard for predicting vomiting (VI) and illness rating (IR) in adults who have no adaptation to the stimuli that trigger these symptoms. The standard BS 6841 [16] determines the limits of "severe discomfort" for exposure to narrowband vertical acceleration of the body, in the frequency range of 0.1 to 0.63 Hz. In addition, this standard defines frequency filters used to determine the frequencies that cause a person to experience discomfort. The Lawther and Griffin's model is based on observations by McCauley et al. [37], as well as previous data from the work of Alexander et al. [1]. Lawther and Griffin divided the problem of motion sickness prediction into two parts. In the first part they used weighted vertical acceleration filtering, and in the second part root mean square of the response time. The developed model contains cumulative measure of motion sickness, which is determined by the Motion Sickness Dose Value (MSDV). In mathematical terms this model has the following form:

$$MSDV_Z=\sqrt{\int_0^T a_v^2(t)\,dt}=a_{RMS,\,v}\cdot\sqrt{T} \quad (10)$$

where: *T* - time of exposition (between 20 min and 6 hours), a_v - vertical acceleration filtered for a given frequency [45], $a_{RMS,\,v}$ - effective acceleration, defined as:

$$a_{RMS,\,v}=\left[\frac{1}{N}\sum_{n=0}^{N-1}a_v(n)^2\right]^{\frac{1}{2}} \quad (11)$$

for which: $a_v(n)$ - acceleration value from the nth sample after taking into account the weight depending on the direction of acceleration, N - number of data samples.

This model is best suited for the prediction of motion sickness, to which the dominant stimuli are vertical accelerations. A dependency was introduced to predict the percentage of people who may vomit VI=K_m*$MSDV_z$ [%].

For parameter K_m=0.333 and $MSDV_z$ determined from equation (10), vomiting index reaches VI < 70%. This result concerns adults who did not have adaptation to the stimuli that trigger these symptoms [23]. In the case of prediction of disease symptoms, the illness rating (IR) is used, described by the dependency IR=1/50*$MSDV_z$ [29].

The use of models in research of severity of motion sickness symptoms

Few models of motion sickness make it possible to predict to what extent adults will be agitated to nausea or vomiting under the influence of movement. Among them are the models described in this article. A significant group are models that can indicate only whether a given situation can trigger motion sickness and why, without determining its severity. Currently, more attention is being paid to the development of models of severity of motion sickness symptoms. The research carried out in this respect mainly concerns taking into account other receptors in the model (e.g. vision, proprioceptors) and the effect of all components of linear acceleration and angular velocity in the induction of motion sickness. Particular attention is paid to the organ of vision, which is known to have a major impact on the severity of motion sickness. The presence of visual indicators such as references to horizontal line may sometimes be necessary to reduce the symptoms of this disease (e.g. nausea) [53]. Below are some examples related to this research.

The limitations of the HFR model, including among others the use of vertical linear acceleration and omitting the presence of visual information, were eliminated by Matsangas [34]. The author expanded the use of the HFR model by validating it, using data from the work of McCauley et al. [37].

Griffin [29,30] used the British model of motion sickness BS 6841 [16] to describe the level of well-being of a person, as an opposition to the disease. In the study, the author used a variety of motion stimuli, including vertical movement with frequencies from the range of 0.1 to 0.5 Hz. In the case of sinusoidal movements lasting up to 2 hours, the Griffin model was compatible with the HFR model, although in rare cases the results were different by up to 25% [8].

Förstberg [23] conducted studies on human response to various motion stimuli occurring in high-speed tilting trains. The author additionally included an assessment of the possibility of occurring of motion sickness symptoms to the assessment of the comfort of movement and ability to work. For this purpose he used the Lawther and Griffin's model [32,33], in which he developed his own weighting band-pass filter with the range of 0.08 to 0.35 Hz. As a result of the comparison of the model's responses with the results of the experimental studies, the author proposed supplementing $MSDV_z$ with a component describing distribution (leakage) of accumulated nausea.

Braccesi et al. [12-15] developed models of motion sickness based on both SC theory and SVC theory. The first UNIPG model was based on vestibular stimuli, which included the interaction of all three components of linear acceleration. The second model UNIPGSeMo also included the presence of the organ of vision. Such an extension of the model enabled to determine the inter-sensory conflict, which was not yet used in models that predicted motion sickness.

Bles [3] conducted a study on the effect of Coriolis and Pseudo-Corliolis on the severity of motion sickness symptoms. In this study, the author showed that the subjective vertical (SV) is a marker that can successfully be used to determine the severity of symptoms of this disease.

Elias et al. [22] developed a model of sensory conflict and motion sickness that they used in the study of the effect of artificially generated gravity. In this study, the authors used a motion sickness model developed by Oman [47], which they modified according to the study conditions. The modification involved the introduction of a quantitative sensory conflict model, by which input data for motion sickness model was determined. In this case, the sensory conflict was determined based on the dynamics of the head movements during spinning, and also on the basis of the developed transmittance, binding the angular acceleration with the response of the semicircular canals to this acceleration. In addition, the authors expanded the structure of the model with the adaptation parameter, which they defined in the process of classical validation of the model (comparison of the signal estimated by the model with the results of experimental studies).

Wada et al. [58] developed a mathematical model of the severity of motion sickness symptoms, integrating knowledge of vestibular system neurophysiology. The authors expanded Bos and Bles's model [8] up to six degrees of freedom, additionally taking into account the change in angular position of the head. This model was used in the studies on the effects of head tilt while driving on a bend on the onset of motion sickness symptoms.

Most of the models described above ignore the interaction between the semicircular canals and the otolith organ. This concerns the problem of determining gravitational acceleration from gravitational-inertia acceleration. This problem in most works was solved by applying the dependence (6) [25,36], while other researchers [5,40,43] use the internal model of the CNS for that purpose. Another limitation of the presented models is that they still omit in their structure the mechanism of habitation and restitution of the vestibular organ and the process of adaptation to the stimuli causing the motion sickness. Apart from the models of motion sickness described above, there is a large number of models that have been developed in accordance with the SC theory and are mainly used in estimating the perception of human spatial orientation [11,18,19,25,36,39,41,44,52,55,60]. These models can ensure the determination of human perception of spatial position and movement, as well as SV. Therefore, they are often the core of the current models of the severity of motion sickness symptoms [13-15].

CONCLUSIONS

In the articles cited above and in the experiments described in them, there are models that meet the highest number of usability criteria, which determines their use in research. The most prospective model in the prediction of motion sickness symptoms seems to be the model developed by Bos and Bles [8,10,11]. This model is an extension of Oman's model [47], which includes the mathematical implementation of the SV conflict theory. Additional modules are used to determine to sensed and expected vertical, as well as the conflict vector between them. This model has several advantages, which include:

- it can be applied to most movement profiles, characteristic e.g. for car, air, maritime sickness, etc. [4].
- limited to only one conflict (subjective sense of the vertical),
- no need to use additional indicators in different movement profiles (situations), to explain why a person under some conditions is sick and under others is not,
- unlike Oman's model [47], as well as Lawther and Griffin's model, [32,33] there is no need for special filtering of the input signal or isolation of the stimulus in the form of pure vertical motion,
- confirmation in numerous frequency validations of 0.2 Hz [37] as the most provocative to the onset of motion sickness symptoms,
- continual development, conducted among others by the authors, as well as Braccessi et al. [13–15] and Wada et al. [58],
- ability to expand its structure in a simple way with additional receptors, e.g. visual [4,11] .

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On 16-17 March 2017, in Warsaw, the 1st National Polish Scientific Conference in the cycle "Diagnosis in psychological practice" entitled "Modern diagnostic practice - achievements and challenges" took place under the auspices of the National Diagnostics Section of the Polish Psychological Association, PTP Test Labs and Psyche Bookshop. Among its participants were psychologists from the Department of Aviation Psychology, Piotr Zieliński, Ph.D., and Marta Górska, MSc. The psychologists from the Department of Psychology of the Military Institute of Aviation Medicine exchanged experiences on the current achievements of psychological diagnostics (research results, standards, diagnostic strategies, tools), and shared their problems related to psychological diagnosis.

Dr Piotr Zieliński took up a highly specialized topic on the accuracy of psychological tests, pointing to other alternative methods that are often more precise than those that are widely known. Dr Zieliński pointed out that modern psychometry has a lot to offer to both the creators and users of psychological tests. Today, the development of computer programs makes it easy to apply even very complex models within the IRT. Within the classical test theory, new methods of estimating reliability are becoming more popular as a reasonable alternative to the increasingly common Cronbach alpha coefficient. Compared to older "classical" methods, all this results in much better coping with the problem of measurement precision. The presentation was a personal reflection of the author, which provoked the audience to a lively, substantive discussion.

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Marta Górska, MSc., opened a session on Clinical Diagnosis by discussing the topic of kinesiophobia - a fear of movement; at the same time, she presented her own tool to measure this phenomenon. Marta Górska's tool was created as a result of two years of psychotherapeutic work with patients after extensive spine and knee surgery. Many of them were referred by physicians or physiotherapists, because the degree of muscle tension and fear of the onset of pain was so strong that it hindered further treatments. The measurement of the level of kinesiophobia aims to show the patient's ways of thinking about pain experiences as well as visualize the effects of this type of interpretation in the patient's behavior. Perceiving painful sensations as a threat can slow down or even halt the recovery process of postoperative patients, which can have important consequences for further functioning. One of them is entering the state of chronic pain. The subject matter raised by Marta Górska is a unique yet very important area, which finds its place in both the psychological and medical approach.

The conference "Diagnosis in psychological practice" entitled "Modern diagnostic practice - achievements and challenges" is an event that is organized cyclically and undertakes multi-faceted and key issues in psychological diagnosis. The conference is intended for psychologists who face the challenges of diagnostic practice on a daily basis but also for scientists interested in dialog with practices and seeking ways to implement today's scientific knowledge into psychological practice. The topics covered concerned mainly diagnostic process and its effects, among others, developed solutions, dilemmas requiring professional disputes, experiences and problems of psychologists related to diagnosis in various fields of psychology. Another important aspect that was raised is the standardization of the diagnostic process in different areas of psychological practice. Also, experiences were shared in the context of challenges and opportunities for psychological diagnosis in the context of modern global problems, including: problems of the contemporary family (e.g. violence, taking children form their parents due to poverty, labor migration, etc.), competition in sport (diagnosis of athletes, relations in a team, families of children-athletes), mobbing in the work environment, disability, unemployment. The speeches that presented the results of research on the usefulness of different tools for psychological diagnosis were particularly interesting.

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SUMMARY OF THE FIFTH SCIENTIFIC CONFERENCE EPIMILITARIS 2017 ENTITLED "UNIFORMED AND CIVIL MEDICAL SERVICES AGAINST CONTEMPORARY HAZARDS", RYN (POLAND), 3-5 APRIL 2017

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Source of support: Own sources

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On 3-5 April current year, the Fifth Scientific Conference EpiMilitaris 2017 entitled "Uniformed and civil medical services against contemporary hazards" was held. The "EpiMilitaris" cycle conferences are held on a regular basis to gather people whose work or duty is associated with counteracting the CBRN (Chemical, Biological, Radiological, Nuclear) hazards. The keynote this year was exchange of experience and considerations regarding cooperation of military and civil services against contemporary hazards, both the ones related with natural disasters and with human activity. The conference was organized by: Epidemiological Response Center of the Armed Forces of the Republic of Poland (CRE SZ RP), Defense Communities Movement Association, Disaster Medicine and Emergency Care Facility of the Jagiellonian University - Collegium Medicum, Military Institute of Hygiene and Epidemiology in Warsaw and the Bureau of the Chief Medical Officer of the Slovak Armed Forces. It should be emphasized that the conference has been enjoying great interest among international experts from day one, which is confirmed by the attendance of numerous representatives of US and Slovak Armies.

During the conference, two main areas of interest could be noticed: rules and procedures following contamination and methods of monitoring, anticipation and prevention. The representatives of both Polish and foreign services and institutions presented a coherent and unanimous point of view on the above-mentioned issues. It is evident that our procedures are similar and, additionally, there is a hazard information exchange system.

A very interesting speech was given by major Łukasz Krzowski. He presented the possibilities of creating genetically mutated viruses with the use of commercial materials in one's kitchen or bath-

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room. Thereby, he showed how easy one can create a dangerous synthetic virus, emphasizing the significant role of hazard monitoring system and the areas that should be covered by such systems.

Early warning systems were covered by Mr. Tony Intrepido from Cubic Global Defense. He presented a concept of a complex CBRN hazards early warning system. IT solutions related with CBRN hazards were also covered in the speeches of the representatives of the Military University of Technology (WAT): Zbigniew Tarapata, PhD, Eng., prof. WAT major Rafał Kasprzyk, PhD, Eng. and Dariusz Pierzchała, PhD, Eng. Their lectures were connected with the project with the acronym of WAZkA, which is currently being implemented by WAT, and the flu virus hazard monitoring and forecasting system named SARNA, which has already been implemented in the Government Center for Security. Both lectures drew great attention of the representatives of uniformed and civil medical services.

In the session devoted to rescue actions, Michał Madeyski, M.Sc. from WIML presented a lecture entitled "Medical evacuation by air - the role of paramedic in cooperation with the crew of a medical evacuation helicopter". The lecture presented the role of a paramedic in proper preparation of a victim for airborne transport and the cooperation with the crew of a medical evacuation helicopter due to handing the patient over to them for transport. Particular attention was paid to non-medical aspects of the cooperation, which are often the key element of a successful evacuation. Also the issues of proper training of paramedics in the field of aerospace medicine basics.

Another interesting speech was given by Mr. Marcin Błeński, who presented rescue actions in hard conditions, such as in high mountains or caves. Presented were examples of some difficult rescue actions and the challenges the rescuers had to deal with, with indication of the essential role of appropriate planning and preparation of such actions. As was highlighted, these elements are essential also in the case of CBRN hazards.

Captain Thomas Lindley Pittman, physician representing the National Guard of the United States, presented the problems related with handling injured victims on contaminated area. He not only pointed out the medical complications related with giving aid, but also the logistic and technical issues related therewith. He indicated that in this kind of situations it is the logistic preparation that often plays the key role in increasing survivability of not only the injured ones, but also determines the security of those staying in the places where the victims are brought.

During the conference the Disaster Medicine and Emergency Care Facility of the Jagiellonian University - Collegium Medicum and CRE SZ RP prepared a simulation of actions related with detecting a biological attack on the area around the conference venue and on the rooms where the participants were gathered. Without announcement, one person (a malingerer) lost consciousness in the room. Thus, a showcase of the services began, including presentation of equipment and procedures both inside and outside the building, deployment of decontamination line and preparation of the persons directly exposed for transport. The showcase was concluded with viewing of the displayed equipment and discussions between the participants and the soldiers who arranged the simulation who, as part of their daily duties, prepare to react to this kind of alarm conditions.

To sum up, it should be stated that the conference proved good preparation of the Polish Armed Forces for acting in the event of a CBRN attack. It covered important issues related to coordination and cooperation of civil services with each other and in joint action with the army. The lectures given by the representatives of the allied armies showed convergence of thinking among us, as well as an increasingly better organization of IT and research systems of the allies.

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Standard journal article

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Article with published erratum

Koffler D, Reidenberg MM. Antibodies to nuclear antigens in patients treated with procainamide or acetylprocainamide [published erratum appears in N Engl J Med 1979;302:322-5]. N Engl J Med 1979; 301:1382-5.

Article in electronic form

Drayer DE, Koffler D. Factors in the emergence of infectious diseases. Emerg Infect Dis [serial online] 1995 Jan-Mar [cited 1996 Jun 5];1(1):[24 screens]. Retrieved 25 January 2013 from: http://www.cdc.gov/ncidod/EID/eid.htm.

Electronic resource

Health on the net foundattion code of conduct (HONcode) for medical and health websites. 1997; Retrieved 9 January 2013 from https://www.hon.ch/HONcode

Article, no author given

Cancer in South Africa [editorial]. S Afr Med J 1994;84:15.

Book, personal author(s)

Lazarus RS, Folkman S. Stress, appraisal and coping. New York: Springer Publishing Co.; 1984.

Book, editor(s) as author

Norman IJ, Redfern SJ, eds. Mental health care for elderly people. New York: Churchill Livingstone; 1996.

Book, Organization as author and publisher:

Institute of Medicine (US). Looking at the future of the Medicaid program. Washington: The Institute; 1992.

Chapter in a book

Charzewska J, Wajszczyk B, Chabrom E, Rogalska-Niedżwiedż M. Aktywność fizyczna w Polsce w rożnych grupach według wieku i płci. In: Jarosz M, ed. Otyłość, żywienie, aktywność fizyczna i zdrowie Polaków. Warszawa: Instytut Żywności i Żywienia; 2006:317-339.

Conference proceedings

Kimura J, Shibasaki H, eds. Recent advances in clinical neurophysiology. Proceedings of the 10th International Congress of EMG and Clinical Neurophysiology; 1995 Oct 15-19; Kyoto, Japan. Amsterdam: Elsevier; 1996.

Conference paper

Bengtsson S, Solheim BG. Enforcement of data protection, privacy and security in medical informatics. In: Lun KC, Degoulet P, Piemme TE, Rienhoff O, eds. MEDINFO 92. Proceedings of the 7th World Congress on Medical Informatics; 1992 Sep 6-10; Geneva, Switzerland.

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