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ORIGINAL ARTICLE

POLISH ADAPTATION OF THE COPENHAGEN PSYCHOSOCIAL QUESTIONNAIRE II (COPSOQ II) IN POLISH PRISON SERVICE STAFF - A TOOL FOR PSYCHOSOCIAL RISK ASSESSMENT AT THE WORKPLACE

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Introduction: The Copenhagen Psychosocial Questionnaire (COPSOQ) is identified to be appropriate to assess psychosocial hazards at work and is recommended in WHO publications. However, the tool was never fully adopted in Poland. The purpose of this paper is to present the psychometric characteristics of COPSOQ II in Polish.

Material and Methods: A validation study of the long (128-item) COPSOQ II was conducted on a stratified sample of the Polish Prison Service staff (N=380). Reliability was tested with Cronbach's α. Validity was verified through factor analysis as well as analysis of correlations with four other relevant measures for psychosocial hazards assessment. All of them were previously widely applied in Poland by many researchers and approved for studying psychosocial environment at work, health and well-being in Polish employees.

Results: The Polish version of COPSOQ II is composed of 42 scales. The greater number of scales compared to the original version results from reliability analysis. As the original Variation scale was the only with unsatisfactory Cronbach's α so it was divided into two separate measures: Work Repetitiveness and Work Variety. Seven factors were identified and labelled as: Demands at Work, Organizational Relations, Physical Violence, Psychological Violence, Health and Well-being, Work Commitment and Development Perspectives, Relations within a Team. All associations were in the expected direction.

Tables: 5 • **References:** 32 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2020 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

Conclusions: The long COPSOQ II PL may be considered as a proper tool to study psychosocial hazards at work in Poland. However, further tests on work environments other than Prison Service are recommended.

Keywords: hazard management, work-related stress, risk management, COPSOQ, Prison Service, work-related health, occupational hazards, psychosocial hazards

INTRODUCTION

The Copenhagen Psychosocial Questionnaire (COPSOQ) was developed by the Danish National Research Centre for Working Environment (NRCWE) [23].

Pejtersen at al. [23] decided that their tool will not be based on any singular theory, but will include many dimensions facilitating the performance of analyses on various levels: organizational, team and individual. The questionnaire makes it possible to study potential stressors at work as well as resources such as social support, feedback, commitment and well-being. The tool takes into account a comprehensive picture of the psychosocial working conditions, can be applied across a variety of work environments and is convenient for users. The tool is also identified to be appropriate to assess psychosocial hazards at work and is recommended in WHO publications [18]. Originally, three different length versions of the questionnaire were developed. Currently, the second version of the COPSOQ [23] is available in three different lengths. The longest COPSOQ II version (the so called long version) originally comprises 41 scales. 7 factors have been identified therein: demands at work, work structure and content, interpersonal relations and quality of leadership, work - individual relations, organizational culture, health and well-being, offensive behaviors [23]. One should also emphasize that even though the authors do not refer to any specific stress theory, COPSOQ II corresponds well with the Job Demands - Resources (JD-R) model [23]. Essentially all work aspects which, according to contemporary science, generate a psychosocial risk, are also included therein [23].

The Copenhagen Psychosocial Questionnaire (COPSOQ) is a widely accepted tool to assess psychosocial hazards at work, also for intervention purposes. The tool can be applied across a variety of work environments and is convenient for users [18,21,23,25]. One should also emphasize that even though the authors do not refer to any specific stress theory, COPSOQ corresponds well with the Job Demands - Resources (JD-R) model [2]. The COPSOQ was translated into a number of languages [3,20,21,23,25], but there was no Polish adaptation of COPSOQ, even though some scales were translated for the needs of various research projects [31]. This paper presents the Polish adaptation of COPSOQ II's long version in Polish Prison Service Staff.

MATERIAL AND METHODS

The procedure for adapting the tool proceeded in accordance with the guidelines applicable to adapting tests designed to measure psychological health for WHO research needs across various countries [30]. To that end, questionnaire questions, possible responses and all test instructions were translated. After an expert's assessment which looked at the content and linguistic quality of the translation, a back-translation was performed, and pilot tests were carried out. The final version was used for validation in a relatively homogenous work environment, on a stratified sample, selected from staff and officers of the Prison Service [pl: Służba Więzienna] (SW), representative in terms of sex, workplace location and officer status. The used questionnaire was fully consistent with the original one in terms of items' content, response format as well as scoring rules Complete description of the original tool is available in another open-access paper [23].

The research was conducted in compliance with ethical standards in social sciences. The study was carried out individually, during periodic health tests of employees. The research was anonymous and voluntary, the participants were informed that they could resign from further participation in the research at any time without suffering any consequences.

The obtained sample size of N = 380 was sufficient to keep the statistical error d below 5%. Men (77,9%) made up the majority of the research subjects. In terms of education, the largest group were individuals with at least a Master's degree (67,8%). A further 10,8% held Bachelor's degrees or completed a post-secondary school and the remaining part of the sample constituted individuals with secondary school education. Most of the research subjects were individuals in the 35-49 years old age bracket (67,1%), 26,6% of the sample was composed of younger individuals (22-34 years old) and the remainder constituted the 50-65 years old age bracket. All professional groups being part of the Prison Service were taken into account by the research. And thus, office and admin staff made up 29,5% of the sample, quartermasters – 7,4%, security – 38,9%, social rehabilitation (including: doctors, psychologists, educators) – 22,9% and teachers – 1,3%. Almost the entire sample (90,5%) was composed of officers.

Reliability and construct validity assessments were carried out within the scope of the validation. Reliability and construct validity assessment results are presented in subsequent parts of the paper. Reliability tests were limited to testing internal cohesion. Construct validity was assessed by way of a factor analysis and analysis of correlation with results obtained using four other tools: two which measured psychosocial working conditions and two which applied to the consequences of exposure to work related stress.

RESULTS

For clarity purposes, the presented results are grouped according to reliability and validity.

Reliability

The COPSOQ II PL questionnaire scales' reliability was estimated using the Cronbach's alpha coefficient. Means and standard deviations for given scales are shown alongside alpha values in table 1.

Tab. 1. Reliability of COPSOQ II scales (N=380).

Scale	Number of Items	M	SD	Cronbach's α
Quantitative demands	4	43,69	20,14	0,848
Work pace	3	65,00	19,38	0,880
Cognitive demands	4	70,18	16,55	0,793
Emotional demands	4	58,36	21,08	0,807
Demands for hiding emotions	3	67,05	24,63	0,743
Influence	4	36,35	18,07	0,741
Possibilities for development (skill discretion)	4	57,84	18,35	0,780
Variation	2	43,21	19,07	0,394
Meaning of work	3	67,49	21,16	0,846
Commitment to the workplace	4	48,99	19,59	0,701
Predictability	2	50,49	22,46	0,788
Rewards (Recognition)	3	56,46	24,59	0,910
Role clarity	3	73,62	17,52	0,825
Role conflicts	4	43,55	22,65	0,820
Quality of leadership	4	52,42	24,61	0,927
Social support from colleagues	3	54,99	19,08	0,801
Social support from supervisors	3	50,53	25,12	0,889
Social community at work	3	70,37	18,05	0,823
Job insecurity	4	25,53	21,21	0,810
Job satisfaction	4	40,89	16,71	0,811
Work–family conflict	4	59,17	23,31	0,816
Family–work conflict	2	88,33	20,11	0,873
Mutual trust between employees	3	53,59	22,75	0,794
Trust regarding management	4	58,16	18,61	0,783
Justice and respect	4	48,40	21,65	0,891
Social inclusiveness	4	52,30	20,86	0,708
Sleeping troubles	4	31,26	22,36	0,923
Burnout	4	42,98	19,20	0,910

Scale	Number of Items	M	SD	Cronbach's α
Stress	4	40,36	19,49	0,916
Depressive symptoms	4	28,56	16,63	0,839
Somatic stress symptoms	4	19,79	16,94	0,813
Cognitive stress symptoms	4	24,74	17,78	0,892
Self-efficacy	6	31,32	13,79	0,82
Self rated health	1	61,24	21,76	-
Sexual harassment	1	3,68	13,70	-
Threat of violence	1	10,07	20,28	-
Physical violence	1	6,38	18,97	-
Bullying	1	9,02	19,93	-
Unpleasant teasing	1	11,25	19,48	-
Conflicts and quarrels	1	15,86	18,08	-
Gossip and slander	1	17,81	22,77	-

M – mean; SD – standard deviation

Validity

In order to verify the validity of COPSOQ II, two methods out of the available construct validity tests [17] were used: factor analysis and correlation matrix.

Factor analysis

42 scales which make up the Polish COPSOQ II version were taken into account by the factor analysis, i.e. 40 scales from the original version and two further scales: "Job variation" and "Repeatability" which were established as a result of splitting the original "Variation" scale. Similar to validation of other COPSOQ II language versions, an exploratory factor analysis was performed on the Polish version as the COPSOQ does not refer to any specific theory and it was hypothesized that intercultural differences will be reflected in the structure of the tool. The KMO value of 0,933 and the Bartlett's test of sphericity: chi2(861)=9054,854; p<0,001 suggest that the EPA is entitled . The maximum likelihood method with an Oblmin rotation was used [23]. Kaiser's method and scree plot analysis [32] were used in order to identify the number of factors. The results are shown in table 2.

The detailed results of the performed factor analysis are shown in table 3.

Due to the use of Oblimin rotation, table 4 presents information on the correlation between the factors.

Tab. 2. Results of COPSOQ II PL factor analysis - Total Variance Explained.

Factor	Initial Eigenvalues			Rotation Sums of Squared Loadings
	Total	% of Variance	Cumulative %	Total
1	12,97	30,87	30,87	3,82
2	3,76	8,95	39,82	7,64
3	3,07	7,32	47,14	6,89
4	1,94	4,62	51,76	5,82
5	1,62	3,85	55,60	5,82
6	1,20	2,87	58,47	5,35
7	1,13	2,69	61,16	5,70

Extraction Method: Maximum Likelihood.

Tab. 3. Results of COPSOQ II PL factor analysis.

Scale	Factor 1: Physical violence	Factor 2: Organizational Relations	Factor 3: Health and well-being	Factor 4: Demands at work	Factor 5: Psychological violence	Factor 6: Work commitment and development perspectives	Factor 7: Relations within a team
Threats of violence	0,985						
Physical violence	0,668						
Sexual harassment	0,356						
Justice and respect		0,867					
Trust regarding management		0,829					
Quality of leadership		0,789					
Social support from supervisors		0,771					
Rewards (Recognition)		0,767					

Scale	Factor 1: Physical violence	Factor 2: Organizational Relations	Factor 3: Health and well-being	Factor 4: Demands at work	Factor 5: Psychological violence	Factor 6: Work commitment and development perspectives	Factor 7: Relations within a team
Predictability		0,703					
Role clarity		0,603					
Social inclusiveness		0,511					
Depressive symptoms			0,842				
Stress			0,827				
Cognitive stress			0,824				
Somatic stress			0,781				
Burnout			0,776				
Sleeping troubles			0,746				
Work–family conflict			0,580				
Self rated health			-0,551				
Self-efficacy			-0,425				
Work–family conflict			0,347				
Job insecurity			0,343				
Cognitive demands				0,838			
Work pace				0,797			
Emotional demands				0,692			
Quantitative demands				0,627			
Role conflicts				0,558			
Demands for hiding emotions				0,537			
Work repetitiveness				-0,324			
Unpleasant teasing					0,830		
Bullying					0,746		
Gossip and slander					0,636		
Conflicts and quarrels					0,562		
Possibilities for development (skill discretion)						0,795	
Meaning of work						0,760	
Job satisfaction						0,675	
Commitment to the workplace						0,645	
Influence						0,544	
Work variety						0,420	
Social community at work							0,797
Social support from colleagues							0,688
Mutual trust between employees							0,586

Tab. 4. Results of COPSOQ II PL factor analysis - Factor Correlation Matrix.

Factor	1	2	3	4	5	6	7
1	1,000	-0,152	0,205	0,260	0,457	0,146	-0,175
2	-0,152	1,000	-0,275	-0,261	-0,388	-0,370	0,463
3	0,05	-0,275	1,000	0,260	0,178	0,284	-0,256
4	0,260	-0,261	0,260	1,000	0,389	0,068	-0,268
5	0,457	-0,388	0,178	0,389	1,000	0,154	-0,281
6	0,146	-0,370	0,284	0,068	0,154	1,000	-0,355
7	-0,175	0,463	-0,256	-0,268	-0,281	-0,355	1,000
Extraction Method: Maximum Likelihood.							
Rotation Method: Oblimin with Kaiser Normalization.							

Analysis of correlations with other measures

Four tools which satisfy the psychometric quality criteria were used for correlation analysis tests: two questionnaires to measure psychosocial working conditions, i.e. Psychosocial Working Conditions (PWP) [5] and Organizational Risk of Bullying (ORM) [29] as well as two tools which operationalize well-being: D. Goldberg's General Health Questionnaire (GHQ 30) [11,19] and the Oldenburg Burnout Inventory (OLBI) questionnaire [1]. The analysis was carried out for all COPSOQ II PL scales. The adopted construct validity criteria are described in detail below. For greater analysis clarity they are presented according to given factors identified in the Polish version of the validated tool. Precise r-Pearson's correlation coefficient values subject to two-tailed significance criteria, stemming from the hypotheses stated below, are presented in table 5.

Scales part of Factor 1: "Physical violence"

The following scales make up the "Physical violence" factor:

1. "Threats of violence", which describes the sense of threat of violence, including physical violence at the workplace.
2. "Physical violence", which refers to experiencing physical violence.
3. "Sexual harassment", which refers to exposure to unwanted sexual attention.

All of these refer to a threat of bodily inviolability infringement. Construct validity of the scales which constitute the "Physical violence" factor was assessed on the basis of convergence of results for these scales with the occurrence of health disorders and burnout indicators. Such an approach is based on numerous empirical studies which show that various forms of violence at work, which include sexual harassment, are linked with negative consequences of symptoms of distress, symptoms of depression and anxiety, sleeping troubles, somatic problems or burnout [7,10]. The obtained Pearson's r coefficients are shown in table 5.

Scales which make up Factor 2: "Organizational relations"

8 scales make up the "Organizational relations" factor, i.e.:

1. "Justice" which applies to the perceived respect and equal rights of employees at the workplace.
2. "Trust regarding management", which refers to the reliability of information and the sense of security in relations with superiors.
3. "Quality of leadership", which refers to an assessment of superiors in terms of selected leadership skills.
4. "Social support from supervisors", which describes the perceived potential and actual help from a superior.
5. "Recognition" which applies to the personal experience of respect and equal rights in the workplace.
6. "Predictability", which means that the required information pertaining to work tasks and organization is passed on.
7. "Role clarity", reflecting certainty as to the scope of duties, targets and work evaluation criteria.
8. "Social inclusiveness", which refers to managing diversity at the workplace.

Validity tests of COPSOQ II PL scales which make up the "Organizational relations" factor were performed by correlating these scales with the general result of the GHQ 30 [11,19] questionnaire, burnout indicators measured using the OLBI [1] questionnaire as well as three scales from the ORM [29] questionnaire: "Clarity of roles and control", "Relations with the direct superior" and "Leadership", as well as two scales from the PWP [5] questionnaire which measured control (autonomy and participation) as well as the noticed support from superiors. Here, a negative correlation was assumed between COPSOQ II PL scales and the scales which measure pathologies at the workplace (ORM scales) [29] and negative consequences of occupational stress (GHQ 30 and OLBI) [1,11,19] and a positive correlation with resources ("Social support from supervisor" and "Control"). These assumptions are cohesive with the JD-R [2] theory as well as empirical studies [18]. Table 5 depicts the correlation results.

The scales part of Factor 3: "Health and well-being"

The "Health and well-being" factor comprises 11 COPSOQ II PL scales, including:

1. "Depressive symptoms", measured using anhedonia and bad mood symptoms.
2. "Stress", which describes the behavioral and emotional stress symptoms.
3. "Cognitive stress symptoms", which refers to the reactive problems with memory and attention span.
4. "Somatic stress symptoms", which refers to the physical stress related ailments.
5. "Burnout", which measures physical and emotional exhaustion.
6. "Sleeping troubles", which measures sleeping problems.
7. "Work-family conflict", which applies to the impact of work structure on private life.

8. "General health perception", which makes it possible to measure the subjective rating of one's own state of health.
9. "Self-efficacy", which refers to the self-assessment of one's own capacity.
10. "Family-work conflict", pertaining to the impact of an individual's private situation on their professional life.
11. "Job insecurity", which means the degree to which employment conditions are seen as stable.

The particular scales part of the "Health and well-being" factor were correlated with the results of GHQ 30 [11,19] and OLBI [1]. It was assumed that the COPSOQ II PL scales which measure disorders ("Sleeping troubles", "Burnout", "Stress", "Depressive symptoms", "Somatic stress symptoms", "Cognitive stress symptoms") will be positively correlated with the results of the aforementioned tools, whereas scales which measure well-being ("General health perception" and "Self-efficacy") will show negative correlations. These assumptions are reflected in the literature on the subject [18,27]. The "Job insecurity" scale was additionally correlated with a scale of the same name that is a part of the ORM [29] questionnaire, assuming a positive correlation between the two scales. Verification results of hypotheses pertaining to the measures of well-being taken into account by COPSOQ II PL are shown in table 5.

The scales part of Factor 4: Demands at work

The "Demands at work" factor comprises the following scales:

1. "Cognitive demands", which pertains to job aspects such as decision making, creativity and attention.
2. "Work pace", which refers to aspects such as time pressure or imposed work rhythm.
3. "Emotional demands", which applies to the need to engage emotions into the task at hand.
4. "Quantitative demands" - describes the degree to which work load reflects the available time.
5. "Role conflicts", pertaining to the requirement to function under conflicting demands, conflicting interests and to solve ethical dilemmas.
6. "Demands for hiding emotions", which means the inability to express emotions freely.
7. "Repeatability", which applies to the degree to which work is routine.

It was assumed that the results obtained for scales which make up the "Demands at work" factor should be positively correlated with the results of other questionnaires which measure workplace demands. The demands scale from the PWP [5] questionnaire was used to test this hypothesis. Furthermore, with reference to the JD-R [2] model, the COPSOQ II PL scales which measure demands were expected to be convergent with the results in "Exhaustion" and "Disengagement" from the OLBI [1] questionnaire. In accordance to literature [16,22,26], positive correlations were assumed between demands and the occurrence of mental health disorders measured by the GHQ-30 [11]. A detailed list of r-Pearson's coefficients obtained whilst verifying the above hypotheses is shown in table 5. Additionally, a correlation analysis between the "Repeatability" scale and monotony-diversity measure in the PWP questionnaire was performed. That analysis showed a positive relation between the tested variables (r= 0,305, p> 001).

The scales part of Factor 5: Psychological violence

The "Psychological violence" factor comprises the following scales:

1. "Unpleasant teasing" which pertains to the exposure to teasing at the workplace.
2. "Bullying", which makes it possible to measure the exposure to harassment and threats at the workplace.
3. "Gossip and slander", which reflects a subjective feeling of being the subject of insinuations at work.
4. "Conflicts and quarrels", pertaining to participation in conflicts at work.

The construct validity of the scales which constitute the "Psychological violence" factor was assessed on the basis of convergence of results for these scales with the occurrence of health disorders and burnout indicators. The hypotheses are based on numerous empirical studies which show that bullying and other forms of psychological violence at the workplace are correlated with the negative consequences of symptoms of depression and anxiety, somatic problems or burnout [9]. Furthermore, the convergence of COPSOQ II PL scales which measure the different forms of violence with the ORM [29] questionnaire results was considered to speak for their accuracy. This assumption is further supported by results of tests on individual and organizational bullying correlates. The obtained Pearson's r correlation coefficients are shown in table 5.

The scales part of Factor 6: Work commitment and development perspectives

The "Work commitment and development perspectives" factor includes 6 scales, i.e.:

1. "Possibilities for development", which pertains to making use of and shaping professional skills.
2. "Meaning of work", which measures the subjective feeling of the importance of the performed work.

3. "Job satisfaction", which refers to the subjective satisfaction derived from working.
4. "Commitment to the workplace", reflecting the degree to which a person shares and approves their workplace culture.
5. "Influence", used to measure the freedom of decision making.
6. "Job variation", which allows for a determination of job diversity.

Thus, one may venture to say that the "Commitment and development perspectives" factor measures the following:

1) job resources, such as the ability to control work, participation in decision making processes, feedback on the performed work, meaning of work, diversity of performed tasks and possibilities for development [6,9] and
2) the employee's attitudes towards their job (job satisfaction, commitment to the workplace), which remain in a close relation with the said resources [24].

Hence, according to the JD-R[2] model, they should be related to health and burnout. And the correlation should be negative: the higher the signs of commitment, the less health problems and burnout symptoms. Additionally, positive relations with other resource measures should also manifest themselves, e.g. the degree of control from the PWP [5] questionnaire.

The scales part of Factor 7: Relations in a team

The "Relations in a team" factor comprises the following scales:

1. "Social community at work", which applies to the atmosphere at the workplace.
2. "Social support from colleagues", which describes experiencing help from colleagues.
3. "Mutual trust between employees", which defines the level of openness and trust in relations with colleagues.

Quality relations at work are considered to be social resources, and thus in accordance with the JD-R[2] theory, high scores in corresponding COPSOQ II PL scales should exhibit a negative correlation with indicators pointing to deteriorating health and burnout. They should also manifest a positive correlation with other tools for measuring job resources associated with colleagues, such as results of "Support from colleagues" in the PWP [5] questionnaire or shortages thereof, such as the "Social atmosphere" from the ORM [29] questionnaire. Results of the conducted correlation analysis are shown in table 5.

Tab. 5. Correlations between COPSOQ II PL scales which make up the "Physical violence", "Organizational relations", "Health and well-being", "Demands at work", "Psychological violence", "Work commitment and development perspectives", "Relations in team" and other tools (Goldberg's GHQ 30 General state of health questionnaire, Oldenburg Burnout Inventory (OLBI) questionnaire, Organizational Risk of Bullying (ORM) and Psychosocial Working Conditions (PWP) questionnaires).

	Scale	General health (GHQ 30)	Exhaustion (OLBI)	Disengagement (OLBI)	Role clarity and control (ORM)	Relation with superior (ORM)	Leadership (ORM)	Job insecurity (ORM)	Organizational risk of bullying (ORM)	Social climate (ORM)	Support from superiors (PWP/ PWP)	Demands (PWP)	Control (PWP)	Support from colleagues (PWP)
Factor 1 Physical violence	Threats of violence	.256**	.178**	.243**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Physical violence	.172**	0.092	.197**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Sexual harassment	.128*	.102*	.169**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Factor 2: Organizational Relations	Justice and respect	-,244**	-.412**	-.524**	-.622**	-.684**	-.720**	N/A	N/A	N/A	.693**	N/A	N/A	N/A
	Trust regarding management	-.292**	-.439**	-.493**	-.605**	-.726**	-.697**	N/A	N/A	N/A	.731**	N/A	N/A	N/A
	Quality of leadership	-.186**	-.370**	-.477**	-.597**	-.725**	-.739**	N/A	N/A	N/A	.705**	N/A	N/A	N/A
	Social support from supervisors	-.208**	-.355**	-.397**	-.544**	-.701**	-.670**	N/A	N/A	N/A	.687**	N/A	N/A	N/A
	Rewards (Recognition)	-.243**	-.457**	-.497**	-.579**	-.701**	-.669**	N/A	N/A	N/A	.714**	N/A	N/A	N/A
	Predictability	-.249**	-.424**	-.522**	-.607**	-.610**	-.617**	N/A	N/A	N/A	.619**	N/A	N/A	N/A
	Role clarity	-.261**	-.353**	-.436**	-.606**	-.511**	-.562**	N/A	N/A	N/A	.534**	N/A	N/A	N/A
	Social inclusiveness	-.116*	-.213**	-.260**	-.307**	-.350**	-.379**	N/A	N/A	N/A	.310**	N/A	N/A	N/A

	Scale	General health (GHQ 30)	Exhaustion (OLBI)	Disengagement (OLBI)	Role clarity and control (ORM)	Relation with superior (ORM)	Leadership (ORM)	Job insecurity (ORM)	Organizational risk of bullying (ORM)	Social climate (ORM)	Support from superiors (PWP/ PWP)	Demands (PWP)	Control (PWP)	Support from colleagues (PWP)
Factor 3:Health and well-being	Depressive symptoms	.630**	.579**	.457**	N/A	N/A	N/A	.349**	N/A	N/A	N/A	N/A	N/A	N/A
	Stress	.639**	.671**	.556**	N/A	N/A	N/A	.315**	N/A	N/A	N/A	N/A	N/A	N/A
	Cognitive stress	.605**	.598**	.455**	N/A	N/A	N/A	.298**	N/A	N/A	N/A	N/A	N/A	N/A
	Somatic stress	.531**	.556**	.408**	N/A	N/A	N/A	.293**	N/A	N/A	N/A	N/A	N/A	N/A
	Burnout	.572**	.666**	.553**	N/A	N/A	N/A	.257**	N/A	N/A	N/A	N/A	N/A	N/A
	Sleeping troubles	.532**	.537**	.379**	N/A	N/A	N/A	.298**	N/A	N/A	N/A	N/A	N/A	N/A
	Work–family conflict	.506**	.616**	.459**	N/A	N/A	N/A	.367**	N/A	N/A	N/A	N/A	N/A	N/A
	Self rated health	-.382**	-.521**	-.390**	N/A	N/A	N/A	-.171**	N/A	N/A	N/A	N/A	N/A	N/A
	Self-efficacy	-.335**	-.374**	-.250**	N/A	N/A	N/A	-.206**	N/A	N/A	N/A	N/A	N/A	N/A
	Work–family conflict	.319**	.247**	.230**	N/A	N/A	N/A	.227**	N/A	N/A	N/A	N/A	N/A	N/A
	Job insecurity	.297**	.252**	.148**	N/A	N/A	N/A	.395**	N/A	N/A	N/A	N/A	N/A	N/A
Factor 4: Demands at work	Cognitive demands	.264**	.224**	.224**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.557**	N/A	N/A
	Work pace	.270**	.354**	.356**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.401**	N/A	N/A
	Emotional demands	.347**	.336**	.316**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.445**	N/A	N/A
	Quantitative demands	.348**	.533**	.488**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.325**	N/A	N/A
	Role conflicts	.341**	.414**	.442**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.382**	N/A	N/A
	Demands for hiding emotions	.232**	.186**	.242**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.298**	N/A	N/A
	Work repetitiveness	.200**	.219**	.293**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	0.066	N/A	N/A
Factor 5: Psychological violence	Unpleasant teasing	.330**	.285**	.305**	N/A	N/A	N/A	N/A	.447**	N/A	N/A	N/A	N/A	N/A
	Bullying	.234**	.234**	.288**	N/A	N/A	N/A	N/A	.465**	N/A	N/A	N/A	N/A	N/A
	Gossip and slander	.314**	.311**	.377**	N/A	N/A	N/A	N/A	.428**	N/A	N/A	N/A	N/A	N/A
	Conflicts and quarrels	.312**	.324**	.350**	N/A	N/A	N/A	N/A	.375**	N/A	N/A	N/A	N/A	N/A
Factor 6: Work commitment and development perspectives	Possibilities for development (skill discretion)	-.145**	-.312**	-.456**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.443**	N/A
	Meaning of work	-.324**	-.439**	-.623**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.528**	N/A
	Job satisfaction	-.387**	-.541**	-.640**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.580**	N/A
	Commitment to the workplace	-.350**	-.465**	-.594**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.541**	N/A
	Influence	-.188**	-.281**	-.332**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.458**	N/A
	Work variety	-.178**	-.246**	-.264**	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	.227**	N/A

	Scale	General health (GHQ 30)	Exhaustion (OLBI)	Disengagement (OLBI)	Role clarity and control (ORM)	Relation with superior (ORM)	Leadership (ORM)	Job insecurity (ORM)	Organizational risk of bullying (ORM)	Social climate (ORM)	Support from superiors (PWP/ PWP)	Demands (PWP)	Control (PWP)	Support from colleagues (PWP)
Factor 7: Relations in team	Social community at work	-.257**	-.362**	-.405**	N/A	N/A	N/A	N/A	N/A	-.523**	N/A	N/A	N/A	.592**
	Social support from colleagues	-.118*	-.288**	-.286**	N/A	N/A	N/A	N/A	N/A	-.337**	N/A	N/A	N/A	.562**
	Mutual trust between employees	-.313**	-.355**	-.446**	N/A	N/A	N/A	N/A	N/A	-.560**	N/A	N/A	N/A	.551**

* $p < 0.05$ ** $p < 0.01$; N/A – non applicable;

DISCUSSION

The COPSOQ II PL is both reliable as well as valid, despite being structurally different from the original version.

Reliability

The reliability of scales may be considered to be satisfactory as the Cronbach's α coefficient is more than 0,7 [28]. The only scale which failed to reach such a value for this coefficient was "Job variation", where α=0,394. It should also be pointed out that the reliability of that scale was also low in its original COPSOQ II questionnaire version, with α=0,5 [23]. The following items are part of the scale: "Is your job varied?" and "In your job are you frequently forced to repeat the same actions?". The content of these items and the low Cronbach's α coefficient value shows the need to split the scale into two, both one-item. The first scale was named "Job variation" (Is your job varied?) and the second "Repeatability" (In your job are you frequently forced to repeat the same actions?). The new scales were used during validity analysis. The Cronbach's α coefficient value is satisfactory for all other scales. Its values are between 0,701 (commitment to the workplace) to 0,927 (Quality of leadership). Thus, the tool should be considered to be reliable, and as such it qualifies for further analyses.

Validity

Both analyses carried out as part of construct validity tests yielded satisfactory results.

Factor analysis

7 factors were identified in the Polish COPSOQ II version, with different scales than those in the original.

The factors identified in the Polish version remain cohesive and theoretically valid. Apart from all the scales in the original version, the "Job demands" factor in the Polish version also includes two additional scales: "Role conflicts" and "Repeatability". In tests carried out on Polish employees, role conflicts remains a dimension of demands associated with a job, as shown by Cieślak and Widerszal-Bazyl [5] in papers on the Psychosocial Working Conditions (PWP) questionnaire. Similarly, monotony (as opposed to diversity) in the PWP questionnaire is treated as a demand. It should be noted that in the COPSOQ II PL validity sample, "Repeatability" was part of the "Demands at work" factor, albeit with a negative sign, which suggests that when it comes to that environment, work routine helps to reduce the burden. Such a result is understandable if we take into account that the test was carried out on a body which comprises uniformed services, wherein as a rule working according to a pre-determined procedure is conducive to a better performance of given tasks and affords greater safety to employees. In the Polish version of COPSOQ II, the scales associated with workplace pathologies were clearly defined. Instead a single "Offensive behaviors" factor, there are two in the Polish version: "Physical violence" which comprises scales associated with danger or infringement of physical inviolability and "Psychological violence" - associated with bullying and other forms of personal dignity infringements short of physical violence. Such a division seems to be a better match for the cultural relations in Poland. The impact of the cultural context is also visible when it comes to scales associated with interpersonal relations and organizational culture. The "Organizational relations" factors identified in the Polish version and "Relations within a team" reflect a clear distinction between psychosocial conditions shaped by superiors and colleagues. That difference between the Polish and the Dutch COPSOQ II versions remains cohesive with comparative tests between the national cultures of

the two countries. As shown by Hofstede [13], the level of cultural hierarchy and acceptance associated with the hierarchy of social inequalities is three times stronger than in Denmark. In the Polish version, the scales which originally comprised the "Work organization and job contents" factor were included in the "Job commitment and development perspectives". This factor also included "Job satisfaction", which was an element of the "Work-individual relation" factor in the original version. However, subject literature [8] shows that there are significant links between job satisfaction and the meaning of work and job resources [24] as perceived by the individual, that is why the obtained structure of the factor in question remains theoretically valid. Whereas face validity dictates the performed factor name change.

The "Work-individual relation" did not figure in the Polish version at all. In the Polish version all the scales of that factor, with the exception of "Job satisfaction" were part of the "Health and well-being" factor. The "Job insecurity" scale is made up of questions which essentially apply to distress associated with lack of job security. All four questions in that scale begin with the phrase "Are you worried about …?".That is why including that scale in the "Health and well-being" factor remains fully justifiable. The remaining two scales, i.e. "Family-work conflict" and "Work-family conflict" may be treated as a social health disorders operationalization [14].

Analysis of correlations with other measures

Criterion validity was tested using convergence analysis of measurements with other tools used to measure job demands and resources as well health consequences such as mental health disorders or burnout symptoms, the validity of which has already been verified. The correlation coefficients published in the paper were not adjusted by scales' reliability factors of COPSOQ II PL or other tools used as a criterion of validity. Thus, the real correlation coefficient values are undoubtedly higher that those shown in table 5 [4]. The strength of the relations was assessed in accordance with the classification proposed by Guilford [12].

Physical violence

Convergent validity indexes for all scales which operationalize physical violence at the workplace remain in accordance with theoretical assumptions. The correlations are statistically significant, and they are positive, which reflects the initial hypotheses. The power of disclosed relations agree with the results obtained by other researchers engaged with the consequences of experiencing physical violence at the workplace amongst uniformed services [10]. After years of studies on the interpersonal aspects of bullying, referring to the personalities of victims and perpetrators, after including organizational factors into the research, it turned out, that in correctly managed organizations bullying was scarce, even if individuals whose traits are conducive to bullying are employed therein [9]

Organizational relations

Also, all COPSOQ II PL scales which measure "Organizational relations" turned out to be valid pursuant to the adopted criteria. The performed correlation analyses yielded statistically significant results, the direction of the identified relations remains as expected and most relations are strong or very strong. Scales being a part of the "Organizational relations" factor were least correlated with the general state of health measured by GHQ 30 [11,19], which is most probably associated with the nature of the validation group. Prison service officers are selected on the basis of their psychological suitability for the job, and as such they are a priori well suited for the working conditions and exhibit above average psychophysical resilience.

Health and well-being

All the scales part of the COPSOQ II PL used to measure health and well-being turned out to be valid. The obtained values of the assumed convergent validity indicators, even though below values which could have been expected, remain satisfactory.

Demands at work

All the assumed correlations pertaining to demands turned out to be statistically significant, whereas the lion's share was at least above-average. The convergent validity of the "Demands for hiding emotions" scale which is weakly or to a slight degree correlated with the adopted validity measures may raise some doubts, albeit its correlation with all measures is statistically significant. Here, the weak or slight relation with the health disorder measures adopted as validity indicators is surprising. Only the specification of the tested sample could have had an impact on the strength of the relation. Earlier tests point to links between hiding emotions and negative health consequences pertained to individuals which frequently come into contact with others as part of their

professional duties [16], nevertheless in most cases these are representatives of professions where a psychological pre-selection is not carried out. Upon starting their job, the subjects part of the validity sample, are subjected to a psychological assessment in terms of emotional control, which might have a significant impact on expressing negative psychological health symptoms. That is why, weak correlations, but ones which are statistically significant and in accordance with expectations as to their direction, may be considered to be satisfactory in this case. At the same time, this might indicate the need for additional "Demands for hiding emotions" scale validity tests, for example by testing convergent validity with the CECS questionnaire [15] and by performing a correlation analysis with health well-being measures in other professional groups.

Psychological violence

The scales part of the COPSOQ II PL for measuring "Psychological violence" indicate a convergence of results with tools measuring organizational risks for bullying and possible health consequences associated with experiencing psychological bullying at the workplace. The obtained correlation results are not only statistically significant and in accordance with the expected direction, but also at least average in terms of strength, which should be taken to be satisfactory in light of the higher psychological resilience of the tested group.

Work commitment and development perspectives

Each COPSOQ II PL scale which was part of the "Commitment and development perspectives" also turned out to be valid. All the correlation coefficients are statistically significant, and their direction reflects theoretical expectations. The strength of those relations varies depending on the scale and criterion, however the results may be considered to be satisfactory.

Relations within a team

The theoretical assumption pertaining to the convergence of measurements obtained using "Social support from colleagues", "Social community at work" and "Mutual trust between employees" and the results obtained GHQ 30 [11,19], OLBI [1], ORM [29] and PWP [5] turned out to be correct. And in this case, all correlations were also statistically significant, in accordance with the expected direction, and their strength may be considered to be satisfactory.

CONCLUSIONS

In accordance with the expectations of its authors, the Copenhagen Psychosocial Questionnaire is to be used to measure the psychosocial work environment, amongst others in order to assess occupational risk [23]. Following validation in a homogeneous work environment, which is recommended also by other researchers [3], the COPSOQ II PL satisfies the reliability and validity criteria, and also objectiveness and standardization criteria. From the point of view of criteria which a good psychometric tool for measuring psychosocial work hazards should satisfy, the COPSOQ II PL may be considered to be sufficient. It should also be noted that the standards for tools of this type should be developed for given professions or work environments. It is also worth pointing out that the prison service is a specific and thus far the only professional environment where the Polish COPSOQ II version was applied. Therefore, further tests on other work environments are recommended which would facilitate the development of standards and provide another verification of its psychometric properties.

AUTHORS' DECLARATION:

Study Design: Katarzyna Orlak, Dominik Gołuch, Mikołaj Stolarski; **Data Collection:** Katarzyna Orlak, Dominik Gołuch, Mikołaj Stolarski; **Statistical Analysis:** Katarzyna Orlak, Dominik Gołuch; **Manuscript Preparation:** Katarzyna Orlak, Dominik Gołuch, Mikołaj Stolarski. The Authors declare that there is no conflict of interests.

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ORIGINAL ARTICLE

THE MODEL OF RISK MANAGEMENT IN THE FIELD OF AVIATION MEDICINE IN THE ASPECT OF THE ACTIVITIES OF THE MILITARY INSTITUTE OF AVIATION MEDICINE

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Abstract: The Military Institute of Aviation Medicine (the Institute) is subject to complex legal conditions resulting from the actions of legislative and executive bodies of the state and their subordinate organs. These conditions, customers and other stakeholders have an impact on the context of the organization. The integrated management system of the Institute, which is compliant with ISO 9001:2015 [10], ISO 27001:2017 [8] and AQAP 2120:2016 [3] standards, systematizes individual scopes of activities so that the requirements of all parties concerned are met. The article presents the risk management model on the basis of which the risk management methodology of the Institute was developed.

Keywords: services, quality management, procedures, risks, opportunities

Figures: 7 • **Tables:** 6 • **References:** 12 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2020 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

Managing an organization requires setting its strategic objectives and defining external and internal parameters that contribute to the proper process management and the ability to achieve the intended results.

The complex external and internal conditions of the Military Institute of Aviation Medicine [1,2,4] and the requirements of its customers necessitate a high quality of management. Therefore, the pillar of the management structure at Institute is the ISO 9001:2015 standard. Its structure and requirements enable the construction and maintenance of simple or complex integrated management systems incorporating also other standards. To meet the expectations of parties concerned, the management of Institute has introduced and maintained an integrated management system based on ISO 9001;2015, AQAP 2110:2016 and ISO 27001:2017 standards.

In accordance with the requirements of ISO 9001:2015 standard, the Institute:

- demonstrates the ability to continuously provide services in accordance with the requirements of the customer and the law,
- strives for customer satisfaction through effective use of a quality management system and its continuous improvement,
- plans activities related to risks and opportunities.

The AQAP 2110:2016 standard is based on the requirements of ISO 9001:2015, expanded with specific NATO requirements. The declaration of application of this standard is an offer of the Institute that takes into account, among other things, the risks associated with the provision of the service (product).

ISO 27001:2017 specifies requirements ensuring the confidentiality, integrity and availability of information and requirements for the management of identified risks and opportunities.

The ISO 9001:2015 and ISO 27001:17 standards set out the requirement that risks and opportunities must be included when developing a management system. An opportunity, according to ISO 9001:2015, leads to taking risk in order to seize this opportunity. Therefore, an opportunity can be managed through the risk it entails.

Risk management is now an integral part of managing any business [6,12].

According to ISO 31000:2009 [9], risk is defined as the effect of uncertainty on objectives. According to the PWN Dictionary of Polish Language [11], risk is:

- a possibility that something might go wrong; also: an undertaking the outcome of which is uncertain,
- to dare to face such a danger.

Risk management consists in identifying, correctly classifying and then dealing with it in the most beneficial and safe manner.

Risk management covers two areas of activity of an organization. The first is the strategic risk, taken by the management most often in the

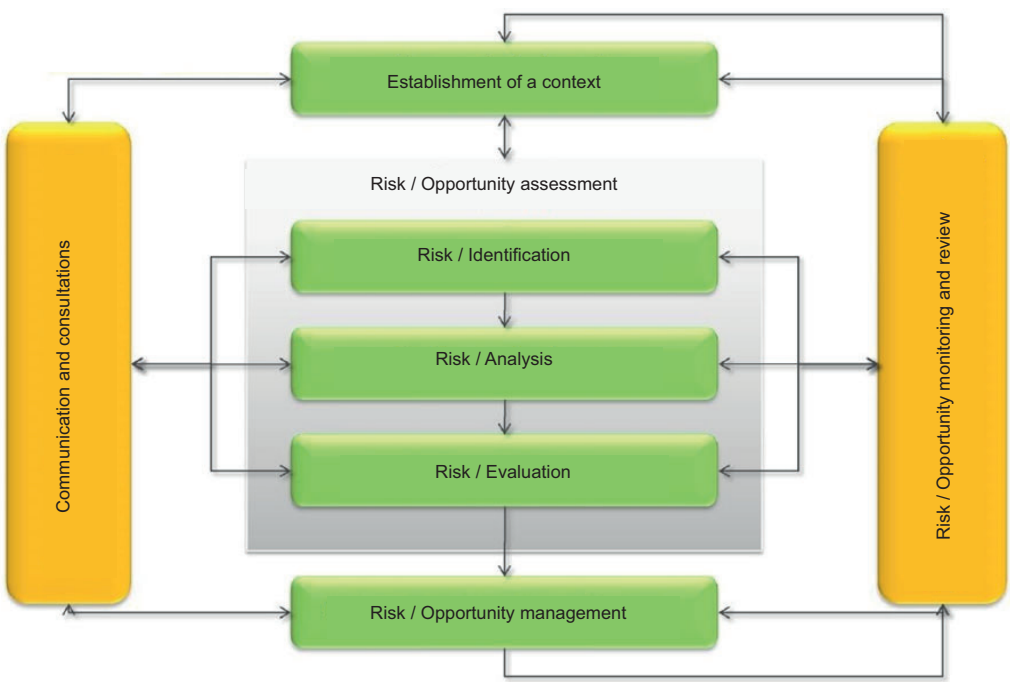

Fig. 1. Diagram of risk and opportunity management.

environment-organization relation. The second area is operational risk, resulting from the process of manufacturing a product (material product or service) [7].

PURPOSE OF THE STUDY

The aim of this study is to present the risk management methodology applied in the Military Institute of Aviation Medicine, which employs a model based on selected risk analysis methods taking into account the recommendations and requirements of ISO 9001:2015, AQAP 2110:2016, ISO 27001:2017 standards, as well as the requirements and expectations of all parties concerned.

RISK MANAGEMENT METHODOLOGY

The methodology systematizes the management of the identified risks related to the implementation of statutory tasks, such as planning the activity of Institute, and systematizes the management of the identified risks in business processes related to the conclusion and performance of contracts signed for the provision of services. The methodology takes into account the requirements of the ISO 9001:2015, AQAP 2110:2016 and ISO 27001:2017 standards as well as the requirements of the Minister of National Defense on planning and settlement of activities in the Ministry of National Defense [5]. The methodology in the field of risk management:

- takes into account requirements resulting from the context of the organization and business requirements,
- meets the requirements of the "Management Control Regulations",
- takes into account the risks associated with information assets,
- systematizes the development of the "Product Quality Plan".

The presented methodology contains a list of basic concepts, general rules of risk management, description of risk components, tables presenting the indexes of threat levels, effects, security and vulnerability, as well as adopted probability indexes. The methodology indicates the sources of input data and describes the methods of calculating the level of risk and the adopted criteria for its acceptance. The necessity to use the context of the Institute in the cyclical process of identification of risks and opportunities was pointed out. The general diagram of risk or opportunity management is shown in fig. 1.

Risk components

The methodology takes into consideration:

- assets / processes / tasks / objectives,
- value (significance) of assets / processes / tasks / objectives,
- location / form of assets,
- potential threats,
- probability of occurrence of these threats,
- vulnerability of assets / processes / tasks / objectives to threats,
- impact of threats on the security of assets / processes / tasks / objectives,
- effectiveness of the applied security measures.

The diagram of the structure of risk components is shown in fig. 2.

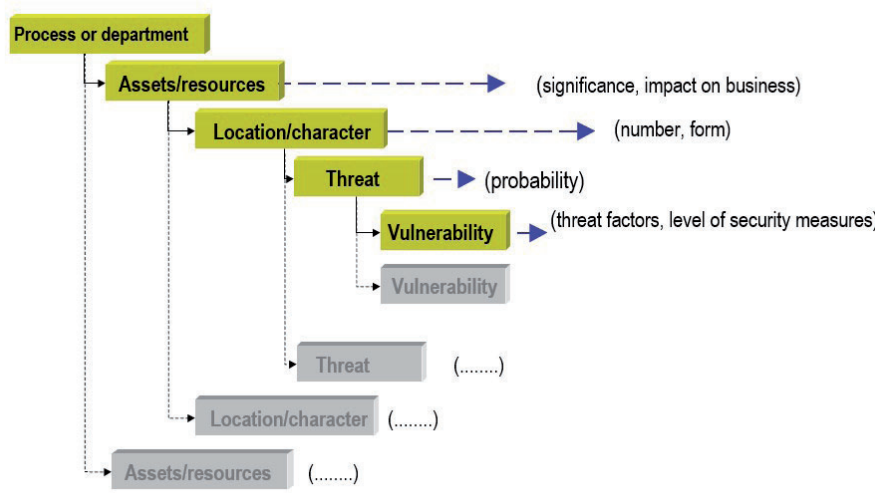

Fig. 2. Diagram of the structure of risk components.

The course of the risk management process

In the process of planning current activities, the result of an analysis of the organization's context (here: Institute) should be taken into account. This planning should consider the risks included in the risk register referred to in the requirements of the Minister of National Defense on planning and settlement of activities in the Ministry of National Defense [5]. As a result of the context analysis, apart from risks, opportunities may be pointed out.

The risk management should be started by carrying out an inventory of assets, processes or objectives in the organizational units within the system and determining their value for the Institute (as an organization), as well as identifying associated threats. Then the relevant characteristics of a given risk should be distinguished, such as the area concerned, the probability of occurrence, the impact of the effects of the event.

Due to the different required purposes of risk analysis and the expected transparency of the analysis results, it is necessary to distinguish three aspects of the risk analysis used at the Institute for:

1) planning of the Institute's activities for the period of the task implementation or for the upcoming planning year,
2) ensuring continuity of information (availability, integrity, confidentiality),
3) performancing of a separate agreement concluded in accordance with the requirements of AQAP 2110:2016.

The risk analysis concerns the assets held, processes carried out at Institute and the assessment of their effect (impact) on its functioning. The effect index values listed in tab. 1 show the power with which neglected assets or a disturbances in functioning of a process may cause disturbances in the functioning of the entire organization.

It is a good practice to identify real threats - i.e. those that can and do occur in the organization (specific breakdowns, power failures, unauthorized transmission of information, theft), and not only those that are easy to name (terrorist attack, fuel dumping by aircraft during emergency landing, especially if there is no airport).

The number of threats identified may be large, which may reflect the reliability of the conducted analysis. However, the identification process should be optimized in terms of the possibility of obtaining up-to-date results on the most relevant threats. If the analysis is too extensive - with irrelevant, unlikely elements - it may be already outdated at the time of its completion, or the cost of obtaining it - the time spent on managing the identified risk factors - will be disproportionately high.

Not all threats occur equally often or are equally likely to occur, hence the concept of the probability of occurrence of a threat has been introduced. Equipment failures or lack of power supply are certainly more frequent than fires or hurricanes with wind force uprooting trees.

A five-grade scale should be adopted to assess the probability: high, large, significant, moderate, small. For each level of probability, a value of the probability assessment index has been assigned. These levels are described in tab. 2.

Tab. 1. The effect (impact) of the event on the functioning of the Institute (effect, impact on business).

Score	Value (E)	Description
Critical	5	a loss or breach of the security or elements of an organizational unit or a process results in interruption of the continuity of the Institute's activity a loss or breach of the security of personal data or the process results in high material and non-material losses, identity theft and loss of control over personal data for the data subject
Very high	4	a loss or breach of the security or elements of an organizational unit or a process results in interruption of the continuity of activity of the Institute's organizational unit a loss or breach of the security of personal data or the process may have a negative impact on the rights and freedoms of data subjects, e.g. as a result of loss of control over personal data, material or non-material loss
Serious	3	a loss or breach of the security or elements of an organizational unit or a process may have a negative impact on the continuity of the Institute's activity a loss or breach of the security of personal data or the process may have a negative impact on the rights and freedoms of data subjects, e.g. as a result of loss of control over personal data, non-material loss
Significant	2	a loss or breach of the security or elements of an organizational unit or a process causes difficulties in the normal functioning of the Institute a loss or breach of the security of personal data or the process has a major impact on the rights and freedoms of data subjects, e.g. as a result non-material loss
Small	1	a loss or breach of the security or elements of an organizational unit or a process has a limited impact on the functioning of the Institute a loss or violation of the security of personal data or the process has a limited impact on the rights and freedoms of data subjects

where "Critical" means the greatest impact and "Small" – the smallest impact.

Tab. 2. The assessment of the probability of occurrence of a threat.

Score	Indicator (P)	Description	
High	5	occurs frequently (e.g. once a month) or regularly with a fixed frequency, or is very likely to occur	>90%
Large	4	occurs relatively frequently (e.g. once a quarter) or regularly with a fixed frequency, or is likely to occur	76-90%
Significant	3	occurred in the last year, occurs irregularly, or there is a real probability of occurrence	41-75%
Moderate	2	has occurred a single time in the last year or is unlikely to occur	10-40%
Small	1	has not occurred even once in the last year and is unlikely to occur	<10%

where "High" is associated with the highest probability and "Small" with the lowest.

Tab. 3. The assessment of the impact of the specific characteristics of the assets on the degree of vulnerability taking into account confidentiality, or integrity, or availability.

Score	Index (Vc, Vi, Va)	Description
Significant	1	assets with certain characteristics are or will be in an environment conducive to the occurrence of the event for an indefinite period
Negligible	0	the characteristics of the asset and its environment are not conducive to the occurrence of the event

Tab. 4. Level of security measures.

Score	Value (S)	Description
High	15	the existing security measure protects effectively against known threats
Significant	10	there are partial security measures that protect only selected areas but are fully effective
Moderate	5	has not occurred a single time in the last year, but there is a real probability of occurrence
Negligible	1	has not occurred even once in the last year and is unlikely to occur

where "High" means the highest value (the highest level of security) and can reach the value of "∞". However, at this stage of effectiveness of security measures a value of "15" is assumed. The "Negligible" level means the lowest value (the lowest level of security measures).

Another group of factors affecting the level of risk are vulnerabilities, i.e. weaknesses in our assets or processes - features and properties of the asset or process that may be exploited by the threat, which may increase the probability of occurrence of an event in specific circumstances.

For example: We protect paper from burning because it is not resistant to fire. Paper is vulnerable to burning.

The information written on paper is at risk of being destroyed, because paper is flammable when the temperature exceeds approximately 250 degrees Celsius. It can be assumed that information written on paper is threatened by high temperatures.

The steel hull of a ship is protected against seawater which accelerates the process of corrosion, because the steel it is made of is not resistant to corrosion. The steel hull of a ship is vulnerable to leakage.

This ship is in danger of sinking because of its steel hull, which is vulnerable to leakage due to corrosion accelerated by seawater.

It can be assumed that it is threatened by seawater accelerating the process of corrosion of the steel hull.

A specific group of assets consists of information assets characterized by vulnerabilities (V) to which apply the following assessment criteria:

1) confidentiality - protection against unauthorized access (Vc),
2) integrity - protection against breaching of information (Vi),
3) availability (Va).

The methodology uses the same scale of impact assessment for the abovementioned vulnerabilities (tab. 3). The vulnerabilities classified as "Significant" increase the value of the probability index (see Formula No. 3).

The impact of the threat on confidentiality, integrity and availability (information security) should be assessed and the level of effectiveness of the implemented security measures should be determined. These are the elements completing

the analysis. The scale of assessment of security levels is specified in tab. 4.

Determination of risk level and residual risk

The risk of an asset (also: process, task, objective) is the basis for assessing the real loss of security of this asset against other assets in a situation where no security measures are yet in place. The list of assets should be arranged according to the associated risk level index values. This list is the basis for determining the methods of risk management and which security features should be selected in order to protect the riskiest assets.

The following calculation method is generally accepted for obtaining mutually comparable indexes of the level of risk of assets. Formula No. 1 is to be filled in with the numerical values from tables 1 to 4, assigned to each item respectively.

$$R = P * E \quad (1)$$

where:

R – risk of an asset / process / task / objective

P – probability of occurrence of the threat (index value)

E – effect (impact) of the occurrence of the threat

$$P = P * (1 + V) \quad (2)$$

where:

V– vulnerability of the asset process, task, objective

$$V = V_c + V_i + V_a \quad (3)$$

where:

Vc, Vi, Va – vulnerability of an information asset, respectively to: confidentiality, integrity, availability.

After the selection and implementation of security measures, the risk assessment should be carried out again, but already considering the levels of security provided by the implemented measures. For each asset, after taking into account the security measures, the residual risk must be calculated.

The residual risk is, as a rule, calculated using the following Formula No. 4:

$$Rs = R / S \quad (4)$$

where:

Rs – residual risk of an asset / process / task

R – risk of an asset / process / task

S – effectiveness of the applied security measures.

Based on the obtained residual risks of the assets, the level of "acceptable risk" should be determined and set as a fixed value of risk below which the risks of assets are considered acceptable.

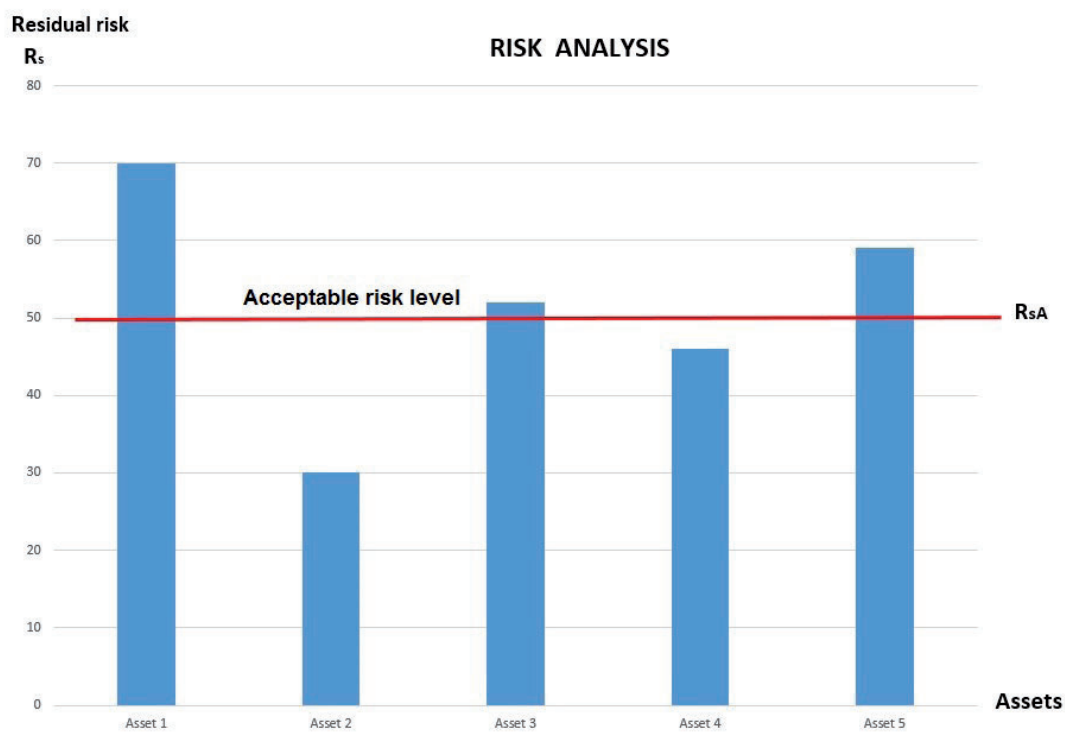

Fig. 3. The result of a risk assessment with a defined level of acceptable residual risk (RsA).

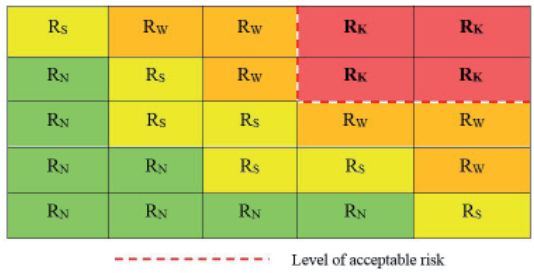

Fig. 4. A risk matrix (R), where: RN - minor risk, RS - moderate risk, RW - major risk, RK - critical risk.

Criteria for the acceptance of risk and the level of acceptable risk

An essential element of the risk assessment process is the definition of "risk assessment criteria", i.e. the approach adopted for dividing risks into acceptable and non-acceptable. The risk acceptance criterion should be to seek to equalize the levels of risk for all assets, in line with the principle that the strength of the security system is indicated by its weakest (riskiest) element. The highest limit value for acceptable residual risk (RsA) should be determined. The assets with risks below the value determined by cutting off the "risk chimneys" have such a risk level that the Institute's management is now ready to accept them .

The level of the acceptable residual risk (RsA) is a specific risk value. In the diagram, an example of which is shown in fig. 3, the level of acceptable risk is marked by a horizontal line running throughout RsA value. The level of acceptable risk should be determined during each risk analysis.

The result of a risk analysis can be presented as a risk quantification matrix, also called the risk matrix (fig. 4) with a dashed line indicating the level of acceptable risk.

The result of the risk analysis can also be presented in a tabular layout (fig. 5) in which, apart from presenting the current value of the level of acceptable risk (RsA), the forecasted result of the level of acceptable risk resulting from the implementation of planned improvement measures can also be determined.

Detailed guidelines for risk analysis, assessment and management

The risk analysis should cover all areas of the Institute's activity that affect the realized processes and be prepared with the participation of the representatives of:

- the main processes,
- the Institute's management,
- Chief Accountant Division,
- Administrative Division (excluding the IT Laboratory),
- IT Laboratory,
- Security Division.

A risk analysis should be carried out:

- when new risks are identified,
- when planning organizational changes,
- in accordance with the adopted plan of activity of the Institute.

The owners of the main processes are responsible for the preparation of partial risk analysis

Risk level index				
R		R_s - current assessment	R_s –subsequent planned periods	
100	critical	Unacceptable - R_{sU}		
50				
16		Acceptable - R_{sA}		
15	major	R_{sA} n		
12		…		
10		…	Unacceptable - R_{sU}	
9	moderate	…	Acceptable - R_{sA}	
8		…	…	
5		R_{sA} 4	R_{sA} 4	Unacceptable - R_{sU}
4	minor	R_{sA} 3	R_{sA} 3	Acceptable - R_{sA}
3		R_{sA} 2	R_{sA} 2	R_{sA} 2
1		R_{sA} 1	R_{sA} 1	R_{sA} 1

Level of acceptable risk

Fig. 5. Limit values of the index grouping risk (R) and residual risk (Rs).

covering assets in their area and submitting them to the Plenipotentiary for the Integrated Management System, who will combine them to obtain a summarized result of the analysis for the Institute's area covered by the system.

For risk analysis one should use a spreadsheet available on the Institute intranet site - a document in the form of an electronic file.

The result of the assessment process should be prepared in the form of a list of the Institute's assets that are most at risk. It allows the Management to decide for which assets additional security measures (technical or organizational) should be implemented first.

The Management should define a risk management plan for risks with values exceeding the adopted acceptable level (RsA). This plan may also include the allocation of resources (including financial ones) to secure the assets that are most at risk and, consequently, reduce the level of residual risk of these assets.

A graphical presentation of the level of acceptable risk should be made in the form of a chart for the assets that are most at risk (fig. 3).

Determining the level of acceptable risk completes the risk assessment stage.

The risk management plan should be prepared in accordance with the form available on the Institute intranet site in the form of an electronic file.

Risk management principles according to AQAP 2110:2016

In accordance with the requirements of the AQAP 2110:2016 standard, contracts for the provision of services by the Institute should take into account the risk associated with the process, as well as the specific features of the product or service, and should also define the principles of risk management associated with the performance of the contract concluded. The AQAP 2110:2016 standard can be applied in case of special requirements of contracts performed for the Minister of National Defense.

In the presented methodology for this type of contracts a method of qualitative risk analysis was adopted. In order to determine the level of risk of factors influencing the performance of contracts, a commonly used risk matrix was used (fig. 6), where:

Level of risk = Probability * Impact on contract performance

Tab. 5. Impact on contract performance.

Score	Value	Description
Critical	4	a loss of a process component or violation of its security results in an interruption of realization of the contract;
Major	3	a loss of a process component or violation of its security may have a negative impact on the date of completion of the contract;
Significant	2	a loss of a process component or violation of its security causes difficulties in the normal course of contract performance;
Normal	1	a loss of a process component or violation of its security has a limited impact on contract performance;

where "Critical" means the greatest impact and "Normal" – the smallest impact.

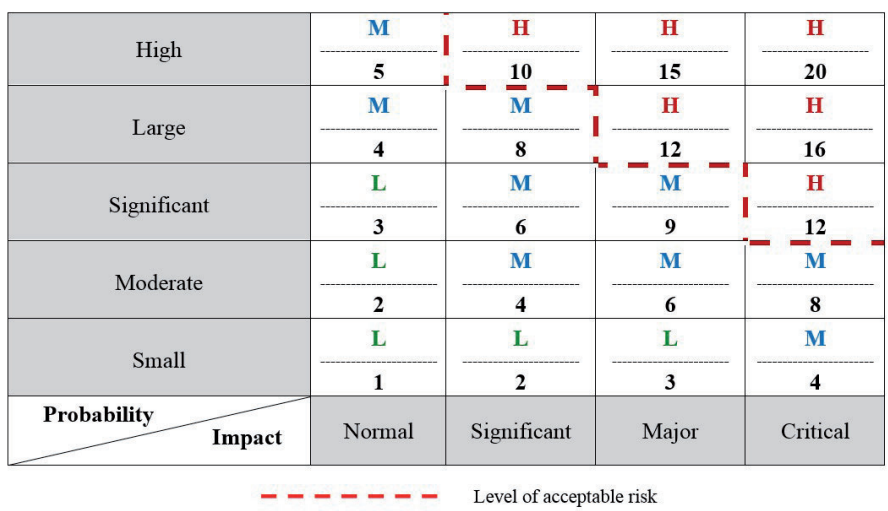

Fig. 6. The risk matrix for the following values adopted in this methodology: values of probability indexes (table 2) and values of threat impact indexes (table 6). The level of risk: Low ("L"); Medium ("M"); High ("H").

Tab. 6. Risks related to the performance of a contract.

Assets/Processes	Symbol	Threat	Probability	Threat impact	Risk
Internet (LAN network)	LAN	broken line	1	1	1
Simulators	Sim	theft	5	1	5
Barofunction test	Bar	upper respiratory tract infection	3	2	6
Technical personnel	Te	absence	3	2	6
…	?	…	…	…	…
Simulators	Sim	break down	3	5	15

In order to assess the probability, the values of the indexes described in table 2 are to be used.

In order to assess the impact on contract performance (effects of the materialization of risks), the criteria in table 5 are to be adopted.

The following general principle has been adopted for the selection of the strategy for the assessed risks of contract performance:

- **high level of risk (10÷20)** – the most effective threat reduction plans should be applied (they may be costly and complex). The possibility of avoiding the threat, i.e. making the given risk factor impossible to occur, should be considered. For example, it's possible to apply withdrawal at the start of the project which also should be considered as a strategy. The decision to withdraw may be preceded by a project feasibility study carried out to assess the chance of providing a product (service) that meets the assumed requirements.
- for **medium-level risks (4÷9)**, less complex (less costly) but perhaps less effective plans for the implementation of mitigating security measures, i.e. reducing the probability or effects of materialization of the risk, may be applied. For **high and medium levels** of risk, a strategy of transfer may also be used. Most often, the transfer of risk consists in taking out insurance against an event or assigning the effects of risk to a counterparty (or a subcontractor),
- for **low-level risks (1÷3)** the acceptance of risks is usually applied. If the threats occur, we accept their effects. Acceptance is divided into active (we have a financial reserve) and passive (no reserves).

Example of a risk assessment in a contract for the provision of a service

Table 6 presents examples of assets and processes, identifies threats, values of indexes of probability of events, and calculates risk values for each asset and process.

The risk matrix has been filled with asset and process symbols put in the fields of the matrix according to the calculated values (fig. 7).

The above example of a risk matrix shows the risk identified by the symbol "Sim" in the high-risk area, above the line indicating the level of acceptable risk ("Risk acceptance line"). It would therefore be advisable, in accordance with the accept-

Probability \ Impact	Normal	Significant	Major	Critical
High	M Sim (5)	H 10	H Sim (15)	H 20
Large	M 4	M 8	H 12	H 16
Significant	L 3	M Te, Bar (6)	M 9	H 12
Medium	L 2	M 4	M 6	M 8
Small	L LAN (1)	L 2	L 3	M 4

Level of acceptable risk

Fig. 7. Risk matrix - example.

ed principles, e.g. to prepare a second, alternative simulator for use. For the assets marked with "Te" and the "Bar" process, preventive measures (reducing the probability of occurrence or the effect of a threat) should be applied. For the asset with "LAN" symbol, the associated risk could be accepted.

CONCLUSIONS

Management in each area is a complex, continuous process supported by the knowledge, innate abilities and acquired skills of the manager. An important component of the management process is risk management. The proposed approach to the identification and assessment of risks in the various areas of activity of the Military Institute of Aviation Medicine is the result of optimization which is based on two criteria: the criterion of the risk factors required by the standards and the transparency of the methods used for all parties

The risk management methodology presented above is a tool that supports making decisions that are strategic for the Institute, operational decisions concerning the implementation of current tasks, as well as the development of the content of contracts concluded for the provision of services.

AUTHORS' DECLARATION:

Study Design: Mirosław Dereń. **Data Collection:** Mirosław Dereń. **Manuscript Preparation:** Mirosław Dereń. The Author declares that there is no conflict of interest.

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REVIEW ARTICLE

DEVELOPMENT OF MOTION SYSTEMS FOR FLIGHT SIMULATORS

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Abstract: Despite the ongoing disputes about the need to use motion systems in flight simulators, the development of this component of simulators has been ongoing since the beginning of aviation. The aim of the article is to discuss the importance of the motion system in the simulation of motion stimuli affecting the aircraft pilot. Selected motion systems of flight simulators and reasons for using these systems are described. The benefits of the use of motion stimuli in flight simulators are discussed and possible directions of development of the motion system are presented.

Keywords: flight simulator, motion system, motion stimuli, motion cueing fidelity

Figures: 9 • **References:** 49 • **Full-text PDF:** http://www.pjambp.com • **Copyright** © 2020 Polish Aviation Medicine Society, ul. Krasińskiego 54/56, 01-755 Warsaw, license WIML • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

Flight simulators were the first devices, whose purpose was not to imitate the appearance of a particular aircraft, but to imitate its dynamic properties [41]. For this reason, one of the most important components of flight simulators was and still is the motion system, the task of which is to imitate motion stimuli occurring in real flight.

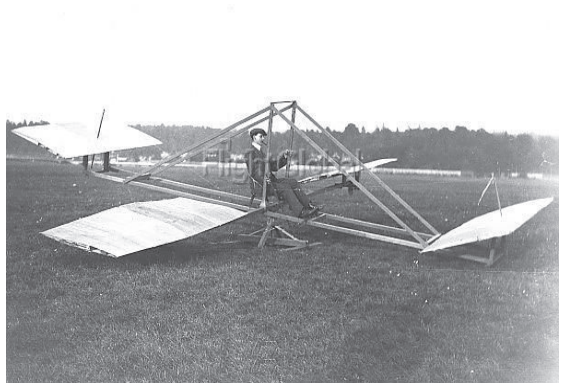
Despite the ongoing disputes about the need to use motion systems in flight simulators, the development of this component of simulators has been ongoing since the beginning of aviation. The aim of the article is to discuss the importance of the motion system in the simulation of motion stimuli affecting the aircraft pilot.

FIRST MOTION SYSTEMS

Already at the time of construction of the first flight simulators, the motion system was an important part of them. One of the first devices simulating the flight conditions was Model B "Flyer" of the Wright Brothers' aircraft without the tail part and engine [29]. The simulator was equipped with a cam driven by an electric motor, which enabled continuous changes in its roll. This motion was a key stimulus during training. The student could keep the wings horizontal by tilting the rudder levers. After a few hours of such training, appropriate habits appeared in the form of movements to correct imbalances during a simulated flight. Mastering this art qualified the student to fly a real Flyer-B aircraft.

In 1909, the Antoinette company, making aircraft and offering pilotage training, developed the Antoinette Trainer training device [15]. It consisted of two half barrels, mounted one on top of the other (fig. 1), which made it possible to simulate the roll and pitch of an aircraft. Changes to these angles were made manually by the staff operating the simulator, and the pilot's task was to keep the horizontal reference beam parallel to the horizon plane using the rudders (two wheels). The pilot's function in this simulator can therefore be compared to that of the most important on-board instrument, the attitude horizon (artificial horizon) indicator. The simulator was used to teach pilots to react correctly to stimuli they experience in flight in the form of typical aircraft pitch and roll movements. In hindsight, it turned out that this representation of the cabin's positions and the acquired ability to maintain reference to the natural horizon was incorrect. However, most of the aviation pioneers were not aware of this fact, as it was only at that time that the first studies on the function and activity of the human vestibular system, co-responsible for the perception of position and movement in space, were conducted.

Fig. 1. Antoinette Trainer flight simulator [1].



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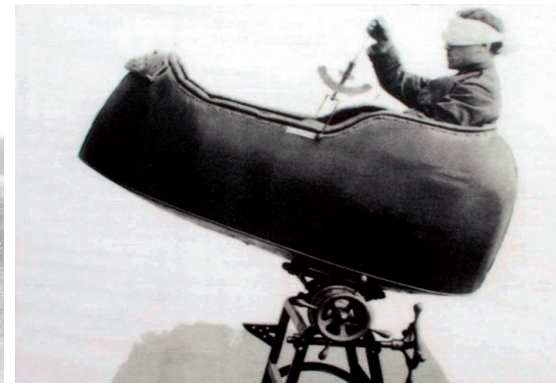

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Fig. 2. Flight simulators: a) Billing's Oscillator [2], b) Bleriot [3].

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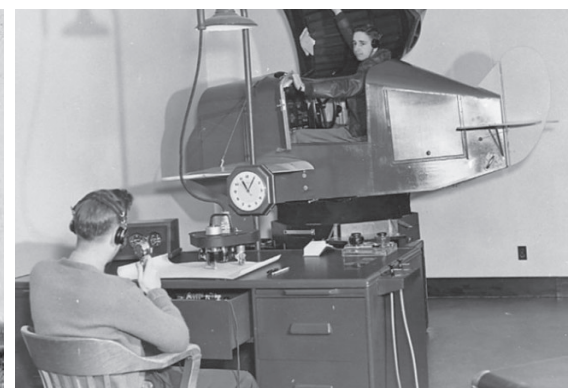


b)

Fig. 3. Simulators [4]: a) Ruggles Orientator, b) Link Trainer simulator.

The Billing's Oscillator (fig. 2a) developed by Eardley Billing, also comes from that period. It was a simple replica of an aircraft mounted on a plinth, which enabled simulation of basic movements during flight (pitch, roll and yaw angles).

By the time World War I began, anyone with an aircraft could have been a pilot. This has contributed to numerous accidents and losses in aviation that were not related to the activities of the enemy. Subsequent studies [3] have shown that out of all aviation accidents, as much as 90% were related to pilot error, 8% were related to aircraft malfunctions and only 2% were caused by shooting down. For this reason, the qualification of candidates for air duty was introduced. One of the first devices to train flying skills, and in particular to train and assess the physiological reactions of a pilot to stress caused by flying, was the Bleriot simulator designed at the University of Turin (fig. 2b). This simulator was able to perform roll and pitch movements that had to be recognized by the pilot candidate during a simulated flight with his eyes covered.

In 1917 the Ruggles Orientator training device was developed in the United States (fig. 3a) for learning and training to recover from an unusual aircraft attitudes. The main element of the simulator was a cabin with a pilot's seat, articulated in a set of rings on a wheeled platform [36]. Such a design allowed for any rotation of the cabin around three axes, with additional horizontal movement of the wheeled carrying platform. The movements were controlled by the instructor and the pilot by means of a rudder and bar, coupled in a system with an electric motor, responsible for generating the desired positions of the cabin. The pilot was able to move forward during the training, while feeling the impressions typical of basic maneuvers during flight.

The next qualitative leap in the flight simulation had not occurred until 1929, when American Edwin Link developed the Link Trainer simulator, also known as the Blue Box (fig. 3b). Adapting the concept of pneumatic bellows from his father's pipe organ factory, Edwin Link developed a structure enabling the generation of the cabin movement in pitch, roll and yaw channels [29]. The cabin movements were matched by trial and error method, independently for each control unit deflection. In addition to the motion system, which

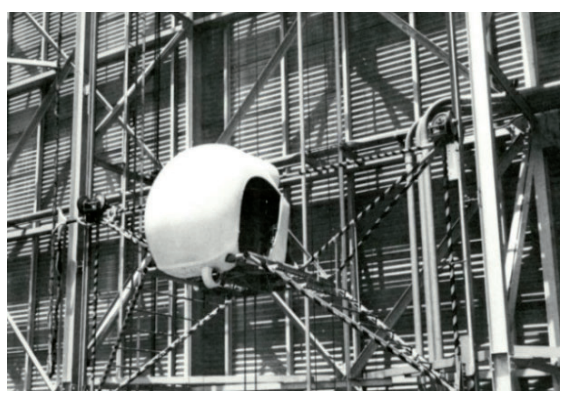
reacted to the rudder deflections, a new solution in Link Trainer was to equip the cockpit with flight instruments, coupled with the rudder system. The pilot, being in a darkened cabin, not only felt how the cabin reacted to the changes in rudder deflections, but most of all he could follow how the instrument indications change. Link Trainer was the first most successful flight simulator used until late 1950s.

NEW DESIGNS OF MOTION SYSTEMS AND THEIR DEVELOPMENT

Until the 1960s, major changes in flight simulation concerned subsystems other than the motion system. At that time, most flight simulators did not have a motion system, which was justified by the statement that modern pilots should not control the flight based on motion stimuli ('modern pilots should not fly by the seat of their pants') [28], considering information from the flight instruments as the most relevant during the flight. At that time it was considered that the lack of motion was partly compensated for by a system of loading the controls, providing a realistic feel for the forces occurring in flight. It was not until 1958 that Redifon company developed a full, motion system equipped simulator dedicated to the Comet IV aircraft. This simulator resembled flight simulators that are currently in operation. With the increased availability of flight test data and the increasing complexity of aircraft, analog computers have become a major limitation in the flight simulator system. The demand for increased fidelity and reliability of simulators was the reason for introducing digital computer techniques. However, digital signal processing has not improved the still low correlation of flight test data with the features of the simulator motion system. Moreover, strong visual stimuli provided by the wide field of view of the visual displayed system, in the absence of signals from the motion system, caused unintentional spatial disorientation in a pilot. At that time the most difficult to develop and the most expensive component of flight simulators was the motion generator.

In 1961, NASA Ames Research Center developed a flight simulator designed to simulate the vertical movements of an aircraft, helicopter or Vertical and/or Short Take-Off and Landing (V/STOL) aircraft [17]. A device fixed to the outer wall of a building (fig. 4a) consisted of a two-seater cabin which, by means of a motorized winch, was moved in a vertical direction within ± 50 feet at a speed of up to 22 feet per second and an acceleration of ± 1.5g (g denotes the earth gravity acceleration).

Successive years of continuous development of aviation, supported by war experience, have made it possible to reach much higher flight altitudes and move at higher speeds. At that time, phenomena that had not occurred in flight before, or whose sources were not known yet [41], began to gain significance. An example of such a situation can be the G-induced Loss of Consciousness (G-LOC), occurring under flight conditions with large, often prolonged G-forces [44,45]. Numerous studies [16,30,47-49] have shown that the pilot's body can be trained to prepare him for the flight conditions in which this type of hazard may occur. For this purpose, specialized simulators was developed, called centrifuges. In 1962, the engineers of NASA Ames Research Center developed five degrees of freedom (DoF) motion simulator - GPN-2000 (fig. 4b). The simulator combined in its design a centrifuge equipped with an arm, at the end of which a cabin was installed. The way the cab was controlled allowed to obtain angular changes of its position in relation to three axes. In addition, the cabin had the ability to move along



a)

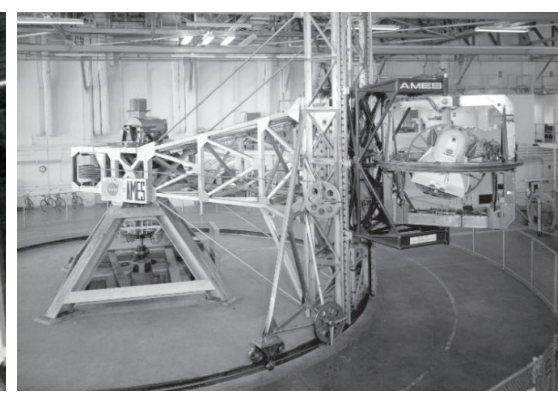


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Fig. 4. Flight simulator: (a) "height control test apparatus" [17], b) GPN-2000 [5].

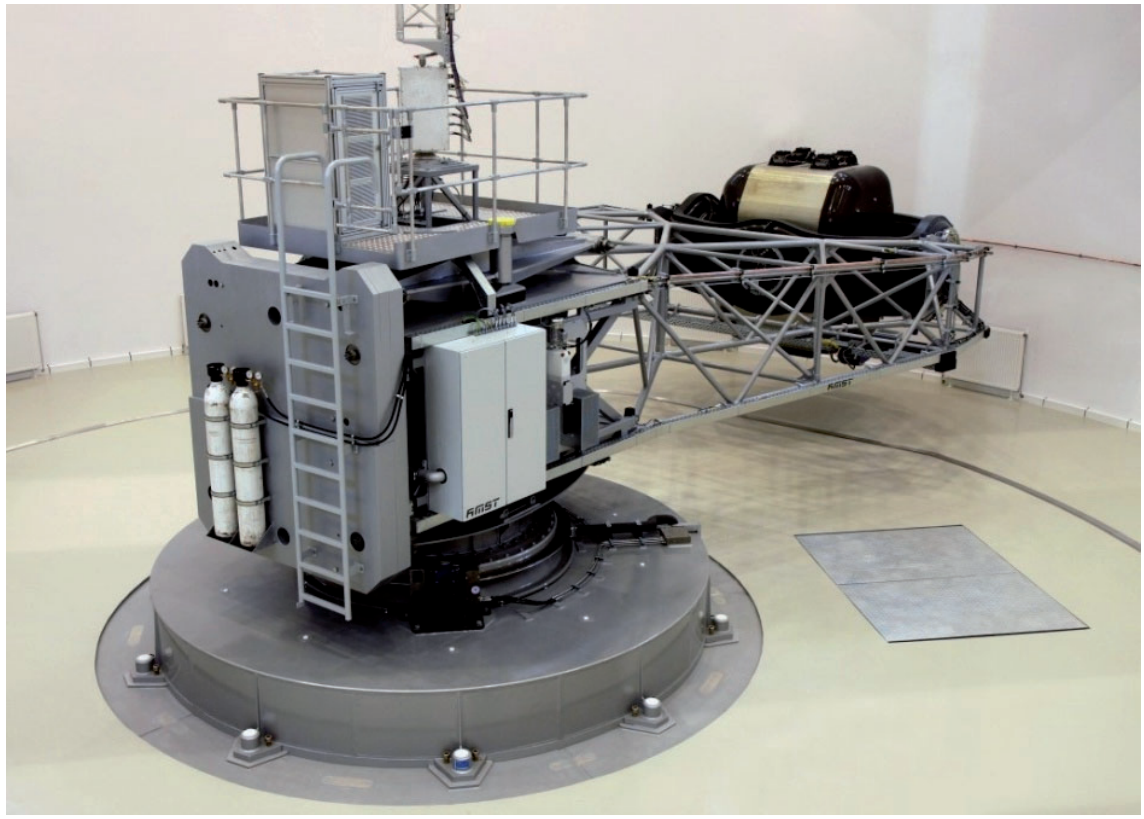


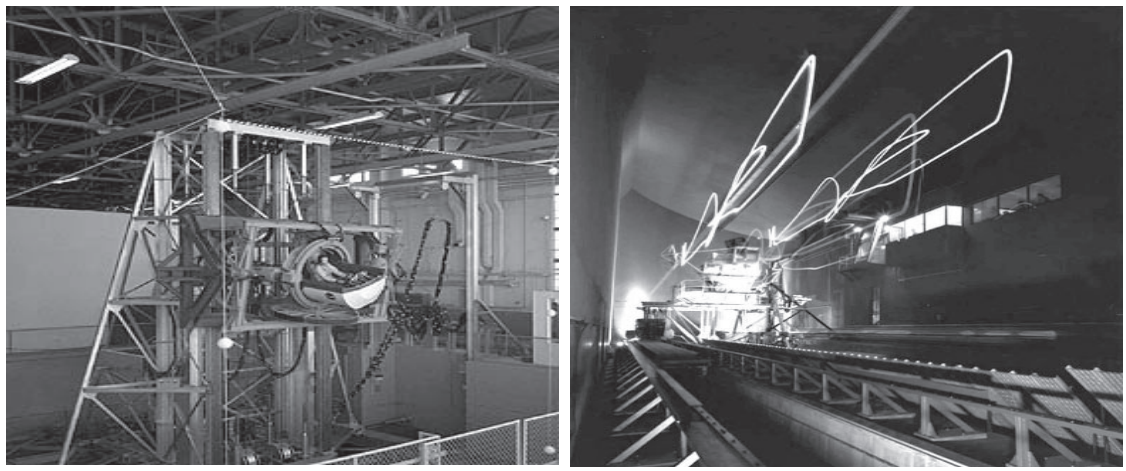
Fig. 5. The latest generation of the human-use centrifuge - a training flight simulator (WIML).

the vertical axis, limited to an offset of ±2 feet. In this way, the simulated cabin movements included three angular movements, one vertical translational and rotation of the arm in the horizontal plane.

In the latest generations of the human-use centrifuges (fig. 5) the way the gondola is fixed (with the aircraft cabin inside) enables its pitch and roll to be changed, providing mapping of linear accelerations with respect to three axes. Apart from many advantages of this type of simulator, there is, however, an inconvenience in the form of negative influence of cross-coupled angular acceleration stimulation (Coriolis stimuli), appearing when a pilot changes his/her head position during rotation of the centrifuge arm. In order to avoid the Coriolis effect, the pilot during centrifugation should maintain the unchanging position of the head, which is not natural when performing e.g. typical flight maneuvers [24].

Along with the rapid development of aviation to check the assumptions of newly designed aircraft, as well as spacecraft the first research simulators was built [41]. An example of such a simulator is the Flight Simulator for Advanced Aircraft (FSAA), built in 1969 and operated in NASA Ames Research Center Laboratory (fig. 6b) [12]. The simulator was originally designed for fixed-wing aircraft research, but was also used in rotary-wing (helicopter) models. Motion systems were usually the largest and most expensive elements of the simulator, expected to reproduce accelerations occurring in real flight more and more realistically. In order to meet the requirements of the V/STOL aircraft simulation, the first six DoF motion simulator was put into service at NASA in 1964 (fig. 6a). This simulator, in spite of the existing limitation in the cabin displacement (to a cube with a side length of 18 ft), demonstrated the importance of motion cues in flight simulation [13].

Almost simultaneously, Stewart [40] developed a motion system consisting of two platforms and six actuators, allowing for the imitation of motion with six DoF. An example of a flight simulator in which this type of motion platform is used is the Iapetus simulator (fig. 7a), manufactured by ETC-PZL Aerospace Industries (Warsaw, Poland), installed as a training and research equipment at the Military Institute of Aviation Medicine (WIML) in Warsaw. This type of motion system, commonly referred to as the Stewart platform, has been recognized and appreciated by the motion simulation community. This platform has a relatively compact design, which allows motion a cabin with a large mass, reaching up to several tons [11]. The translational DoF include forward and backward movement - the so-called surge,

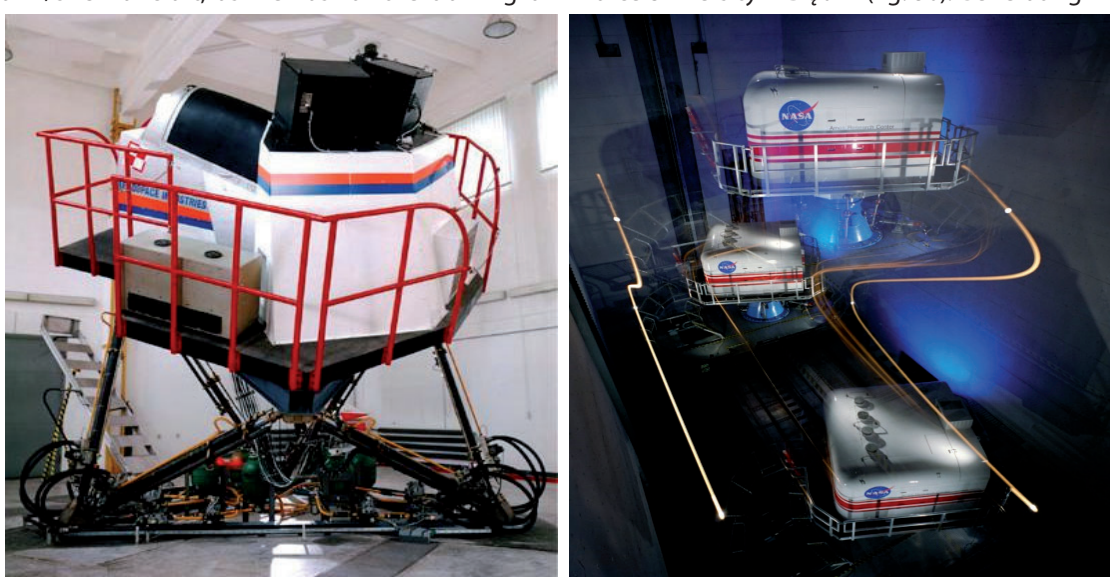


a) b)

Fig. 6. Motion simulator: a) with six degrees of freedom [6], b) FSAA [41].

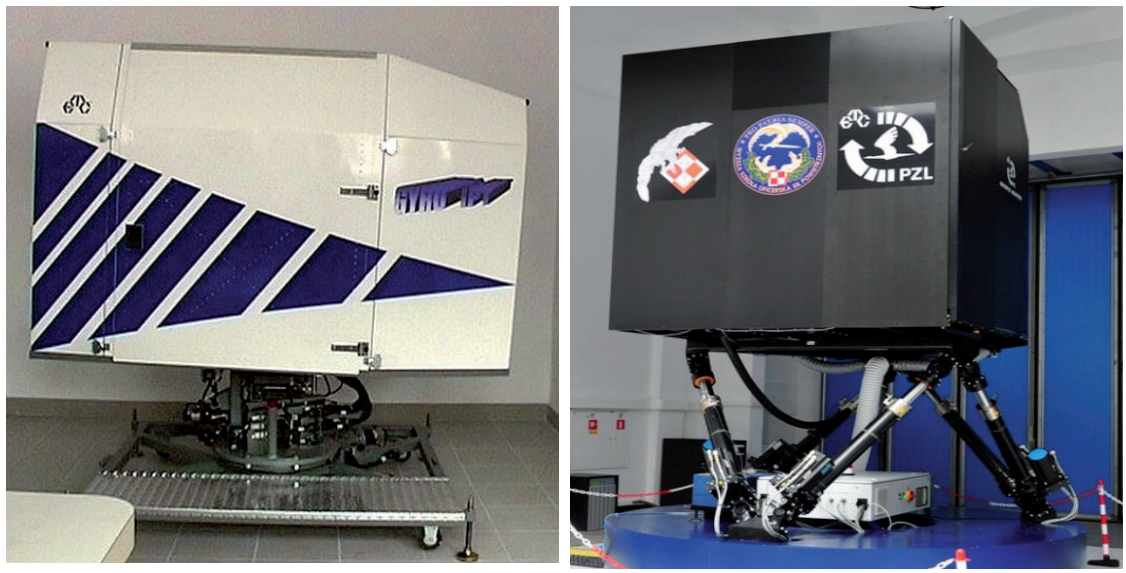
sideways movement - the so-called sway, and up and down movement - the so-called heave. In the case of rotary motion, DoF include: roll, relative to the longitudinal horizontal axis, pitch, relative to the lateral horizontal axis, and yaw, relative to the vertical axis [37].

By the end of the 20th century, the Stewart platform was the most widespread six DoF motion system. The search for a more efficient motion platform to test all types of aircraft with very diverse flight dynamics led NASA Ames Research Center to develop the Vertical Motion Simulator (VMS) (fig. 7b). Its high mobility capabilities made it ideally suited for pilot-aircraft interaction studies. This simulator provided a realistic, in-flight substitute, environment used for the assessment of V/STOL aircraft, as well as for the training of space shuttle pilots [14]. Reproducing the motion stimuli was achieved through the use of a special motion system with six DoF, for which, compared to the standard system, the range of vertical motion has been significantly increased - to 18.3 m, with a maximum acceleration of ±10 m/s^2.With the emergence of new generations of aircraft with high maneuverability, loss of spatial orientation has become one of the more frequent causes of aviation accidents. At that time, pilots were not familiarized with this phenomenon during flight training [41]. One of the most effective methods used to counteract the phenomenon of spatial disorientation include practical training in spatial disorientation simulators such as Gyro-IPT located at WIML (fig. 8a) or a simulator installed at the Air Force University in Dęblin (fig. 8b). Generating mo-



a) b)

Fig. 7. Flight simulators: a) Japetus (WIML) [42], b) VMS (NASA ARL) [7].



a) b)

Fig. 8. Spatial disorientation simulators: a) Gyro-IPT (WIML), b) WSOSP [8].

a) b)

Fig. 9. Flight simulator: a) Desdemona [9], b) DLR [10].

tion cues that cause spatial disorientation in flight are provided by appropriate kinematic properties of motion system.

The demand for greater motion fidelity affecting the pilot in real flight contributed to the development of complex structures of motion systems and their control systems [33]. Improvement in this fidelity is achieved by using multi-stage, cascading motion system connections. In this way, it is possible to increase the useful workspace of the motion system as well as the range of generated accelerations [11]. An example of such a solution is the Desdemona flight simulator developed by the AMST-Systemtechnik GmbH (Austria) (fig. 9a) [22,46]. This device is equipped with a motion system with six DoF ensuring full cabin rotation about three axes, its vertical movement within ±1m and horizontal movement along a rotating arm within ±4m. It has the capability to generate angular velocities up to 180°/sec with a maximum acceleration of 90°/sec^2, and maintain prolonged linear acceleration up to ±3g. Another example of a simulator with an advanced motion system is the DLR flight simulator (fig. 9b), which is mainly used for research purposes [43].

Today, flight simulators are used not only during the lifetime of an aircraft, but also in the research and development, helping to develop new aircraft designs and improve existing ones. They are also helpful in pilot assessment, reducing costs and risks associated with flight tests. However, the most commonly used flight simulators are flight simulation training devices (FSTD) designed for the training of pilots, flight crew and flight equipment service [41].

THE NEED TO REPLICATE AIRCRAFT MOTION

To date, despite numerous achievements in flight simulation, the simulator environment is not able to replace the actual aircraft flight. There is still a lot of discussion about the benefits of motion stimuli. There have been many prominent scientists in the group who were against the use of motion systems [31]. Caro [20] noted that the view negating the need for motion systems is not supported by evidence [34]. McCauley [31] was of a similar opinion, stating that the motion of the platform contributes to the precision of the pilot's actions and improves his/her performance. This applies especially to experienced pilots [27]. Although the author did not find any evidence for this, he pointed out that motion stimuli have a positive influence on flight training in unstable aircraft and when failures of systems responsible for maintaining stability may occur. Although the benefits of high motion fidelity have not been finally demonstrated, most experienced, qualified pilots prefer simulators with a motion platform [31]. According to Slob [38], the main reason for the need to use motion stimuli in simulation is to prevent the occurrence of simulator sickness (motion sickness). This simulator sickness is mainly the result of a lack of synchronization of visual stimuli with signals from the motion system. It is assumed that the motion cue delay should be lower or equal to the value of the visualization delay [38]. Burki-Cohen et al. [18] conducted a number of studies on the influence of flight simulator motion systems on the effectiveness of airline pilot training. Together with Sparko et al. [39] they demonstrated that during take-off and landing with high cognitive workload, the presence or absence of motion stimuli in the simulator does not significantly affect this efficiency. However, the authors of these studies concluded that higher dynamics and low flight altitude (e.g. rotary-wing aircraft flight) cause that pilots maintain their spatial orientation mainly based on signals from the vestibular system, rather than based on indications of flight instruments. It was proved by the studies [23,32], in which the researchers confirmed that the presence of motion stimuli in a flight simulator affects the pilot's performance. On the other hand, there are numerous studies [19,21,25-27] indicating that increased realism in motion replication is not necessary for all elements of pilot training. This is justified in situations where the performance of certain tasks, for example communication with air traffic control and changes in autopilot settings, do not affect the pilot's behavior in the absence of motion stimuli. Nevertheless, the view that a full flight simulator is required to integrate all skills and pilot behavior during flight still remains [25,35]. In the course of disputes about the need to use physical motion stimulus in simulation, an attempt was made to classify the characteristics of motion systems in flight simulators [12]. The most important criteria were considered to be, the motion frequency translation band and response times (time delay of the system between the introduction of the control signal and the response of the actuators). Considering the large capabilities in flight simulator applications, the Federal Aviation Authority in the USA and the Joint Aviation Authority in Europe issued a motion system requirements specification in 1980. Leaving these standards mostly unchanged for the next 15 years has practically stopped the development of motion systems. The current standards, which describe the requirements for flight simulator motion systems, are introduced by the European Aviation Safety Agency - certification specifications for areoplane and helicopter flight simulation training devices (CS-FSTD A/H). Similar qualification testing criteria for fixed-wing and rotary-wing aircraft simulators and training devices have been issued by the International Civil Aviation Organization in standard 9625 Issue 3.

CONCLUSIONS

Unfortunately, the motion system still remains one of the most expensive components of a simulator and one of the more troublesome in achieving high fidelity motion cueing. These limitations make the motion system an obligatory element of the simulator, only in the highest class of these devices, the so-called full flight simulators. Therefore, further development of motion systems seems to depend mainly on the costs of their production and operation and the quality of the replication physical motion stimuli in flight. An alternative to current motion systems are designs that combine low manufacturing cost with low fidelity. The increase in interest in such systems results mainly due to the availability of cheap devices for visual presentation of virtual reality.

It should be expected that also among the users of these motion systems, there will be "a hunger" for motion cueing fidelity. Perhaps this will be an impulse that will stimulate the development of motion systems and improve their fidelity. If with current technology it is possible to improve the motion cueing fidelity, there is a chance to increase interest in motion systems. Otherwise, it

can lead to stagnation in their development. The current research on improving the motion cueing fidelity is focused mainly on:

- designing new motion system structures,
- creating new motion cueing algorithms to control motion systems,
- developing objective methods to assess the motion cueing fidelity.

While designing a new motion system is not a major problem, developing an appropriate algorithm to control this system is already quite a challenge. Human beings have numerous limitations in the perception of motion stimuli, both visual and vestibular. This knowledge is extremely useful for developing motion cueing algorithms and determining effective motion stimuli for specific device design.

AUTHORS' DECLARATION:

Study Design: Rafał Lewkowicz, Grzegorz Kowaleczko, **Data Collection:** Rafał Lewkowicz, Grzegorz Kowaleczko, **Manuscript Preparation:** Rafał Lewkowicz, Grzegorz Kowaleczko. The Authors declare that there is no conflict of interest.

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TELEMONITORING OF BIOMEDICAL PARAMETERS TECHNOLOGICAL ASPECTS AND APPLICATIONS

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Abstract: The article presents the main technological aspects of systems of telemonitoring of biomedical parameters, based on the example of research carried out in the Łukasiewicz Research Network - Institute of Medical Technology and Equipment, Zabrze. Medical telemonitoring covers technologies for the acquisition, processing and analysis of biomedical information. Data sources and technologies for obtaining biomedical information are an important element of medical telemonitoring. Medical telemonitoring systems are one of the main elements of telemedicine or telehealth. Telemonitoring of vital biomedical parameters is mainly used to perform remote diagnostics and medical rehabilitation. This applies primarily to patients from the so-called "high risk" groups, who are treated or rehabilitated outside hospitals. An important area for the application of medical telemonitoring is the safety of people working under extreme or stressful conditions. Telemonitoring of vital parameters can also be used to increase the safety of those who engage in physical activity for health promotion, sports and performance.

Keywords: telemedicine, telehealth, medical telemonitoring, biomedical parameter acquisition, vital signs monitoring, long-term surveillance

Figures: 9 • **References:** 32 • **Full-text PDF:** http://www.pjambp.com • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

Medical telemonitoring can be defined as a use of ICT to transmit biomedical information in order to perform a remote diagnosis and medical surveillance. Medical telemonitoring systems are an important element of telemedicine. Telemedicine or telehealth is an interdisciplinary branch of medicine integrating medical and technical sciences. Within the framework of telemedicine, five main groups of telemedicine technologies can be distinguished: telemonitoring, telediagnostics, telerehabilitation, telesurgery and teleconsultation. The primary function of medical telemonitoring systems is to transmit information, generated and preprocessed in the patient's environment, to a local or remote monitoring and surveillance center, where this information is further processed and analyzed to support diagnosis or medical surveillance [11,24,26,25,28,27,31]. In this case, information generated in the patient's environment means biomedical signals and parameters recorded inside or on the surface of the patient's body, visual or thermal imaging of patient's body parts, parameters of the patient's environment. Medical telemonitoring systems transmit information including biomedical signals, parameters and images. Bioelectric signals, such as: ECG, EEG or EMG are recorded directly by means of appropriate sensors — electrodes. Biomedical parameters, such as: body temperature, pulse, respiratory rate or blood pressure are measured by means of appropriate transducers, which transform the physical quantity, corresponding to the measured parameter, into the value of this parameter. The measurement of environmental parameters is carried out in a similar manner, such parameters include: air temperature and pressure, atmospheric particulate level or noise level. The generation of biomedical images, such as visual imaging, thermal imaging, ultrasounds or X-rays, requires the use of appropriate devices, generally operated by qualified medical personnel. The final recipient of information generated in medical telemonitoring systems is always a medical specialist, who conducts medical supervision and, based on the processed information, decides on appropriate treatment. Medical telemonitoring systems will be used with increasing frequency in everyday medical practice [7,8,22,23,31]. The use of teletransmission technologies to transfer biomedical information overcomes geographical barriers and provides remote medical care to patients wherever they may be located [18,23,24,28,30]. In particular, telemonitoring of biomedical parameters provides the basis for building telemedical systems for various applications.

There are biomedical parameter telemonitoring systems solutions available on the market, mainly for the purpose of performing remote cardiac surveillance [7,11], in particular of patients with the latest generation of cardioverter-defibrillators offered by the manufacturers of these devices [6,15]. By contrast, biomedical parameter telemonitoring systems for other applications are still not very widespread. In this respect, intensive research and development work is being carried out in a number of scientific centers aimed at the development of effective, non-intrusive technologies for the acquisition and processing of biomedical information under conditions of normal patient life activity [5,12,21]. Such works have also been carried out for a number of years at the Łukasiewicz Research Network — Institute of Medical Technology and Equipment (abbreviated to Łukasiewicz-ITAM). The results of these works have been used in Łukasiewicz-ITAM in the development of usable versions of various medical telemonitoring systems. The technological solutions of the systems developed enable surveillance of patients, including pregnant women, at their place of residence, monitoring of people in various environmental conditions and long-term monitoring (periods longer than 7 days). These systems are presented in the second part of this article.

GENERAL STRUCTURE OF MEDICAL TELEMONITORING SYSTEMS

Medical telemonitoring systems are an essential part (subsystem) of telemedical systems, which constitute the technical implementation of functions enabling the remote provision of medical services [7,18,19]. The basic function of telemedicine systems is the transmission of information between the patient and the doctor under conditions that exclude the possibility of direct contact. To carry out this teletransmission, the available telecommunication technologies are used. These mainly include online wireless communication technologies [1,23,28]. Telemedicine systems must ensure the mutual, undisturbed flow of information between the patient and the doctor, which means that the required medical action is taken remotely on the basis of an analysis of the information obtained by the doctor, but with the addition of informing the patient of the results of that analysis and the necessary follow-up action to be taken by the patient. The general

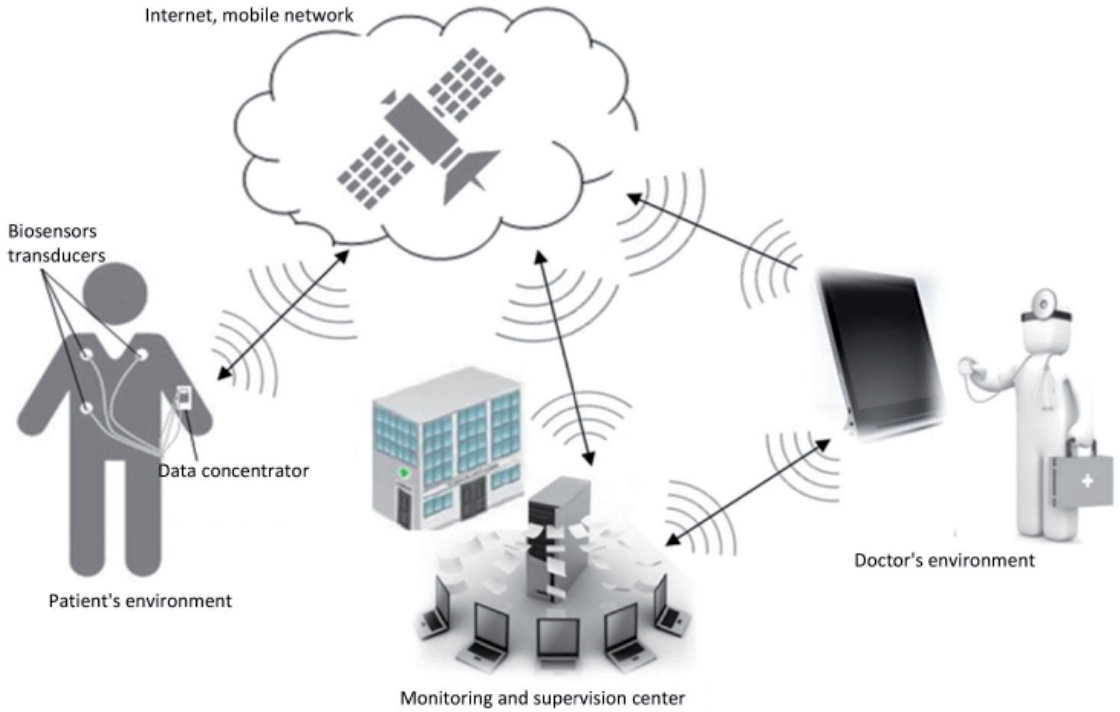

Fig. 1. General structure of a medical telemonitoring system.

structure of the medical telemonitoring system is presented in fig. 1.

Modern medical telemonitoring systems consist of four essential elements:

1) Devices in the patient environment - forming a data acquisition network.
2) A telecommunications network enabling local (within the data acquisition network) and remote (to a monitoring and surveillance center) transmission of biomedical information.
3) Devices storing, processing and analyzing medical information in the monitoring and surveillance center (servers in the monitoring center, distributed servers forming a computing cloud).
4) Devices in the doctor's environment.

The patient's environment features devices enabling the acquisition of biomedical information, its initial processing and sending it through a telecommunications network to the information collection and processing center. There are communication devices on the doctor's end, such as desktop or laptop computers, PDAs or smartphones, allowing the doctor to access individual patients' medical information, stored and properly processed in the monitoring and surveillance center [21,26,28].

The most important part of medical telemonitoring systems is a biomedical signal and parameter acquisition network called the Body Area Network (BAN), which consists of sensors and biomedical signal transducers placed on the patient's body and connected to a concentrator data communicator module (usually a smartphone), worn by the patient [1,25,28]. The system can use a wired connection - Cable Body Area Network (CBAN) as presented in fig. 2a or a wireless connection - Wireless Body Area Network (WBAN) as in fig. 2b. The design of the BAN depends on the purpose of the medical telemonitoring system. The technical and operational parameters of this network determine mainly the quality and usefulness of the entire medical telemonitoring system.

The acquisition of information in the patient's environment involves the recording and processing of signals received directly from the patient's body as well as other biomedical and environmental data generated by devices worn by the patient or located in the patient's environment. Depending on the purpose of the medical telemonitoring system, the data acquisition network includes various sensors and transmitters of biomedical signals (including bioelectrical signals) as well as transmitters and instruments measuring environmental parameters [9,10,12,21]. The sensors are used to directly record bioelectrical signals from the body surface. Surface bioelectrical signals, i.e. electrocardiogram (ECG), electroencephalogram (EEG), electromyogram (EMG), are generated by tissues of individual organs, in this case the heart, the brain and muscles. On the surface of the body, variable electrical potentials are recorded over time.

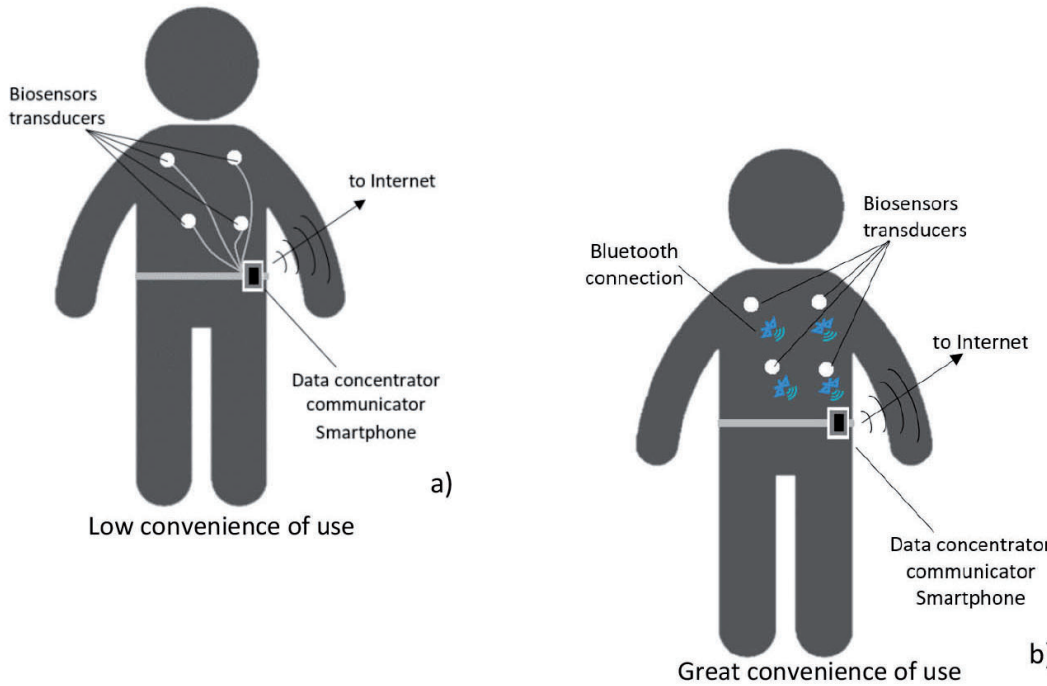

Fig. 2. a) Sensors of Cable Body Area Network — CBAN. b) Sensors of Wireless Body Area Network — WBAN.

In turn, transducers convert various physical biomedical signals, e.g.: breathing movement of the chest, exhaled air flow, heart sounds, blood flow, ECG signal, bioimpedance signals - into another physical value, which corresponds to the measured medical (vital) parameter. Based on studies carried out at Łukasiewicz - ITAMand available literature data [1,8,19,26] a set of signals, biomedical and environmental parameters monitored in various medical telemonitoring systems can be defined. This set includes:

1) Biomedical signals: ECG, EEG, EMG, REO and ICG (bioimpedance signals).
2) Biomedical parameters: heart rate (HR), heart rate variability (HRV), oxygen saturation (SpO2), heart stroke volume (SV), chest and abdominal impedance changes, chest hydration (TFC), abdominal hydration (AFC), pulse rate, blood pressure, peak expiratory flow (PEF), respiratory rate, tidal volume, minute ventilation, frequency of coughing, cough intensity. body temperature, blood sugar level, fat layer thickness, physical activity.
3) Environmental parameters: particulate matter level (PM2.5), sulfur dioxide content (SO2), nitrogen dioxide content (NO2), temperature, humidity, atmospheric pressure, insolation (light intensity in the patient's environment).

The value of these parameters is determined by special modules for the measurement of physiological and environmental parameters, to which appropriate sensors and signal transducers are wired or connected wirelessly. Data from these modules are transmitted via Bluetooth to a smartphone, with a special application installed, and from where they are transmitted via GSM network to the monitoring center.

In medical telemonitoring systems, the quality of monitoring and remote supervision of patients depends mainly on the quality of acquired biomedical information and the quality of transmission channels transferring data to the medical supervision center. The quality of information obtained in the patient's environment is determined by the design technologies of sensors and biomedical signal transducers used for this purpose, while the quality of data transmission channels in the telemedical system depends on the technology and technical parameters of the communication network.

In medical telemonitoring systems, the acquisition of biomedical signals and parameters under natural life activity conditions is particularly important. This area includes the development of technologies for the acquisition of biomedical information by non-invasive and non-intrusive methods. Research work in this area is aimed at developing bioelectric signal acquisition systems, in the form of textronic structures integrated with clothing — the so-called "wearable health monitoring systems". The basis of these systems are maintenance-free sensors (biosensors) and biomedical signal transducers, integrated with clothing, providing effective, reliable measurements of

bioelectrical signals under natural life activity conditions of adults and children. Including developing physical activity for rehabilitation, recreation and sports purposes.

Another observed area of intensive development of medical telemonitoring systems is the broad application of computational intelligence for processing and analysis of biomedical information in these systems. Computational intelligence or CI is a field of science that deals with solving problems that cannot be described by means of effective models, effectively algorithmicized. To solve these problems, the methods of computational intelligence are used, which allow to build "intelligent" (self-improving, heuristic) computational algorithms based on "data-based learning methods". Computational intelligence methods are widely used in medicine to process and analyze biomedical information. These find application in particular in: processing and analysis of biomedical signals and images, processing and analysis of medical data of patients, design of medical procedures, design of the so-called "patient flow" in a hospital, creating expert systems supporting prophylaxis, diagnostics and medical therapy, management of health care units.

Four groups of medical technologies can be distinguished within the framework of telemedicine: telemonitoring and medical supervision, telediagnostics, telerehabilitation and teleconsultation.

There are solutions available on the market, dedicated mainly for telecardiology in hospital applications. The technological and conceptual challenge is to develop systems to monitor and supervise various biomedical parameters collected in the patient's natural living environment as well as the hospital environment and beyond it. Teleminitoring and medical surveillance systems have been developed in Łukasiewicz - ITAMto meet these challenges, enabling: supervision at the patient's home, including of pregnant women, monitoring people in various environmental conditions and long-term monitoring.

Selected telemonitoring and medical surveillance systems for various areas of application, developed in Łukasiewicz - ITAMare presented further in the article.

HEALTH SURVEILLANCE AT THE PATIENT'S HOME

Integrated systems of medical telemonitoring developed in Łukasiewicz-ITAM enable comprehensive care of the patient [26]. The designed solutions enable health surveillance of the elderly, chronically ill patients and pregnant women at their place of residence [14,16]. It is well known that telemedicine care systems become particularly effective if they promote health-oriented behavior and healthy lifestyles, allowing patients to continue to function in their existing environment [14,24,27]. Such systems include:

A. The Revitus Home Rehabilitation System

The system uses Adaptive Network Topology (WPAN - Wireless Personal Area Network) for communication of modules located on the patient, the WPAN Bluetooth network for communication inside the house, the GSM network (WWAN - Wireless Wide Area Network) and the Internet (WAN - Wide Area Network) for communication with the monitoring and surveillance center. The Revitus system is equipped with an effort controller and a communicator and monitoring module (Fig. 3). The monitor module is used to monitor electrical heart activity, respiratory function, body water accumulation, blood pressure, body weight and motor activity. The results of the measurements are available only to authorized medical personnel in the monitoring center. The system configuration is presented in Fig. 4.

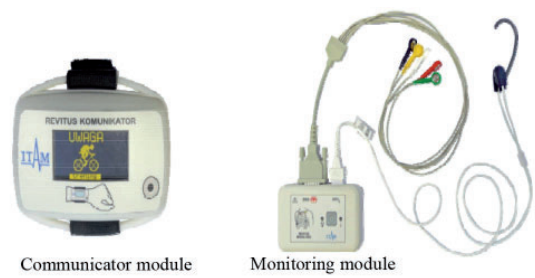

Fig. 3. Revitus system components.

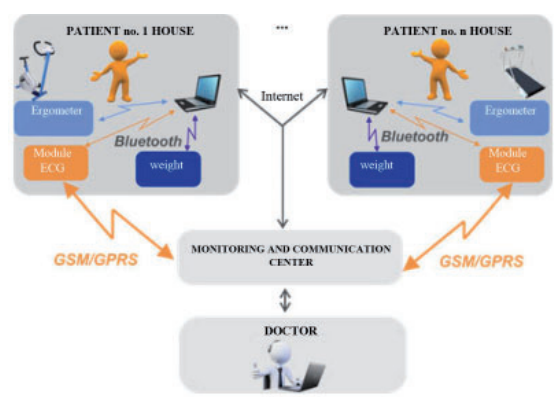

Fig. 4. Configuration of the REVITUS home telemedicine system.

B. EDFAS - Telemedical surveillance of the elderly and disabled

EDFAS was developed as part of the EUREKA initiative. It enables remote surveillance of elderly and disabled people at their homes (Fig. 6). The monitoring module included in the system enables non-invasive acquisition of two differential ECG leads including a chest impedance signal, a photopletismogram and acceleration signals to which the patient is subjected in three orthogonal axes. The system allows to indicate the position of the monitored patient's body - standing, lying or sitting. The system software allows to determine the patient's condition on the basis of decision parameters determined with the Moore and Mealy automata algorithm (Fig. 5).

Based on the obtained analysis results, the software operating in an online mode generates special notifications (green, yellow, or red) on the screen. If a situation potentially dangerous to the patient is detected, the software generates an audible signal (a beep) to warn the patient and sends the analysis results to a physician consultant. While operating in an offline mode, the physician has an overview of the recorded processes allowing for a detailed analysis of the recorded events.

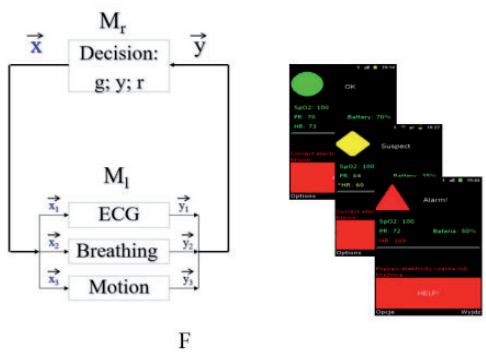

Fig. 5. Convolution of Moore and Mealy automata in a monitoring system.

C. Telemedical surveillance system for pregnant women

The telemedical monitoring system for pregnant women allows for performing cardiotocographic monitoring of the patients' at their homes, with real-time monitoring carried out by a central station located in the hospital (Fig. 7). The conventional monitoring of the fetus is carried out by means of monitoring devices called cardiotocographs [14,16]. In the system, the basic method of assessing the condition of the fetus during pregnancy is recording and analysis of the mother's and the fetus's biophysical signals, such as:

1) Fetal heart rate (FHR)
2) Uterine contractions (UC):
   - Automatically detected fetal movements, i.e. fetal movement profile (FMP),
   - the movements of the fetus as reported by the mother.

MONITORING PEOPLE IN VARIOUS ENVIRONMENTAL CONDITIONS

ICT systems for interactive assessment and shaping of a person's physical activity in their environment will make it possible to take into account individual psychophysiological characteristics and environmental conditions during rehabilitation, training or professional activities. An example of such a solution can be the system for monitoring psychophysiological parameters of people during the performance of their professional activities SMP-300.

A. SMP-300S — System for monitoring psychophysiological parameters of persons during their professional activities

The SMP-300 system is designed to register psychophysiological and environmental signals under flight conditions and is primarily used to

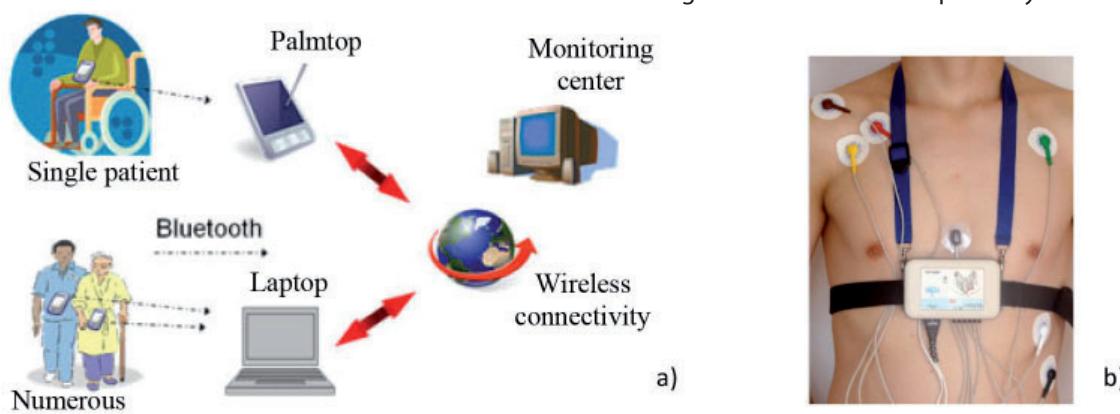

Fig. 6. a) EDFAS system, b) Monitoring module.

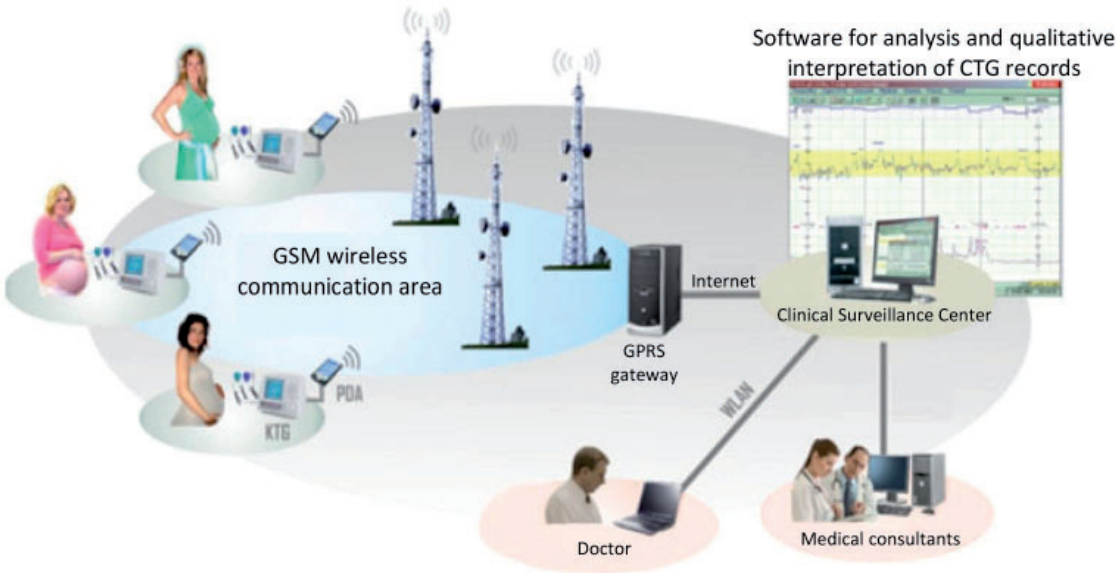

Fig. 7. Telemedical surveillance system for pregnant women.

examine pilots (Fig. 8). However, its scope can be extended to other professional groups, such as: drivers, machinery operators, miners or athletes.

The system allows to monitor ECG signals, pulse and electromyographic signals, measure heart rate, respiratory rate, blood saturation, arterial blood pressure as well as skin acceleration and impedance. It also monitors environmental parameters, such as ambient temperature and humidity, atmospheric pressure, as well as flight parameters, such as speed, altitude, slope and course. The system allows to document the course of the examination in the form of reports and records in the database.

LONG-TERM MONITORING

The possibility of 24-hour monitoring and consultation allows for comprehensive patient care while reducing the cost of patient treatment. In order to be able to monitor the patient around the clock in a non-invasive manner and with the least possible inconvenience for the patient, it is necessary to develop the smallest possible portable, battery-powered measuring modules. The MONITEL-HF system offers such possibilities.

A. MONITEL-HF - Heart failure monitoring system

The Monitel-HF system was developed as part of a project financed by the STRATEGMED programme. Monitel-HF is a multi-module system consisting of an ECG and pulse wave signal recording unit (Monitel 1), a unit for recording body position, galvanic skin response and temperature (Monitel 2), a unit for recording chest and abdominal bioimpedance signals (Monitel 3), Fig. 9. The system is used to acquire, visualize, process and save data obtained from measurement modules

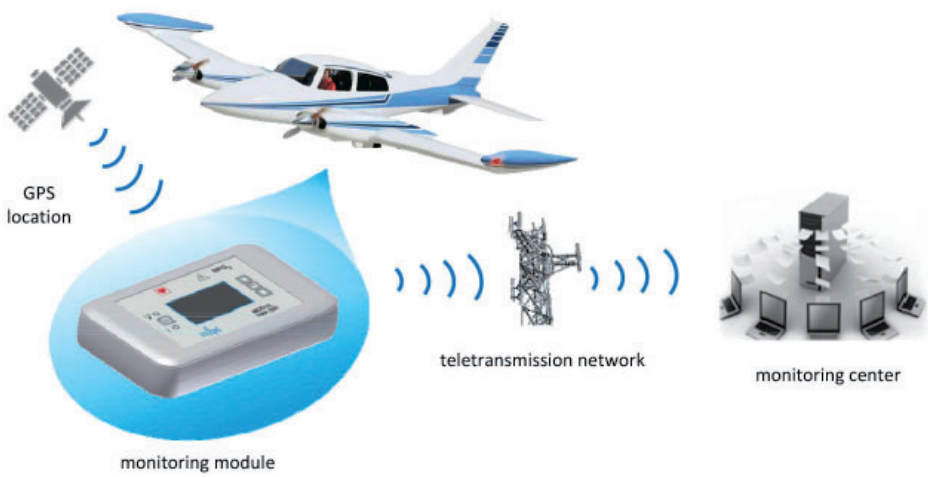

Fig. 8. SMP-300S — System for monitoring psychophysiological parameters of persons during their professional activities.

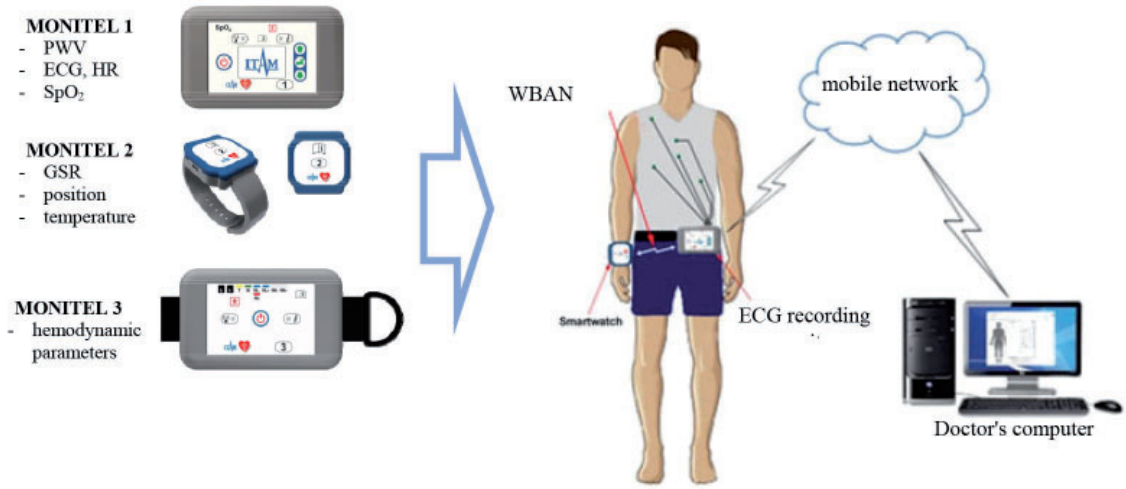

Fig. 9. MONITEL-HF - Heart failure monitoring system.

[21]. The monitored parameters are collected by a network of personal sensors located on the patient's body and transmitted wirelessly to the operator's station. The operator's station in the MONITEL-HF system is a desktop or laptop computer with an operating system running the Monitel-HF application.

CONCLUSIONS

The recent years have seen an extensive development of medical telemonitoring systems, which are used in practically all fields of medicine. As a result of the technological advancements, it is possible to implement innovative solutions which until recently seemed to be nothing more than a vision of a distant future. Progressive miniaturization of electronic circuits, development of telecommunication and Internet technologies, advanced mobile devices (smartphones, such as the iPhone), have contributed to the creation of a number of original designs, such as Revitus, EDFAS, SMP-300 or Monitel-HF, dedicated to specific applications.

For several years now, medical telemonitoring systems have become increasingly widespread to carry out monitoring and health surveillance of people of various age groups and suffering from a variety of medical conditions. Although this mainly concerns the elderly, there is also a growing interest in telemedicine surveillance among younger people, e.g. pregnant women, people working in extreme conditions, people engaged in extensive physical activity for recreational or sports purposes. An example of an offer for these groups are the systems developed in Łukasiewicz - ITAM, which have been additionally commercialized (SMP-300, Monitel-HF and a telemedicine system for the health surveillance of pregnant women).

However, it should be borne in mind that, despite the benefits of telemedicine, its widespread use still requires intensive patient education and a steady increase in the availability of information technologies allowing for remote health monitoring.

Medical telemonitoring systems require effective technologies for extracting biomedical information from the human body, in its natural living conditions, in particular those related to its motor activity. The motor activity of both a healthy person and a patient is the main source of bioelectrical signal interference, recorded by means of electrodes (biosensors) on the body surface. As we know, these signals are the basis for determining numerous biomedical parameters. Also, the biomedical parameters recorded or determined indirectly by transducers are very susceptible to disturbances resulting from the motor activity. Therefore, work is underway in a number of research centers to develop effective, non-intrusive technologies for the acquisition of signals and biomedical parameters [4,16,17,32] that are much less susceptible to disturbances caused by motor activity. A focused research direction is emerging to develop a biomedical information acquisition network fully integrated with clothing which can be worn with ease. These clothes take various forms, of e.g.: T-shirts, H-shirts, vests, belts, necklaces, bracelets, ear plugs.

A prospective solution for this purpose seems to be the development of a textual network of bioelectrical signals acquisition, adapted to the conditions of human motor activity, realized as a network of bioelectrical signal sensors (biosensors, dry electrodes) and biomedical parameters

transducers, placed directly within the structure of the fabric, or built into the fabric of which the clothing is made. The network could be made in the form of a flexible T-shirt or H-shirt or vest. Biomedical parameter sensors and transducers (piezoelectric, resistive, inductive, capacitive, bioimpedance) would be connected by flexible signal paths or wirelessly with a miniature signal and biomedical parameter recording unit (concentrator-transmitter), also built into clothing.

The opportunity of providing continuous medical care without the need for physical presence of a doctor, makes telemedicine systems particularly useful in obstetrics. The IoT-type system of telemonitoring high-risk pregnancy provides the possibility of controlling the recording equipment located on the patient's side remotely and enables interactive communication with medical personnel. In this case, the development of an effective algorithm to control the monitoring session is an important research problem. Biomedical information acquisition technologies used in modern medical systems are still quite burdensome for the patient (e.g. ECG electrodes are difficult to put on, the electrodes cause skin irritation on contact points, skin-to-electrode contact is unstable), sometimes even invasive (e.g. blood sugar measurement by puncturing) and often require the help of another person in order to properly attach sensors and transducers to the patient's body.

The need to reduce the inconvenience of modern biomedical information acquisition technologies is a condition and at the same time a motivator for further development of medical telemonitoring systems. These technologies are based on the achievements of biomedical engineering, which have seen a particularly intensive development in recent years. This is an encouraging premise for the further development of medical telemonitoring and telemedicine in general.

AUTHORS' DECLARATION:

Study Design: Ewelina Sobotnicka, Daniel Feige, Aleksander Sobotnicki, Adam Gacek, **Data Collection:** Ewelina Sobotnicka, Daniel Feige, Aleksander Sobotnicki, Adam Gacek, **Manuscript Preparation:** Ewelina Sobotnicka, Adam Gacek. The Authors declare that there is no conflict of interest.

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SHORT COMMUNICATION

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SAFETY OF USE OF HIGH ALTITUDE PROTECTION SUITS FOR KINESITHERAPY – PRELIMINARY REPORT

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Abstract: Apart from protection from very high altitude or influence of increased gravitational accelerations protective suits sometimes are used for another applications like supporting kinesitherapy. Because of some safety considerations connected with possible cardiovascular system overload and dangerous blood pressure increase we tested if these concerns are valid. Main aim ot presented research performed with participation of healthy volunteers was to confirm that use of High Altitude Protection (HAP) suit is safe in terms of increased cardiovascular.

Keywords: altitude protection suit, kinesitherapy, cardiovascular load, therapy safety

Figures: 6 • **Tables:** 2 • **References:** 7 • **Full-text PDF:** http://www.pjambp.com • • **Indexation:** Index Copernicus, Polish Ministry of Science and Higher Education

INTRODUCTION

High altitude protection suits (HAP suits), sometimes called also pressure suits, are devices designed and normally used for protection of aircrew in case of emergencies connected with exposition for very low atmospheric pressure (e.g. lost of cabin pressure at high altitude). The need for mechanical compression on the wearer body arises from two reasons. First, at the altitudes above around 10,000 m (33,000 ft) breathing even 100% oxygen under atmospheric pressure at such altitude does not meet human organism needs and oxygen must be administered under pressure greater than surrounding atmospheric pressure. Such condition, called positive pressure breathing (PPB), can lead to lung and thorax distension or even risk of lung tissue rupture hence there is need for external compression on the chest to balance intrapulmonary pressure. Secondly, at even higher altitudes – around 18-19000m (60-62000ft) there is a risk of boiling of exposed body liquids. Pressure at such altitudes is low enough (around 47mmHg) to allow water boiling in temperature of human body. For protection of life at such altitudes both positive pressure breathing and external pressure on the body is critically required.

Apart from being a safety device, high altitude protection suits sometimes are used in another applications like increasing blood pressure in vertical position in person after lengthy microgravity exposure or in kinesitherapy as a supporting devices for persons with antigravitational muscles deficits [4]. Additional advantage of using body compression techniques is concurrent both muscular and proprioceptive stimulation ongoing during therapeutic session [7]. Overall view of suit is present on fig. 1, it's principle of operation is shown on fig. 2.

Major safety concern in normobaric and non-emergency conditions is increased blood pressure and breathing difficulties caused by high mechanical pressure on the wearers body.

Use of pneumatic assembles exerting the force on body in kinesitherapy is not frequent and the bibliography associated with this subject is scarce. Main system used in this application is Russian "Atlant" system [2]. We did not find any publications concerned on safety of their use, especially in terms of possible cardiovascular overload of patients involved. Some available data [1,6] suggest, that inflation below 70mmHg is completely safe in terms of significant blood pressure increase.

As a part of broader project in area of kinesitherapy we tried to investigate if wearing HAP suit inflated to pressures from range planned for future experiments is safe in terms of cardiovascular burden put on the participants organisms. Main aim of this paper is to assess performed research results in terms of safety to the suit wearer expressed with increase of HR and RR within safe limits.

MATERIAL AND METHODS

In presented work we used WUK-90 high altitude protection suit (Air-Pol, Legionowo, Poland). It is a capstan-type suit. In this system compression over the body is done through inflating rubber tubes which are increasing pressure on the body with non distending tapes sewn into suit fabric. In addition suit is equipped with abdominal bladder exerting pressure on lower abdomen and frontal pelvic region. Precise adjustment of suit is done with use of polypropylene laces. Closing of suit is done by means of metal zippers.

Therefore increasing of air pressure in capstan system and abdominal bladder is increasing mechanical force exerted by suit on the body of person wearing it.

Before experiments we obtained written approval from Military Institute of Aviation Medicine in Warsaw Ethics Committee in accordance with the Helsinki Declaration of 1975, as revised in 2000. Each participant signed informed consent

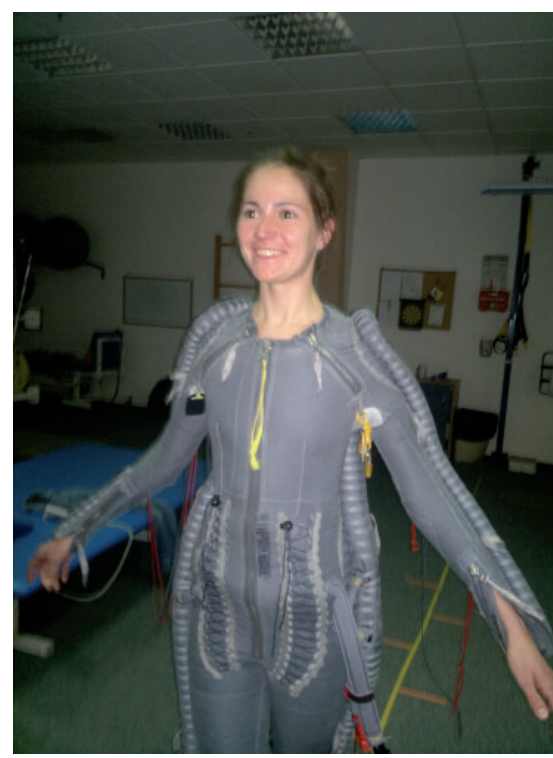


Fig. 1. WUK high altitude protection suit used in experiments (photo presented with patient's consent).

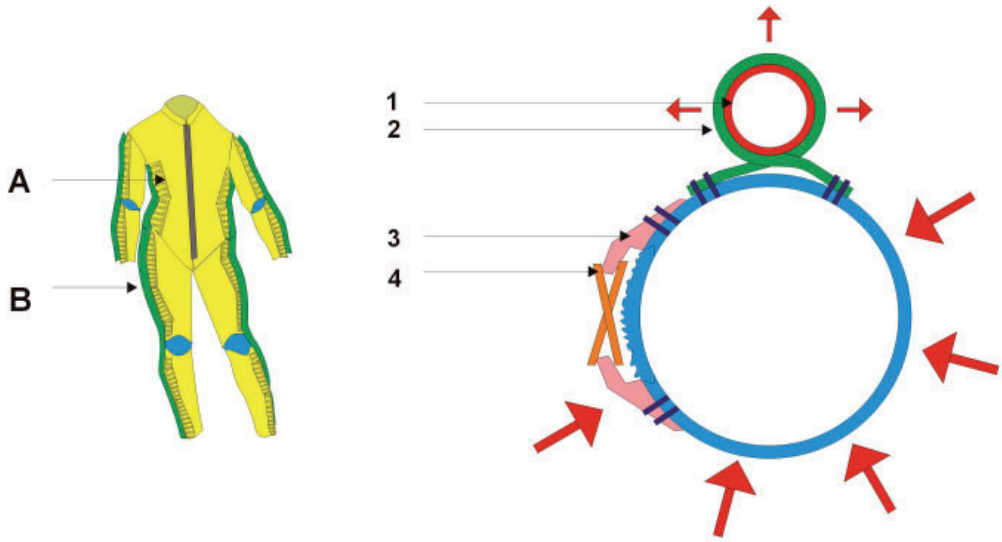


Fig. 2. Capstan type suit work principle. A-laces B capstan tube covered by fabric tapes, 1 - rubber tube 2-capstan tapes 3-laces mount 4-lace.

Fig. 3. First subject during experiment (photo presented with participant consent).

statement and was informed about possibility to cease his or her participations anytime. Volunteer subjects were not paid for participation in presented research.

Research was conducted in two main parts: firstly we performed tests on one healthy individual. Subject was male professional soldier 38 years of age, 170cm tall, weight 64 kg. He possessed valid fit for military duty assessment from military medical board. Subject during test is shown on fig. 3.

In second stage results were confirmed with group of 17 healthy volunteers who performed one real kinesitherapy session with use of the HAP suit. Mean age of control group was 29,5 years of age (SD ± 4,69y; age span was from 23 to 41 y.o.). Eight females and nine males constituted our control group.

Each participant has systolic and diastolic blood pressure measured (with OMRON™ R7 blood pressure monitor), arterial blood saturation SpO2 (with finger pulse oximeter). Results were recorded and analyzed with paired t-tests. Measurements of blood pressure were taken 5 min before donning of HAP suit and after that RR and SpO2 measurements were taken in 3 minutes intervals. Each examination were 24 minutes long. Last measurements were taken 5 minutes after HAP removal.

RESULTS

As a starter we tried investigation with one volunteer using inflated WUK on the treadmill normally used for stress test cardiography. Physical load was in accordance with Bruce protocol [5]. Physical workload was increased in 3min intervals. Increase was both in terms of speed and angle of elevation. Stages of exercise test are presented on table (tab. 1) below:

Our subject has attained Stage 4 according to this protocol. Measurements of systolic and diastolic pressures are provided on graph (fig. 4) below:

Control group of 17 volunteer participants were tested in similar manner, but we broadened measured parameters with pulse oximetry. During 24

Tab. 1. Bruce protocol stages (from [3]).

Stage	Time (min)	Speed (km/hr)	Gradient (%)	Metabolic equivalents of tasks
1	3	2.7	10	5
2	6	4.0	12	7
3	9	5.4	14	10
4	12	6.7	16	13
5	15	8.0	18	15
6	18	8.8	20	18
7	21	9.6	22	20

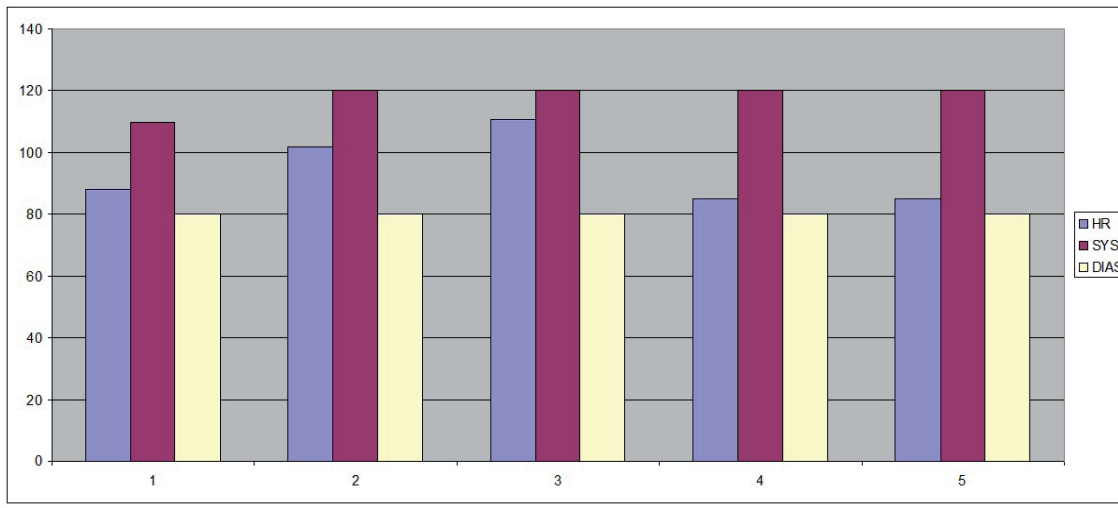
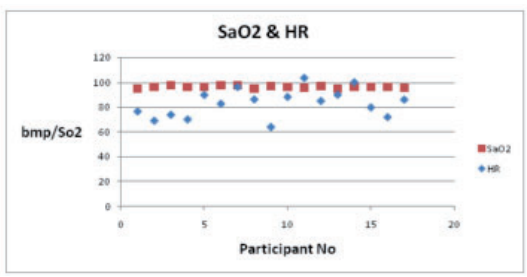


Fig. 4. HR, SYStolic and DIAstolic blond pressure in first subject. 1-baseline before test, 2- results after stage 1, 3- results after stage 2, 4- results after stage 3, 5 - results after stage 4.



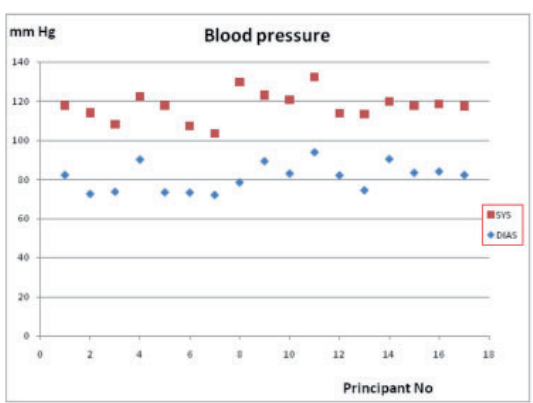


Fig. 5 & 6. Results of measurements in control group. Means of measurements before and after each session are provided.

minutes of measurements period participants performed sets of physical exercises designated for patients (research) group. Results of control group parameters after exercises are presented below (fig. 5 & 6):

Results obtained indicate, that blood pressure changes (both diastolic an systolic) were on minuscule level (- well below 1%) (table 2), p=NS.

DISCUSSION

Main safety concern associated with use of compressing devices, especially if they cover chest region is increase of blood pressure resulting from addition of mechanical external pressure to the "normal", heart generated blood pressure. In physiological condition blood pressure is regulated on correct level by reflex from carotid baroreceptors. Distending of carotid artery walls caused by increased blood pressure activates heart inhibition, mainly through vagal nerve. In opposite situation decreased blood pressure on carotid receptor is inhibiting parasympathic activation of vagal nerve thus increasing heart output. This is phenomenon thoroughly studied during head- foot directed acceleration exposures in flight or on the centrifuge.

Tab. 2. Averaged blood pressures, HR and saturation for 17 persons control group before and after the session.

	Systolic	Diastolic	SaO2	HR
BEFORE	127,2	84,6	96,5	78,2
AFTER	130,1	82,6	96,3	84,8
CHANGE (%)	**0,023**	**-0,024**	**-0,0021**	**0,085**

This is quite powerful reflex, allowing human body to compensate lower body blood retention up to around four times Earth's gravity. In experiments described in this paper we wanted to check if potential of this reflex going the opposite way i.e. decreasing heart's output in conditions of increased pressure is enough to allow overall blood flow close to normal. Because of systemic nature of the reflex we have chosen wrist blood measurement instead of neck pressure measurements, which are more technically complicated and hardware involved is precluding free movements necessary to perform therapeutic exercises. From centrifuge experiments we know, that use of height compensated limb pressure measurement is sufficient to assess both heart and brain level blood pressure.

All performed measurements have confirmed that use of WUK-90 high altitude protections suit is safe in terms of cardiovascular system parameters in area of pressures used in experiments. We did not encountered any increase of blood pressure which may be considered as a harmful, for participants.

Results obtained suggest that increasing physical pressure on the body is successfully corrected by body homeostasis system. Cardiovascular reflexes from carotid baroreceptors are sufficient to tame increase of hydraulic blood pressure induced by over-the-chest pressure. No breathing difficulties reported by our participants is another prognostic which gives us a rise to conclusion that therapeutic use of high altitude protection suit for kinesitherapy is safe alternative to "normal" sets of exercises planned to perform in therapy of patients.

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AUTHORS' DECLARATION:

Study Design: Maciej Abakumow, Krzysztof Kowalczuk. **Data Collection:** Maciej Abakumow. **Statistical Analysis:** Maciej Abakumow, Krzysztof Kowalczuk. **Manuscript preparation:** Krzysztof Kowalczuk, Maciej Abakumow. The Authors declare that there is no conflict of interest.

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