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ORIGINAL ARTICLE

AUTONOMIC DYSFUNCTION IN EXTREME OBESITY

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Abstract: Heart rate variability (HRV) provides valuable information in various clinical settings. Limited information exists on changes in cardiac autonomic modulation in extremely obese patients (BMI>40). The aim of this study was to investigate the influence of extreme (morbid) obesity and concomitant diseases on cardiovascular autonomic function. Participants of this study are 40 women and 40 men with a mean age of 47.9 diagnosed with morbid obesity (mean BMI 47.49) and hospitalized to further bariatric treatment. In 42 patients diagnosed with hypertension (treated with beta blockers and ACE inhibitors along with well controlled blood pressure), type 2 diabetes (treatment with oral drugs) also occurred. Furthermore, 46 patients were diagnosed with depression. None of the participants used antidepressants or sedative agents. A total of 80 healthy people (40 women and 40 men) with a mean age of 42.7 and with a mean BMI of 24.6 formed the control group. All patients had 24-hour ECG monitoring using the Holter method in order to evaluate the autonomic activity with time and frequency domain analysis (heart rate variability – HRV).

Figures: 2 • **Tables:** 3 • **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

Results: The obese group showed a significant reduction of parasympathetic activity and a significant increase in sympathetic activity. No significant differences in cardiac autonomic modulation were noted between the Hypertensive-Diabetic patients and those with morbid obesity only. However, the in studied group, obese patients with depression had lower time and frequency domain parameters ($p<0.05$) except Standard deviation of NN intervals (SDNN), and the ratio of Low frequency (LF)) / High frequency (HF) power (LF/HF) in contrast to obese non-depressive individuals. The additional burden of diabetes and hypertension in depressed patients did not affect the cardiac autonomic modulation differences.

Further prospective study can be undertaken within the same subjects to evaluate the effect of weight loss on the cardiac autonomic activity.

Conclusions: 1. Extreme obesity altered cardiac autonomic activity independently of hypertension and diabetes.

2. Depression associated with morbid obesity intensified HRV reduction.

Keywords: heart rate variability, obesity, concomitant diseases

INTRODUCTION

Proper cardiovascular function is essential in maintaining homeostasis of the body as a whole [31]. The autonomic nervous system (ANS) plays an essential role in the regulation of cardiovascular homeostasis, in which the sympathetic and parasympathetic nervous systems should remain in balance [13,36]. One of the most advanced and widely used methods of assessing ANS activity is Heart Rate Variability (HRV), which is the evaluation of cyclic, temporal differences between successive heartbeats, corresponding to the R-R intervals of an electrocardiogram (ECG). Changes in the length of the R-R intervals depend on the activity of the sinus node and reflect the influence of the functional state of the autonomic system on the heart. A normal HRV confirms a healthy status, whereas a low HRV may be a predictor of various disease states [49]. Several studies have shown that ANS dysfunction occurs in obesity and imbalance between components of the autonomic nervous system may be one of the most important predictors of cardiovascular death [8,16].

The prevalence of obesity worldwide is reaching epidemic proportions [43]. Obesity, especially severe – morbid obesity (body mass index – BMI $\geq$40 kg/m^2) and its metabolic consequences are associated with increased risk of morbidity and mortality and reduced life expectancy [28]. It should be emphasized that adipose tissue is not only a fat storage, but also an endocrine organ, which is both a place of formation of many biologically active substances and integration of signals sent from others. It should also be noted that a significant percentage of obese people also have other diseases that are most often complications of obesity. These include, among others: hypertension, diabetes, dyslipidemias, heart failure, ischemic heart disease and depression [5]. Both depression and obesity are significant public health problems [3] with high prevalence worldwide and an associated increased cardiovascular risk [17]. Studies have shown an association between depression and obesity, with the prevalence of depression in obese individuals being twice as high as in normal weight individuals [5]. The relationship between depression and obesity, while established and confirmed in numerous epidemiological studies and meta-analyses, has yet to be fully elucidated. The relationship has been studied repeatedly, with some authors arguing that depression causes weight gain and obesity, and others that obesity leads to depression, suggesting bidirectional causality [48]. It has been suggested that both depression and obesity result from dysregulation of the stress response, primarily involving the hypothalamic-pituitary-adrenal (HPA) axis [26]. Further mechanisms linking these two conditions include inflammation, oxidative stress, and other endocrine dysfunctions [27] as well as psychological mechanisms such as ruminations, stigma, and ostracism, which contribute to and maintain a bidirectional relationship [27].

It is known that obesity, hypertension, diabetes mellitus and depression are associated with dysregulation of autonomic functions independently [14,40]. Unfortunately, there is limited information on changes in cardiac autonomic modulation in extremely obese patients (BMI ≥40 kg/m^2), especially those burdened with comorbidities.

The aim of this study was to investigate the influence of extreme obesity and concomitant diseases on cardiovascular autonomic function.

MATERIALS AND METHODS

Participants

Participants of this study are 40 women and 40 men with a mean age of 47.9, diagnosed with morbid obesity (mean BMI 47.49) and hospitalized to further bariatric treatment. In 42 patients diagnosed with hypertension (treated with beta blockers and ACE inhibitors along with well controlled blood pressure), type 2 diabetes (treatment with oral drugs) also occurred. Furthermore, 46 patients were diagnosed with depression based on the results of the Beck Depression Inventory II (mean 15.6). None of the participants used antidepressants or sedative agents. A total of 80 healthy people (40 women and 40 men) with a mean age of 42.7 and with a mean BMI of 24.6 formed the control group. The participants were informed about the procedures and objectives of this study and signed informed consent forms.

Hrv Analysis

All subjects had 24-hour ECG monitoring using the Holter method in order to evaluate the autonomic activity with time and frequency domain analysis (heart rate variability – HRV). After manual correction for artifacts and ectopic beats, HRV analysis was performed. The recordings were evaluated temporally, including 24-hour recording, separately for the hours of daytime activity (6:00-22:00) and nighttime rest (22:00-6:00), and a 15-minute period from day and night. A spectral analysis was performed on the same 15-minute intervals of ECG recordings from the daytime and nighttime hours.

Time-domain indices were calculated as follows:

1. Standard deviation of NN intervals (SDNN) expressed in ms, which reflects the cyclic components responsible for the variability of heart rate.
2. Root mean square successive difference of NN intervals (rMSSD) expressed in ms, which reflects estimates of short-term variability of heart rate. rMSSD is highly sensitive to the fluctuation of high frequency of HRV and is an index of vagal control of the heart.
3. Number of interval differences of successive NN intervals greater than 50 ms in the entire recording (NN50), which reflects estimates of short-term variability of heart rate and is an index of vagal control of the heart.

Frequency-domain indices were obtained through autoregressive (AR) spectral analysis. The frequency-domain indices were calculated as follows:

1. Low frequency (LF) power (0.04 to 0.15 Hz) in ms2, which reflects both sympathetic and parasympathetic cardiac activity and is strongly related to blood pressure regulation [12,38].
2. High frequency (HF) power (0.15 to 0.40 Hz) in ms^2, which primarily reflects cardiac parasympathetic tone [12,38].

In addition, the LF/HF ratio was computed as the ratio of LF(ms^2)/HF(ms^2) as it is thought to be a measure of sympathovagal balance [25].

Depression Measurement

The previously validated Beck Depression Inventory-II (BDI-II) was used to measure depressive symptoms. BDI-II is composed of 21 multiple-choice questions (scores range between 0 and 63) and takes approximately 5 min to complete. According to the original data, 14 points were taken as the cut-off point.

Statistical Data Analysis

Data were expressed as mean values ± standard deviation (SD). The normal distribution of data was tested using Shapiro–Wilk tests. Unpaired t – tests were used to compare the differences between the two groups. $P < 0.05$ was considered to be statistically significant.

RESULTS

Obesity effects on 24-h Heart Rate Variability in time and frequency domain analysis and statistical differences between groups were shown in Table 1.

Analysis of time domain parameters, SDNN, pNN50 and RMSSD of obese subjects were significantly lower, compared to volunteers with normal BMI. The frequency domain parameters, the LF and LF/HF ratio in both groups was also statistically different. The obese subjects had an HF and TP values lower then healthy, and the LF values and LF/HF ratio was higher than in the control group.

Tab. 1. Age, BMI, and cardiac-autonomic markers in obese and healthy subjects.

Mean	Obese	Healthy	P value
Age	47.5	45.9	0.3
SD	2.32	3.41	
BMI	47.3	24.6	0.001
SD	3.26	2.81	
SDNN	41.21	83.45	0.0001
SD	15.88	27.31	
rMSSD	33.75	54.69	0.0001
SD	32.11	45.43	
pNN50	7.4	11.3	0.001
SD	2.3	3.45	
HF ms²	324.5	764.1	0.001
SD	231.2	268.7	
LF ms²	1245.8	947.6	0.01
SD	561.23	248.61	
LF/HF	3.7	2.1	0.01
SD	1.22	2.67	
TP	2876.9	3798.6	0.01
SD	582.55	834.21	

Results are reported as Mean and Standard deviation SD. SDNN = standard deviation of all NN intervals in ms; rMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals in ms; NN50 = number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; LF = low frequency power; HF = high frequency power; LF/HF = the ratio LF(ms²)/HF(ms²).

The spectral components changes of HRV in a healthy person and a obese patient is shown in figure 1 and 2.

Concomitant disease effects on 24-h Heart Rate Variability in time and frequency domain analysis and statistical differences between groups were shown in Table 2.

Results are reported as Mean and Standard deviation SD and . SDNN = standard deviation of all NN intervals in ms; rMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals in ms; NN50 = number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; LF = low frequency power; HF = high frequency power; LF/HF = the ratio LF(ms^2)/HF(ms^2). OO - Only Obese patients; O&HD - Obese with Hypertension and Diabetes.

No significant differences in cardiac autonomic modulation were noted between the Hypertensive-Diabetic patients and those only with morbid obesity.

Impact of depression on 24-h Heart Rate Variability in time and frequency domain analysis was shown in Table 3.

SDNN = standard deviation of all NN intervals in ms; rMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals in ms; NN50 = number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; LF = low frequency power; HF = high frequency power; LF/HF = the ratio LF(ms^2) /HF(ms^2).

In the studied group, obese patients with depression had lower time and frequency domain parameters ($p<0.05$) except SDNN, and LF/HF ratio in contrast to obese non-depressive individuals.

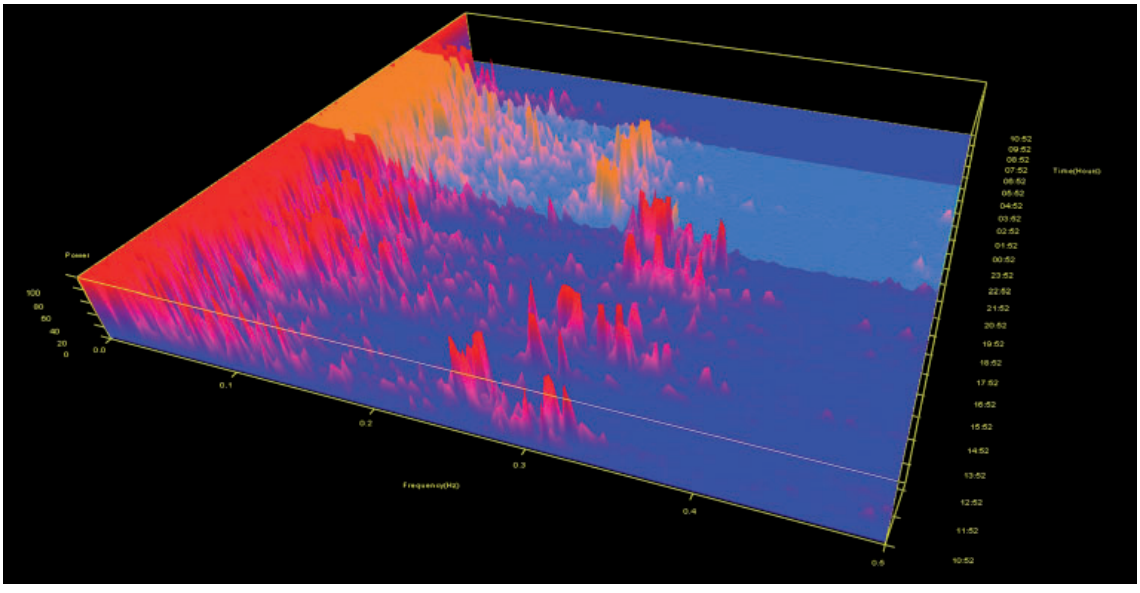

Fig. 1. The spectral components changes of HRV in a healthy person.

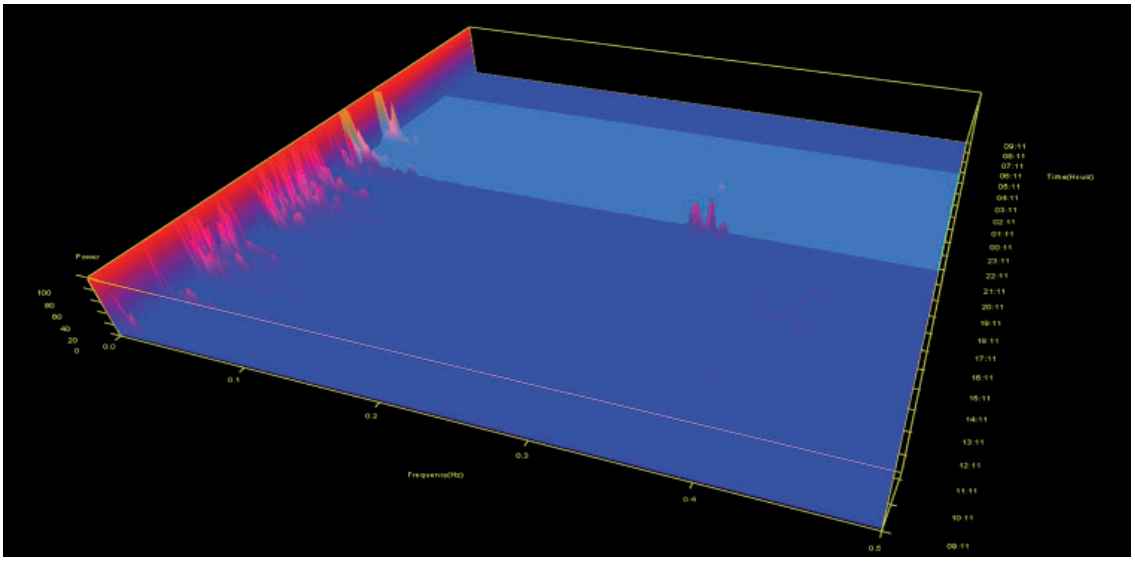

Fig. 2. The spectral components changes of HRV in an obese patient.

Tab. 2. Age, BMI, and cardiac-autonomic markers in obese and obese with concomitant disease subjects.

Parameter	OO	O&HD	P value
Age	47.5	49.2	0,3
SD	3,3	5,4	
BMI	48.3	49.6	0.7
SD	5.2	1.8	
SDNN	46.2	44.7	0.21
SD	16.8	12.3	
rMSSD	36.7	34.6	0.65
SD	32,1	30,7	
pNN50	12.5	12.6	0.9
SD	1.3	2.4	
HF ms²	365.9	341.5	0.2
SD	261.2	208.7	
LF ms²	1285.8	1311.9	0.6
SD	666.3	578.2	
LF/HF	3.5	4.2	0.09
SD	1.2	2.6	
TP	3111.3	2982.7	0.08
SD	502.5	689.2	

Results are reported as Mean and Standard deviation SD and . SDNN = standard deviation of all NN intervals in ms; rMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals in ms; NN50 = number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; LF = low frequency power; HF = high frequency power; LF/HF = the ratio LF(ms²)/HF(ms²). OO - Only Obese patients; O&HD - Obese with Hypertension and Diabetes.

Tab. 3. Age, cardiac-autonomic markers in obese depressive and non-depressive patients.

	Depressive N=46		Non-Depressive N=34	
	Mean	SD	Mean	SD
Age	47.2	2.5	46.9	3.6
SDNN	33.5	10.2	44.1	15.8
rMSSD	23.8	11.3	34.8*	18.2
pNN50	4.9	2.5	11.4*	7.5
HF ms²	187	115.6	341.1*	221.4
LF ms²	882.5	154.7	1259.2*	321.2
LF/HF	4.1	2.5	3.9	2.5
TP	2534	2.5	4250.9*	2.5

SDNN = standard deviation of all NN intervals in ms; rMSSD = square root of the mean of the sum of the squares of differences between adjacent NN intervals in ms; NN50 = number of pairs of adjacent NN intervals differing by more than 50 ms in the entire recording; LF = low frequency power; HF = high frequency power; LF/HF = the ratio LF(ms²) /HF(ms²).

DISCUSSION

Over the past few decades, the prevalence of obesity in the world has been increasing at a rapid rate [11]. Overall, obesity can be considered a chronic relapsing and progressive disease and a leading risk factor for global deaths [3]. According to the severity and duration of weight gain, obesity can progressively cause and/or exacerbate a broad spectrum of comorbidities, including type 2 diabetes, hypertension, dyslipidemia, cardiovascular disease, liver dysfunction, respiratory and musculoskeletal disorders, infertility, psychosocial problems, and certain types of cancer [19]. Another important manifestation of obesity is impairment in the autonomic nervous system (ANS), present in all age groups [35]. Numerous studies have shown that obesity is characterized by a dysfunction of the sympathetic and parasympathetic nervous systems, and that an imbalance between the components of the AUN may be one of the most important predictors of cardiovascular death [29,39].

In epidemiological studies, obesity has been proven to be associated with AUN dysfunction regardless of coexisting diabetes or hypertension [14,40]. However, the impact of other diseases that could potentially intensify ANS dysfunction in obese individuals has so far been the subject of few studies.

Our study was carried out to find out the HRV response in obese patients with hypertension and type 2 diabetes and obese patients with depression to find out the presence of additive effects of HRV changes in obese patients with comorbidities. If obesity can alter the HRV response as much as hypertension, diabetes, or depression solely, then obese patients burdened with these diseases should have more severe HRV changes.

In this study, the obese patients had significantly lower parameters of time domain analysis (SDNN, pNN50 and RMSSD) compared to volunteers with normal BMI. The frequency domain parameters, the LF and LF/HF ratio in both groups was also statistically different. The obese subjects had HF and TP values lower then healthy people, and LF values and LF/HF ratio was higher than in the control group. These results are in accordance with reports from other authors [20,46,47].

The pathophysiology of obesity and its comorbidities is complex and involves many different pathways. Many studies highlight the role of inflammatory adipokines. These comorbidities include type 2 diabetes, in which insulin resistance is exacerbated by TNF-α and other inflammatory secretagogues in adipocytes; endothelial dysfunction and hypertension, which result from the activity of renin angiotensin system -secreting adipokines; and dyslipidemia, which is caused by hypercholesterolemia and hypertriglyceridemia. These comorbidities and the effects of fatty acid lipotoxicity promote atherogenesis, including coronary artery disease. The presence of insulin resistance, sympathetic nervous system activation and sodium retention in obesity are overlapping mechanisms [32]. Insulin resistance activates the sympathetic nervous system, upregulates angiotensin II receptors and reduces the synthesis of nitric oxide, leading to increases in heart rate and blood pressure [1,17,23,24]. Furthermore, increased effects of leptin, the activation of hypothalamic-pituitary-adrenal axis, the presence of obstructive sleep apnea and baroreflex dysfunction in obesity further contribute to the activation of the sympathetic nervous system [18,37]. Finally, in obese patients there is an increase in renal tubular reabsorption with a consequent sodium retention, further contributing to the development of hypertension [33].

In the aspect of ANS activity in subjects with obesity and comorbidities, our results were surprising. In the groups of subjects with obesity alone and with obesity combined with hypertension and diabetes, no statistical differences in the values of the parameters of both time and frequency analysis of HRV were found. These results are in contrast to reports by other authors who showed an increase in the autonomic imbalance in patients with diabetes and hypertension compared to the non-diabetes group [2], and multiple studies which have shown that diabetes (hyperglycemia) may lead to neuronal damage and subsequent autonomic dysfunction measured by high heart rate or low HRV [4,7,9,45]. Moreover, also reduced HRV in patients with hypertension alone [41] and in persons with obesity alone [30,44] were found. Study of Mamatha S. D et al. revealed that significant reduced HRV indicating alteration in both parasympathetic and sympathetic outflow, which is manifested by the more positive correlation of HRV with obese hypertensives, compared to non-obese hypertensives [22].

Discrepancies in our results in relation to those obtained by other authors may be due to the severity and time of duration of obesity in the studied group (morbid obesity), as a positive correlation between anthropometric indices and ANS imbalance was shown [34], and /or from the fact that both hypertension and diabetes were, in this group, very well treated with oral medicines (beta blockers, ACE and Metformin), which offsets, to some extent, the increased sympathetic stimulation.

Our study has shown that obese depressed patients had lower HRV parameters in the time and frequency domain ($p<0.05$), except SDNN and LF/HF ratio, compared to obese non-depressed subjects. The results obtained in our study are consistent with the reports of others. Yadav and colleagues have shown that obese patients have lower HRV parameters except LF/HF parameter [46]. Depression and obesity are interrelated health burdens. Both conditions are associated with AUN deregulation. Typically, they are associated with overactivity of the sympathetic nervous system; however, researchers emphasize that the patterns of activation may be different and result from either a direct predominance of the sympathetic component or a decrease in parasympathetic activity. It should be emphasized here that decreased autonomic system activity in obesity may be an independent cause of the development of

depression, in which decreased parasympathetic component activity is a major factor in the development of the disorder [31,46]. Additionally, it has been shown that lower HRV in depressed individuals reflects impaired integration of brain mechanisms underlying effective autonomic and behavioral control (underlying obesity) [11]. Multiple studies indicate that some reduced parameters in HRV analysis values are characteristic of depressed individuals [10,15,21,42]. It has also been shown that lower HRV parameters positively correlate with the severity of the depression symptoms [19]. These reports explain little specificity of the reduction in HRV in the studied group, in which depression was detected during screening tests and the patients had not been treated because of it before. It has also been shown that HRV analysis is a better predictor of the development of full-blown depression than it is a marker of current depressive state [6]. It has also been shown that obese individuals are twice as likely to develop depression [39-41] and that depression may be not only the effect but also the cause of obesity [9]. Reported decreased mood has been associated with an increase in food intake, also among college students [2].

The bidirectional relationship between depression and obesity is associated with dysfunction of the psycho-immune neuroendocrine (PINE) network. Disturbances within the network, common to both metabolic disorders and depression, explain the development of depression among obese patients as well as obesity among depressed patients [31]. Studies also highlight changes in autonomic system activity among the mentioned groups [31]. The dependence of emotional regulation on autonomic processes and its relationship with regulatory metabolic processes is also described in the polyvagal theory [34].

To summarize, despite the limited number of cross-sectional studies, there is a series of reports that associate various HRV indices with obesity and comorbidities. Because HRV is a measure of the body's ability to maintain homeostasis, therefore, HRV analysis is an easy marker of worsening health, especially in patients with chronic diseases. Therefore, clinicians should include the assessment of ANS activity in the diagnostic and therapeutic process because it depends on many psychophysiological parameters and provides good feedback for the success of complex therapy.

CONCLUSIONS

1. Extreme obesity altered cardiac autonomic activity independently of hypertension and diabetes.
2. Depression associated with morbid obesity intensified HRV reduction.

AUTHORS' DECLARATION:

Study Design: Ewelina Zawadzka-Bartczak, Dagmara Bartczak-Szermer. **Data Collection:** Ewelina Zawadzka-Bartczak, Dagmara Bartczak-Szermer. **Manuscript Preparation:** Ewelina Zawadzka-Bartczak, Dagmara Bartczak-Szermer. The Authors declare that there is no conflict of interest.

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ORIGINAL ARTICLE

THE STRUCTURE OF VISUAL OBJECT PERCEPTION AND PSYCHOLOGICAL DISTANCE IN THE LIGHT OF THE CONSTRUAL LEVEL THEORY BY N. LIBERMAN AND Y. TROPE: A POTENTIAL APPLICATION IN AVIATION PSYCHOLOGY

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Introduction: The aim of the study is to determine the relation between the form of visual presentation of an object and the psychological distance included in the four dimensions (spatial, temporal, social, hypotheticality). The construal level theory by Nira Liberman and Yaacov Trope is used as a theoretical point of reference.

Methods: 400 people participated in the experiment. All distance dimensions were subjected to the same procedure: estimating the percentage value of the extent to which the objects presented in sixty slides (plus a second similarly constructed variant) were related to a specific context determined by the magnitude of psychological distance, in each dimension separately (for example, whether the object came from a shop in Poland or Ireland – small vs. large spatial distance). Six formal features of the visual presentation of an object were manipulated: size, exposed part, level of detail, color, background, technique.

Results: On the basis of the results obtained, it can be concluded that photographs generate less psychological distance than pictures, only in some conditions, determined by the quality of dimensions and stimuli, objects represented in color are associated with greater distance than black-and-white ones; size, exposed part, level of detail and background shape, in most conditions determined by the dimensions of distance and the quality of stimuli, influence the psychological distance significantly, albeit in different ways (different directions of influence).

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Discussion: The hypothesis concerning the mechanism linking the formal features of an object (presented in a visual form) to psychological distance can be illustrated by using the context of the basic distance – the spatial distance at the two poles of which any object can be located, "looked at" from two perspectives –short and long distance, and then extracting those properties which depended on the magnitude of the spatial distance.

Conclusions:
1. Photographs are associated with less psychological distance compared to pictures.
2. Objects presented in color generate a greater distance than those in black and white (in many conditions defined by the dimension of distance and the quality of the stimuli).
3. Size, exposed part, level of detail and background influence the distance in most conditions, but the direction of the influence is not constant – it depends on the specificity of these conditions (on the dimension of distance and the quality of stimuli).
4. The principle of perception of visual objects and psychological distance finds a valuable application in aviation psychology, as a basis for research on general issues of visual situational awareness of a pilot.

Keywords: psychological distance, construal level, form of visual presentation of an object, visual perception

INTRODUCTION

Looking at a painting at a close range, one can see small elements, details, simultaneously not seeing its essence. Looking at the same painting at a certain distance, it is difficult to notice the details, but only then, when one is able to look at the whole canvas, it is possible to discover the most basic element – the main motif. As we approach and distance ourselves from the picture, we perceive it differently. This art-based analogy – both in literal and figurative sense – was used by Nira Liberman and Yaacov Trope to show different ways of perceiving the same reality in the context of different psychological distances [20].

The construal level theory is an attempt to explicate the conditions of qualitatively different representations of the same objects and events within the mind in relation to psychological distance – it defines how psychological distance affects the construal level (and vice versa), and then the way of thinking and behavior, and using a symbolic language, it describes the conditions and consequences of perceiving a fragment of an image vs. the entire image [22].

The construal level, which gives the theory its name, is one of its basic concepts. It is a construct that expresses the way objects and events are represented within the mind. Usually analyzed in a dichotomized form, it is in fact a continuum whose poles are described by low and high construal level [22]. The low construal level includes specific, incidental, peripheral and local features, is context-dependent, inconsistent and poorly structured. The high construal level includes abstract, general, global, central, prototype features, is schematic, simple, internally consistent, structured and not context-dependent [4,10,20,21].

Moving along the continuum from low to high construal level, the number and power of central features – important from the point of view of the object's purpose – increases, while losing, omitting, or ignoring less important features [6,21].

Psychological distance – another theoretical construct important in the CLT, is described by its authors in the following way: "Psychological distance refers to the distance of a stimulus (object or event) from the perceiver's direct experience [3]. This direct experience is defined as falling at a zero-point common to all dimensions, defined by the location – "here", the time – "now", the person – "self" and the existence – "reality". The distance, anchored at a common point, is divided into four dimensions: spatial distance, temporal distance (defining both the distance from the present to the future and from the present to the past), social distance and hypotheticality, which are the tracks that can be used to distance oneself from direct experience towards mental constructs [3,11,20,21].

The term "psychological distance" comprises four forms, which due to their numerous similarities are treated as dimensions of distance and not as completely independent constructs requiring separate explanatory contexts. However, they

have their own individual specific content. They are not clearly translatable, as stated by the authors of the CLT, so that it is impossible to provide a general estimate of how much spatial distance is equivalent to the difference between today and next week [12]. However, the dimensions are interlinked – distancing the object in one modality is transferred to another [3,11,15,18,19].

The basic assumption of the presented theory concerns the relation between psychological distance and the construal level. The distance between the person's direct experience and the stimulus affects the way it is represented, so that as the psychological distance increases, it is more likely that objects or situations will be represented at a higher level. By conditioning the way of representation, distance determines the psychological response to objects or situations in many dimensions: cognitive, affective, behavioral [2,3,10,14,20,22].

Usually, the level of possible influence, as well as our knowledge of a specific object or situation, depends on the psychological distance between us and it. The repetitiveness of the association of the magnitude of distance and level as well as the quality of knowledge leads to its consolidation and excessive generalization, resulting in heuristics [11,13,20].

The research conducted so far shows that the general regularities defined by the CLT are also applicable to the visual presentation of an object. In one study concerning the creation of names for presented visual stimuli, the participants were primed to achieve a high or low level of social power (representation), and then asked to name pictures of unfinished objects. The results obtained indicated a relationship between higher power and image perception in terms typical for a higher construal level, as well as with higher indicators concerning the accuracy of names given. In another experiment, the task was to recognize simple patterns among complex patterns. In the group where a higher construal level was primed, a better distinction was made between primary and secondary features [16].

A greater psychological distance, just like a higher construal level associated with it, favors the perception of the entirety, of the figure. At the same time, it was diagnosed that due to the activation of specific forms of information processing, it may hinder the performance of tasks in which the functions weakened and slowed down by the distance are important. An example of this is the experiment being part of the WISC test carried out in conditions of arousing various distance magnitudes. It transpired that greater psychological distance makes it difficult to perceive details, which was reflected in lower scores obtained in the incomplete pictures sub-test [23].

The visual perception confronted with the reception of words was subjected to theoretical reflection and empirical verification also by researchers. On this plane of comparison, the basic difference between an image and a word concerns the similarity to the represented objects – the images are physically similar to them, while words are not. Pictures are particular, specific like objects, while the meaning of words belongs to a wider category. The specificity of information carriers determines the probable manner of their representation from the very beginning. The "particularization" of the pictures, perceiving similar to the perception of objects, and the connection of this perception with the present time determine the feeling of closeness to what is presented in the visual form. This set of properties favors representing images within the mind at a lower level compared to the representation of words. This was confirmed by experiments in which reactions to images vs. words were compared. The "adaptation" of pictures to what is psychologically close and of words to what is distant was verified within the scope of various dimensions of distance, as well as with the use of various indicators – processing speed and selective attention [1].

In another group of studies on the links between psychological distance and visual perception, the nature of the relationship was checked based on Navon tasks. The participants wrote an essay about their lives tomorrow vs. next year. After using such a manipulation of time distance, the participants were asked to name the presented stimulus, which was a capital letter composed of lowercase letters of another type (e.g. uppercase L composed of lowercase letters h). The obtained results confirmed the hypothesis that a longer time distance favors the perception of capital letters and that temporal proximity facilitates the perception of lowercase letters. Similar conclusions were drawn from similar studies in which other distance patterns were analyzed. Thus, the increase in psychological distance leads to a global perception and the decrease to a fragmented one, to a focus on elements and details.

The authors of the experiment also applied a procedure with reversed direction of the tested impacts. The results obtained indicated the same type of relationships between the analyzed variables. In the conditions of capital letters priming, the participants estimated the spatial, temporal

and social distance as well as the hypotheticality as greater than after emphasizing the lowercase letters [8].

Another experiment in the CLT area, in which visual stimuli were applied, consisted of the evaluation of the exposure time of a series of letters. As in the previously reported studies, the uppercase letters were composed of lowercase letters. During the presentation, the upper or lowercase letters were changed. Specific states of mind were obtained by emphasizing single elements or categories, which activated a lower or higher construal level. The participants generating a higher construal level were convinced that time would pass faster with changes at a global level (capital letters) and those with a lower construal level would be more likely to do so with changes at a local level (lowercase letters). The results obtained confirm the hypothesis of the relationship between the construal level and the quality of perception, more specifically the perception focused on details or the whole [5,9].

In conclusion, a greater psychological distance and a higher construal level direct perception, making it more holistic, while a small distance and a low construal level favor focusing on details. At the same time, the way of perceiving the object as a whole vs. focusing on details proved to be important for the construal level and psychological distance.

Hypotheses

The aim of the experiment was to investigate the relationship between the form of visual presentation of an object and the psychological distance.

The dependent variable in the experiment in question was the psychological distance, appearing in four dimensions: spatial, temporal, social, hypotheticality. The independent variables were the formal features of the visual presentation of objects: size (large vs. small), exposed part (fragmentary vs. whole), detail level (detailed vs. schematic), color (in color vs. black and white), background (with a background vs. without background), technique (as photographs vs. pictures). As can be seen, the independent variables formed 12 levels and the participants estimated the psychological distance on each of them, in each of the four dimensions. The indicator of the dependent variable was the average distance rating at each level of the independent variable.

It was expected that the formal features of the visual presentation of an object: size, exposed part, level of detail, color, background and technique influence the psychological distance within each dimension in a way expressed in the following hypotheses:

H1. Large objects (vs. small objects) generate less psychological distance.

H2. The objects presented in a fragmentary way (vs. the whole ones) generate less psychological distance.

H3. Objects presented in detail (vs. schematically) generate less psychological distance.

H4. Objects presented in color (vs. those in black and white) generate less psychological distance.

H5. Objects presented with a background (vs. those without background) generate less psychological distance.

H6. Objects presented as photographs (vs. pictures) generate less psychological distance.

The hypotheses were tested for each dimension of distance separately under two conditions: when different values of features were assigned to different or the same objects (intra-group and inter-group comparisons). Hence, the experimental conditions were defined by 2 factors: distance dimension (spatial, temporal, social, hypotheticality) and stimulus variant (basic and mirrored) – which resulted in a set of 8 experimental groups.

Due to the editorial requirements for the articles (volume), the report contains selected results of the experiment. A detailed description of the materials, additional hypotheses and full results were presented in the doctoral dissertation of the author [17].

METHODS

Participants

400 people participated in the test – 8 groups, 50 person each. The participants were students of higher education institutions. 75.8% of the participants were women, 24.2% were men. The mean age was 23.810. All participants gave written informed consent to all procedures prior to the study. All procedures were approved by the Institutional Review Board of the Faculty of Christian Philosophy, Warsaw, Poland and have been performed in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans.

Materials and procedure

Two multimedia presentations (basic and mirrored variants) were prepared, containing graphical stimuli to be evaluated and four types of questionnaires.

Photographs of 60 everyday objects were selected. They were divided into six sub-groups, ten photographs each. For each of the sub-groups of photographs, one formal feature was manipulated, creating two variants for each photograph. The size (large vs. small), exposed part (fragment vs. whole), level of detail (detailed vs. schematic), color (in color vs. black and white), background (with background vs. without background), technique (photograph vs. picture) were manipulated.

Two PowerPoint presentations were prepared – one basic and one mirrored. The basic version contained slides from the first half of the image set (objects no. 1-5, 11-15, 21-25, 31-35, 41-45, 51-55) in the first version (large, parts only, detailed, color, with background, photographs) and from the second half of the set (objects no. 6-10, 16-20, 26-30, 36-40, 46-50, 56-60) in the second version (small, whole, schematic, black-and-white, without background, pictures). The order of objects in the presentation was randomized in order to eliminate the influence of grouping stimuli of a common feature.

The second presentation, named the mirrored presentation, contained the same objects as the first, arranged in the same order, but in different, "mirrored" variants. For example, the second slide in the basic presentation is the "sofa – fragment" and in the mirrored presentation the "sofa – whole"; the third slide in the basic presentation is the "wicker basket – black and white" and in the mirrored presentation the "wicker basket – in color".

A questionnaire prepared in four variants was used to evaluate the objects presented in the slides – for each of the dimensions of the distance, separately. In each variant, the task was to estimate where the products presented in the slides came from. Depending on the variant, the participants were informed in the instructions that the displayed objects would come from two sources: Poland and Ireland (spatial distance), from a current offer or from an offer from three years ago (temporary distance), are bought by persons similar or different from the participants in terms of selected characteristics (social distance) and are already available for sale or may be available for sale (hypotheticality). Next to each slide's number, the participant' sheet included a dotted place and a % symbol, where they were supposed to assess how sure (percentage value) they were that the given object, depending on the variant, comes from Poland, from the current offer, was bought by similar people and is already available for sale. Therefore, the questions concerned each time the percentage amount in which an object is associated with a small distance.

For example, in the first variant, where the participants estimated the spatial distance, the title was "From Poland or from Ireland – consumer research". The part of the instruction which suggested different sizes of the spatial distance reads: "Some of the presented products come from a certain retail chain in Poland and some from Ireland. During the presentation of each product, consider which retail chain it comes from (...)". The other three variants of the questionnaire were constructed in a similar way, by manipulating the title and instructions.

Procedure

The study participants were tested in groups during didactic classes at a higher education institution. After a general presentation of the research objective – consumer research, questionnaires were distributed, which were to be filled in during the presentation of the slides containing visual stimuli. The time provided to estimate each of the 60 stimuli was 10 seconds. The study was conducted in eight conditions determined by the crossing of the dimensions of psychological distance (spatial, temporal, social, hypotheticality) and the variant of presentation (basic, mirrored).

RESULTS

The structure of the experiment made it possible to analyze the relationship between the formal features of the visual presentation of objects and the estimation of psychological distance in two planes – intra-group and inter-group.

In the first variant, the dependent variable was analyzed within the group of participants subjected to the same stimuli. Different values of the same features were compared in the presence of different objects. The inter-group comparisons (between the groups subjected to different stimuli) made it possible to determine how a change in the value of a formal feature in the same objects affects the locating at a distance.

Estimation of spatial distance is shown in Figure 1. The intra-group scheme analyses were carried out by means of one-factor analysis of variance with repeated measurement.

The measures of estimation of distance in the scope of particular formal features of objects were compared in pairs.

In the basic variant, the estimation of the spatial distance proved to be sensitive to the manipulation of the following formal features: back-

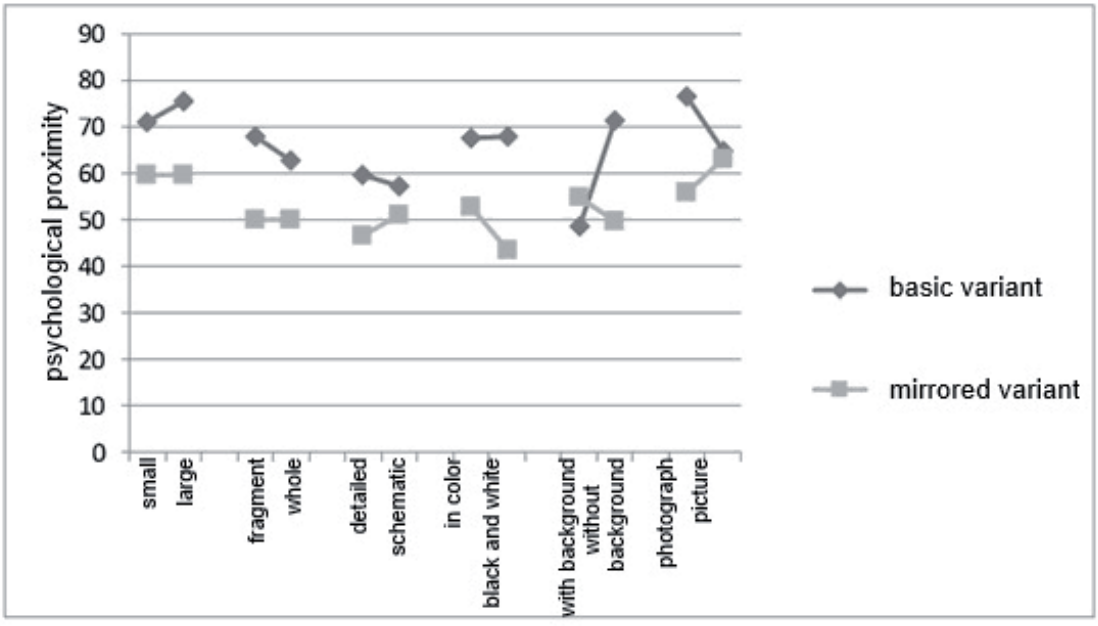

Fig. 1. Estimation of spatial distance (measures of psychological proximity are given; high proximity means short distance).

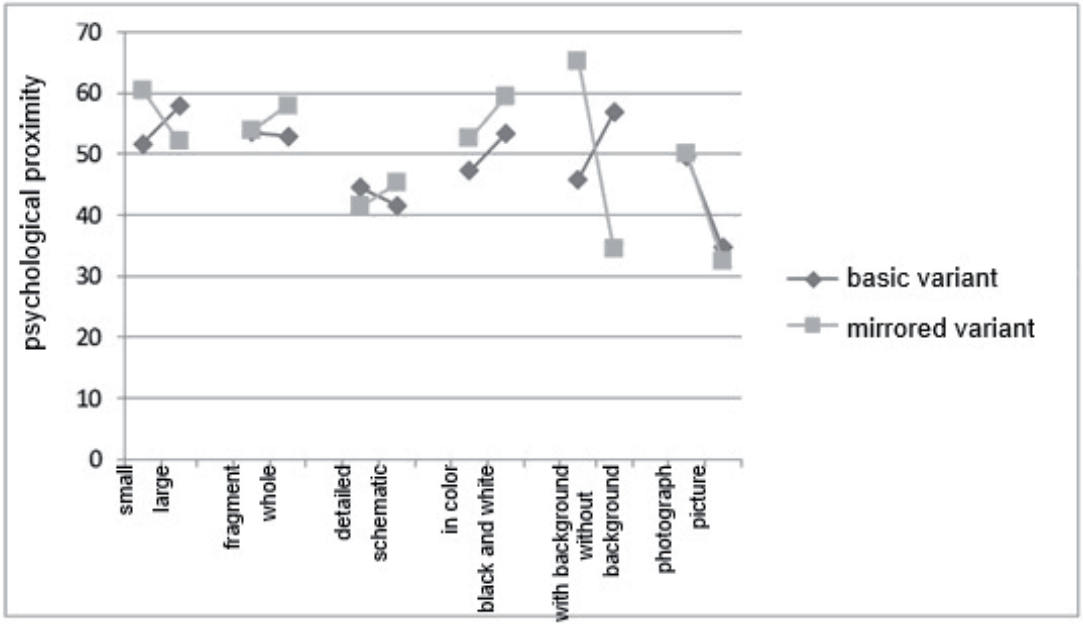

Fig. 2. Estimation of temporal distance (measures of psychological proximity are given; high proximity means short distance).

ground (mean difference=22.69; p<0.000), visual presentation technique (mean difference=11.69; p<0.000), expose part (mean difference=5.34; p<0.019), size (mean difference=4.43; p<0.014).

In the mirrored variant, the assessment of objects in the spatial dimension of psychological distance proved to be dependent on such formal features as: color (mean difference=9.51; p<0.004), technique of visual presentation of an object (mean difference=7.25; p<0.010), background (mean difference=5.13; p<0.023).

Estimation of the temporal distance in both variants of the experiment is shown in Figure 2.

In the basic variant of the experiment, the influence of: visual presentation techniques (mean difference=14.91; p<0.000), background (mean difference=-10.97; p<0.003), color (mean difference=-6.17; p<0.011), size (mean difference=-6.25; p<0.012) was proven to be significant.

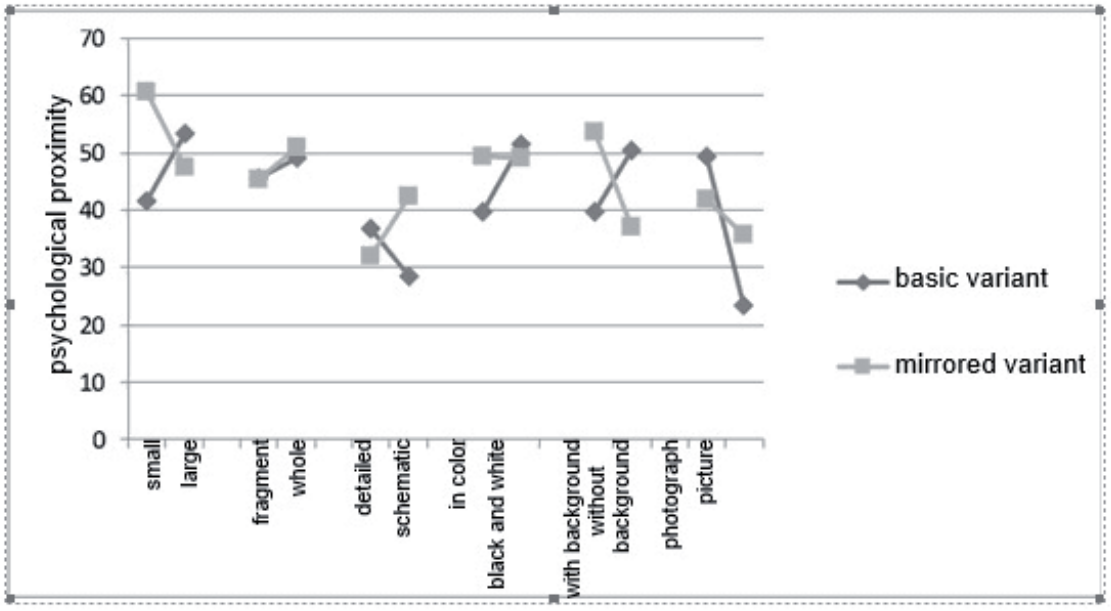

Fig. 3. Estimation of social distance (measures of psychological proximity are given; high proximity means short distance).

In the parallel version of the experiment, a significant influence was associated with the manipulation of the following formal features of an object: background (mean difference=30.99; p<0.000), technique of visual presentation (mean difference=17.53; p<0.000), color (mean difference=6.76; p<0.010), size (mean difference=6.53; p<0.000), exposed part (mean difference=-4.29; p<0.039).

The estimation of social distance is shown in Figure 3.

In the basic variant, significant differences in distance estimation occurred when the following formal features of the perceived objects were manipulated: visual presentation technique (mean difference=25.90; p<0.000), size (mean difference=-12.01; p<0.000), color (mean difference=-11.78; p<0.000), background (mean difference=-10.78; p<0.000), level of detail (mean difference=8.15; p<0.000).

In the mirrored variant, the differences in the estimation of the distance, which reached the level of statistical significance, were related to the following formal features of the visual presentation of an object: background (mean difference=16.64; p<0.000), size (mean difference=13.28; p<0.000), level of detail (mean difference=-10.45; p<0.000), visual presentation technique (mean difference=6.28; p<0.000), exposed part (mean difference=-5.54; p<0.016).

Figure 4 shows the measures of estimating the distance in the hypothetical dimension.

In the basic variant of the experiment, the estimation of psychological distance in the hypothetical dimension proved to be sensitive to manipulations of the following formal features of objects: visual presentation technique (mean difference= 14.34; p<0.000), background (mean difference=-8.85; p<0.000), level of detail (mean difference=6.69; p<0.008), size (mean difference=-4.65; p<0.002). In the mirrored variant, the statistically significant impact was revealed when estimating the distance in the context of the following formal features: level of detail (mean difference+=-20; p<0.000), background (mean difference=17.75; p<0.000), size (mean difference=7.41; p<0.000), color (mean difference=-4.58; p<0.020).

Within the scope of inter-group analyses, for each of the levels of the dependent variable, after separating the data according to the distance dimension criterion, a one-factor analysis of variance with the stimulation factor was applied. The distribution of effects (statistically significant relationships) obtained through the use of this procedure, together with effects obtained as a result of intra-group comparisons, are included in Table 1. Within each cell resulting from the intersection of the distance dimension and a formal feature, up to two statistically significant effects were possible: in intra-group comparison – one for each variant of the study, and in inter-group comparison – for comparison of one value of the feature, e.g. large (from the basic variant and the other small (from the mirrored variant and vice versa), small (from

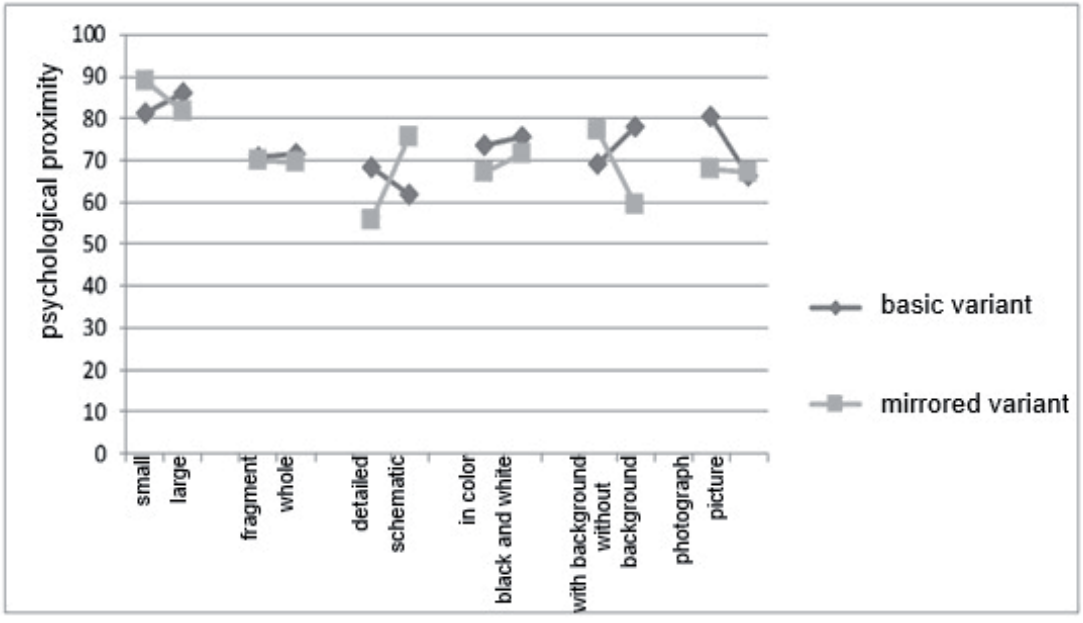

Fig. 4. Estimation of distance in the hypothetical dimension (measures of psychological proximity are given; high proximity means short distance).

the basic variant) and large (from the mirrored variant). In the vast majority of analyzed conditions resulting from the intersection of formal features and the dimension of distance, significant effects occurred. Each of the features proved to be important in shaping psychological distance, although not always in every dimension. Also, all dimensions of the distance proved to be dependent on the influence of formal features of the visual presentation of an object, although some of them were less susceptible to manipulation of certain types of formal features. A large number of significant effects were obtained, but a large portion of them was of an inconsistent nature – the same values of formal features in some conditions significantly favored the perception of psychological distance as small, and in others as large.

DISCUSSION

The main expectation derived from the CLT was that the formal features of the visual presentation of objects influence the perceived psychological distance. The terms used to describe the construal level, relating inter alia to complexity, level of detail, importance of the context, background, structure, are also features of visual presentations and therefore, according to the CLT, should favor

Tab. 1. Comparison of effects related to the influence of formal features of visual presentation of an object on the psychological distance in all dimensions, in the scope of different groups of objects (different comparisons).

	Inter-group comparisons					Intra-group comparisons				
	special distance	temporal distance	social distance	hypotheticality	total	special distance	temporal distance	social distance	hypotheticality	total
size	-	+ -	+ -	+ -	7	+ -		+ -		4
exposed part	+	-	-		3	+ -				2
level of detail			+ -	+ -	4	+ -				2
color	+	- -	-	-	5	+ -	-	-	-	5
background	+ -	+ -	+ -	+ -	8	-	+		+	3
visual presentation technique	+ -	+ +	+ +	+	7	+ -	+ +	+ +	+	7
total	7	9	10	8		11	4	5	3	

+ statistically significant effect; direction consistent with the hypothesis
- statistically significant effect; direction inconsistent with the hypothesis

reception in terms of a certain magnitude of psychological distance [4,10,21].

The hypothesis of the authors of CLT concerning the genesis of the relationship between the construal level and the distance is important in the context of explaining the proposed links between the form of visual presentation of an object and the psychological distance. It is a consequence of generalization, in which the fact that we usually have a different scope and specificity of knowledge about objects and situations close to us, and a different one about psychologically distant situations, becomes a principle that organizes and explains even those situations for which it is not true [20]. Thus, if we have a lot of detailed information about the object, but with little variation in terms of significance, we know a certain context, details, it will probably be associated with less psychological distance (because according to previous experiences, usually this type of knowledge concerned what was close).

Liberman's and Trope's explanation of object or situation knowledge can, by analogy, also be applied to a more direct experience – not only to our presentation of reality in our minds, but also to the objects themselves and perception thereof. The hypothesis concerning the mechanism connecting the formal features of an object (presented in a visual form) with a psychological distance can be illustrated by using the context of the basic distance – the spatial distance at the two poles of which any object can be located, "looked at" from two perspectives – the short and long distance, and then extract those properties which depended on the magnitude of the spatial distance. For example, a person observed from a very close distance seems to be large, fills most of the field of vision, is seen in a fragmentary way, because from a short distance it is impossible to see the whole figure, the person is seen clearly, precisely, in detail (the level of detail also includes the background, the surroundings), many colors, shades clearly delimited within the human figure can be observed; a person seen from a close distance is, by the specificity of such a perspective, perceived as "life-like", realistic, true, certain, specified. On the other side of the analyzed continuum there is a figure observed from a distance – small, seen in the entirety, in low detail, almost monochromatic, blended into an unclear background; due to the lack of details, vivid colors, diverse structures – in a way the person is perceived as unreal, "like painted". The basic properties listed that differentiate the perception of a person from the perspective of a small and large spatial distance are size, exposed part, level of detail, color, background and a certain level of realism defined in the context of own research as a technique of visual presentation of an object. The levels of these formal features, as they are repeatedly combined within experience with their typical spatial distance (e.g. what we see from up close is usually large and from a distance – is small), become associated with it. These links, according to the CLT, are generalized to other dimensions of distance. In conclusion, the CLT-based theoretical justification for the proposed link between the formal features of the visual presentation of an object and the psychological distance is of a two-way nature. It results from the fact that particular levels of features, due to their specificity corresponding to the features of representation, favor the generation of representations of a certain level, which in turn is connected with the corresponding magnitude of psychological distance (e.g. a very detailed object → favors a low construal level – because it is characterized by detail → favors a small psychological distance). In addition, it is a consequence of direct connection of certain levels of features with typical for them magnitudes of psychological distance (e.g. a very detailed object → this is usually how an object is seen from up close → it favors a small spatial distance → it favors a small psychological distance).

These two complementary justifications, relating to Liberman's and Trope's theory, formed the basis for the hypothesis that what was visually presented as large, in a fragmentary way, in detail, as colorful, with a background, in the form of a photograph, is more closely linked to a small psychological distance and what is small, holistic, schematic, black-and-white, without background, pictorial – to a large psychological distance.

This hypothesis is further supported by research in a similar area. It shows that the perception of visual stimuli is susceptible to manipulation in terms of the construal level and that psychological distance was combined with the quality of perception [1,5,8,13,16,23]. These experiments, however, differed from own research in that the visual material presented was rather simple and constant – the formal features of the visual presentation of an object were not manipulated, but only certain properties were brought to attention, investigating the consequences thereof or checking how certain manipulations on variables affected the perception of the same visual stimuli.

In view of the consistent justification of the hypotheses formulated, which refers to the CLT, as well as other studies of a similar area, the results

of the experiment can be described as surprising: usually the same formal properties of the visual presentation of objects, depending on the variant of comparisons (i.e. the quality of visual stimuli), significantly favored the perception of distance as small or large. These discrepancies would not have been evident had only one variant of studying and comparing distances at different levels of formal features been used. In such a case, unambiguous results would have been obtained, most of the time indicating a significant influence of formal features of the visual presentation of an object on the psychological distance; an influence of a specific direction. The results obtained in the additional, mirrored variant, as well as doubling the types of comparisons used (intra-group, inter-group), showed that the conclusions drawn from a single strain of results would significantly distort the real relationships between the analyzed variables.

Both versions of the presentations used in the experiment were prepared on the basis of identical rules. This adequateness of the version of the stimulus material, combined with the assumption that the formal features of the visual presentation of objects with psychological distance deduced from the CLT are relatively independent of the quality of stimuli, led to the expectation that four results describing each of the types of relationships studied within the selected dimension of distance would converge. Contrary to expectations, different directions of influence on psychological distance were diagnosed in terms of size, exposed part, level of detail and background. This does not allow to accept, neither to reject, hypotheses about the relation between the aforementioned formal features of the visual presentation of an object and the psychological distance. It points to the important dependences present in certain conditions, which are strongly modified by additional, undiagnosed factors specific to a given stimulus. A safe conclusion for the discussed issue can be a statement that large vs. small objects, presented fragmentarily vs. as a whole, as detailed vs. schematic, with a background vs. without a background usually combine with different magnitudes of psychological distance, but, to a large extent, it is the additional properties of objects that determine whether the distance is small or large. Learning about these properties would require separate research aimed at manipulating the specificity of the presented stimuli.

A more unequivocal picture of the relationship emerges from the analysis of the role of color in perceiving psychological distance. This feature produced 10 significant effects (out of 16 possible) in all types of comparisons of stimuli in all dimensions, indicating the influence on distance in specific conditions, including 8 consistent in terms of direction, which indicates (contrary to the assumption) the connection of objects in color (vs. those in black-and-white) with a large psychological distance. The relationship of simplified coloring with a larger distance predicted on the basis of CLT, in accordance with the principle of loss of significance of secondary properties for the sake of the basic ones as the distance increases, and also as a result of repeated experiences of seeing many colors up close and a simple color scheme from a distance, proved to be inconsistent with the observed regularities.

The technique of visual presentation of an object was the only feature among those analyzed, which significantly influenced the psychological distance as a whole, and considering each of the dimension of distance, produced as many as 14 out of 16 possible effects, including 12 consistent in terms of direction and with the hypotheses, and these effects occurred in all the dimensions of distance. As expected, the objects presented in the form of a photograph were perceived as related to notions of "here", "now", "our" and "real"; in general, to what is close psychologically. The presentation of the same objects in the form of pictures (although the pictures were very similar to photographs because they were computer-generated and based on those photographs) proved that they were perceived as related to a more distant place, time, further social context and less possible circumstances. It can be concluded that the level of detail, realism, "genuineness" of a photograph fosters psychological closeness when confronted with the "fictitiousness" of a picture, with the fact that it is always a certain representation made by a human being and not (relatively) an unprocessed presentation of an object as it is, with its higher degree of abstractness and with the typical for pictures omission of details. The results of the experiment support the previously presented explanation of the relationship between the form of visual presentation of an object and the psychological distance, referring to the convergence of formal features of visual presentation of an object with those of the representation, which in turn favor a specific psychological distance and a mechanism of perpetuating typical connections between the specificity of perception and distance, especially in the spatial dimension.

Since the experiment was aimed at exploring the area that thus far has been studied only to

a small extent, it provided a large number of results, often inconsistent and difficult to interpret, it would be advisable to continue the research aimed at diagnosing the causes so variated in terms of specificity, and concurrently, the significant impact of particular formal properties of objects (presented in a visual form) on the psychological distance.

CONCLUSION

Photographs are associated with less psychological distance compared to pictures of objects presented in color, which generate a larger distance than those in black and white (in many conditions defined by the dimension of distance and the quality of the stimuli).

Size, exposed part, level of detail and background influence the distance in most conditions, but the direction of the influence is not constant – it depends on the specificity of these conditions (on the dimension of distance and the quality of stimuli).

The principle of perception of visual objects and psychological distance in the light of the construction level theory originally developed by N. Liberman and Y. Trope has a valuable application in aviation psychology, especially in the construction of the visual part of the aircraft cockpit and as a basis for research on general issues of visual situational awareness of pilots [7,24].

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TOWARDS THE DEVELOPMENT OF A PATIENT MONITORING SYSTEM: REVIEW OF AVAILABLE SOLUTIONS AND ASSUMPTIONS FOR BUILDING A FUNCTIONALLY OPTIMAL SYSTEM

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Abstract: The article reviews the technical solutions of devices that enable the patient to monitor selected medical parameters in time. The authors referred to solutions that record data in internal memory as well as solutions enabling direct transmission of medical data, including information on the current location of the patient in the open space and inside buildings. The latest technical solutions of subassemblies allowing us to design a functionally optimized patient monitoring system in the field of sensor and telecommunications technology were also reviewed. Finally, the authors proposed preliminary assumptions for a functionally optimized patient monitoring system.

Keywords: continuous patient monitoring, life monitors, patches, vital signs recorders, wearable sensors, wrist band, indoor and outdoor positioning, locating systems

Figures: 1 • **Tables:** 6 • **References:** 48 • **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

As a result of the analysis of the problem of patient monitoring over time, it can be concluded that the earliest appeared the design of personal recorders of medical parameters recording data in internal memory, with the possibility of reading it only offline. This group includes the Agat [4] and Ventus [30,42] recorders developed by WIML.

With the development of wireless data transmission (GSM, Bluetooth, Wi-Fi, etc.), devices have begun to emerge that offer online patient monitoring and visualization of medical data. In this scope, a series of SMP recorders (SMP-100, SMP-200, SMP-300) [32,33,34], developed under research and development projects carried out by WIML can be used as an example. The development of the GPS system and miniaturization of the receiver modules have made it possible to equip personal medical recorders with the function of tracking the location of people in open space (outdoors) [11,21]. Examples include the SMP-300 recorder or the FT (FlagTag) victim tagging micromodules of the system that supports the evacuation of victims in mass casualty events [12]. Nowadays, there is a clear trend of research groups to search for solutions to monitor physiological parameters and track the location of people inside buildings [45].

Recorders to date have taken a variety of forms, such as electronic and optoelectronic devices with sensors embedded in the mattress of a bed, the seat of a chair, or a wheelchair [6]. The disadvantage of this type of solution is the limited ability to monitor the patient – only while they are on the bed/chair/wheelchair. Embedded devices may be considered for necessary but only temporary monitoring of the patient, such as during sleep or MRI [14].

Attempts have been made to embed sensors in elastic belts worn over the chest or in undergarments such as T-shirts [19,27,38], but the need for a relatively wide range of shirt sizes to achieve satisfactory contact of a sensor with the patient's skin surface and the relatively rapid wear and tear of textile sensors result in a fact that research groups quite rarely develop this type of device. An example of a commercially available system of this type is the Equivital EQ02 Lifemonitor, which is available at WIML [23]. Experience with the use of this system indicates a rather poor quality of recording of the measured signals, even with average physical activity of a patient.

A separate group of recorders is the so-called patch recorders glued on the skin of a patient, which can record selected parameters for up to several days [9]. Despite initial power problems, frequent instances of dampness of electronic circuits, and limited data transmission capabilities, this type of recorder continues to be used in telemedicine. At least a dozen different solutions are known [23,7], the most well-known of which are listed in Table 1 [8,17,31,43,48].

Previous work suggests that airtight bands, the form of which resembles a wristwatch, worn on the wrist or arm are the optimal solution [36]. Recorders of this type are currently most intensively developed by designers because of their convenience of use. Batteries of bands can be recharged multiple times, bands can be retrofitted with additional functionality, and can be used interchangeably for continuous recording. The limitations of such recorders are primarily related to the small number of parameters that can be extracted from a small area of the patient's skin and the artifacts created by the movements of the band on the subject's arm. The available devices are shown in Table 2 [20,42,46].

There are also recorders where the sensor is placed shallowly under the surface of the skin (invasively). The sensor transmits data via radio to a receiver stuck to the skin. Such recorders are mainly used to measure blood glucose levels. Available solutions are listed in Table 3 [16,13].

Monitoring basic vital signs such as heart rate (HR) and transmitting these data for online analysis can provide very valuable information about

Tab. 1. List of skin-adhesive recorders.

Patches – non-invasive recorders						
Model	Recorded parameters		Connectivity	Working time [h]	Data recording time [h]	Manufacturer
	medical	other				
Biosensor BX100 [8]	HR, respiration	Body position detection	BLE 4.2	120	115	PHILIPS
FreeStyle Libre [17]	blood glucose level	-	13.56 MHz	336	8	ABBOTT
Sensium Vitals [31]	HR, respiration, body temp	-	Wi-Fi 802.11 b/g	120	3	Sensium
VitalPatch [43]	HR, HRV, respiration, body temp	Body position detection	BLE	168	10	VitalConnect
Zephyr BioPatch [48]	HR, respiration	Body position detection, device temp, location (GPS)	BLE	28	500	Medtronic

Tab. 2. List of non-invasive recorders made in the form of bands.

Model	Recorded parameters		Connectivity	Working time [h]	Data recording time [h]	Manufacturer
	medical	other				
IntelliVue Cableless Measurement Solution [20]	blood pressure, SpO_2	-	Wi-Fi	no data	no data	PHILIPS
ViSi Mobile [42]	ECG, HR, respiration, SpO_2, blood pressure, body temp	body position detection	Wi-Fi 802.11	14 hours	no data	Soltera
Wireless Vital Signs Monitor (WVSM) [45]	ECG, HR, SpO_2, blood pressure	-	BLE, Wi-Fi 802.11g	4.5 hours	no data	Athena GTX

Tab. 3. List of recorders with implanted sensors (invasive).

Model	Recorded parameters		Connectivity	Working time [h]	Data recording time [h]	Manufacturer
	medical	other				
Eversense XL [16]	blood glucose level	-	sensor no data transmitter BLE	sensor 2160 hours, transmitter 24 hours	no data	Ascensia Diabetes Care
DEXCOM G6 [13]	blood glucose level	-	Sensor BLE transmitter BLE	sensor 240 hours, transmitter no data	no data	DEXCOM

the condition of the monitored person and, if necessary, refer such a person for outpatient testing, extended diagnostics [5,39], and, in life-threatening situations, send medical assistance to the patient. Telemedicine systems are increasingly being used to identify patient health risks 24 hours a day, 7 days a week [35]. The devices listed above communicate with a smartphone, which is used to transmit data to the medical provider responsible for monitoring the patient. Most are equipped with an alert system that informs both the patient and the medical provider of the type of threat. Also increasingly popular smartwatches, offered by smartphone manufacturers, allow for monitoring heart rate and physical activity (e.g. number of steps). An available option for these solutions is to monitor patient location, but only outdoors, based on the smartphone's built-in GPS receiver. None of the systems mentioned above allow for patient location inside buildings and none allow the patient to send an alarm by pressing a button.

The patient location tracking option only allows for identification of the location of, for example, residents of care and rehabilitation centers, hospitalized patients, as well as other people in public buildings such as offices, airports or railway stations. In the context of the current global epidemic situation, telemedicine systems can be successfully used to monitor both patients infected or suspected of being infected with pathogens, such as SARS-CoV-2, as well as medical personnel exposed to infected patients. Monitoring of medical personnel working with infected patients is advisable because of the optimization of the organization of medical supplies in terms of staff workload, stressful situations and cumulative psychological stress [18]. It is also possible to detect unsafe gathering of patients, which is related to the failure to maintain the required distance.

An essential element of a comprehensive monitoring system should be a paging functionality (e.g., an emergency button) that allows a monitored person to send an alarm to a medical provider, with information about their location, in order to enable the activation of the procedure of immediate assistance. While there are various paging button solutions, including personal ones, there is only one solution offered on the market that comes close to the comprehensive monitoring system outlined above. Chinese manufacturer – Shenzhen Xexun Technology Co. Ltd. offers wrist bands and band tracking modules. The U01 (UWB tracking watch) wrist band allows monitoring of heart rate, number of steps walked, and patient location indoors where U20 (UWB indoor anchor) tracking modules are installed or outdoors where U21 (UWB outdoor anchor) outdoor modules are installed [41]. According to the manufacturer, the wrist band has a touch button that can be used as an alarm button. The wristband's battery is inductively charged and allows for 14 hours of wristband use. Documentation of the system is only available in Chinese, and no scientific paper using this monitoring system has been published to date.

The experience in designing and constructing medical recorders was used by WIML engineers to develop and patent a warning device in the form of a wrist band that warns an aircraft crew member of the threat of hypoxia. Details of the design solution of the warning device are described in the invention patent, confirmed in the Polish Patent Office, registered under PL.238338(B1), "Hypoxia warning device" [29].

This warning device comes in the form of a wrist band. Among other features, the device is equipped with an oximetry sensor, indicator LEDs, a wireless inductive charging module, and a vibrating module that notifies the person wearing the wrist band of the risk of hypoxia.

The above-mentioned FT (FlagTag) victim tagging micro-modules of the system supporting the process of evacuation of victims in mass events, developed at the WIML, were made within the framework of the project titled "The system for evacuation and rescue of victims of natural disasters – EvaCopNet" (original title "System ewakuacji i ratowania poszkodowanych podczas klęsk żywiołowych – EvaCopNet"), contract with the National Centre for Research and Development (NCBiR) No. BS3/B9/37/2015 [10,12]. The FT (FlagTag) victim tagging micro-modules were made in the form of bands used to determine, by the rescuer, the victim's health status (triage), their location and to determine parameters such as geographical location, blood oxygen saturation (SpO_2), heart rate (HR) value and ambient temperature. The bands have radio modules with which they form a Mesh radio network. This network, expanded by radio modules placed on drones, enables the transmission of information about the injured person's condition to the rescue command center.

The above review of technical solutions of monitoring systems was based on own materials and using PubMed, Scopus and Web of Science databases. Literature from the last 5 years was included. The following keywords and their combinations were used for the search: "continuous patient monitoring", "indoor positioning", "life monitors", "patch monitors", "real-time locating systems", "ultra-wideband", "vital monitor devices", "vital monitoring indoor", "vital signs recorders", "vital signs recording", "wearable sensors", "wrist band", "wrist monitoring".

DIRECTIONAL ASSUMPTIONS FOR CREATING A REMOTE PATIENT MONITORING SYSTEM

The assumptions will incorporate the results of an analysis of the data processing, sensor, localization, and signal transmission technologies available in the global electronics equipment market. Ready-made, commercial solutions of recorders are also available for use in one's own remote patient monitoring system designs. One such solution is a project by the US chipmaker Maxim Integrated Products. The cited project is a demonstration design platform [46] for making a recorder in the form of a wrist band. The manufacturer declares the ability to measure medical

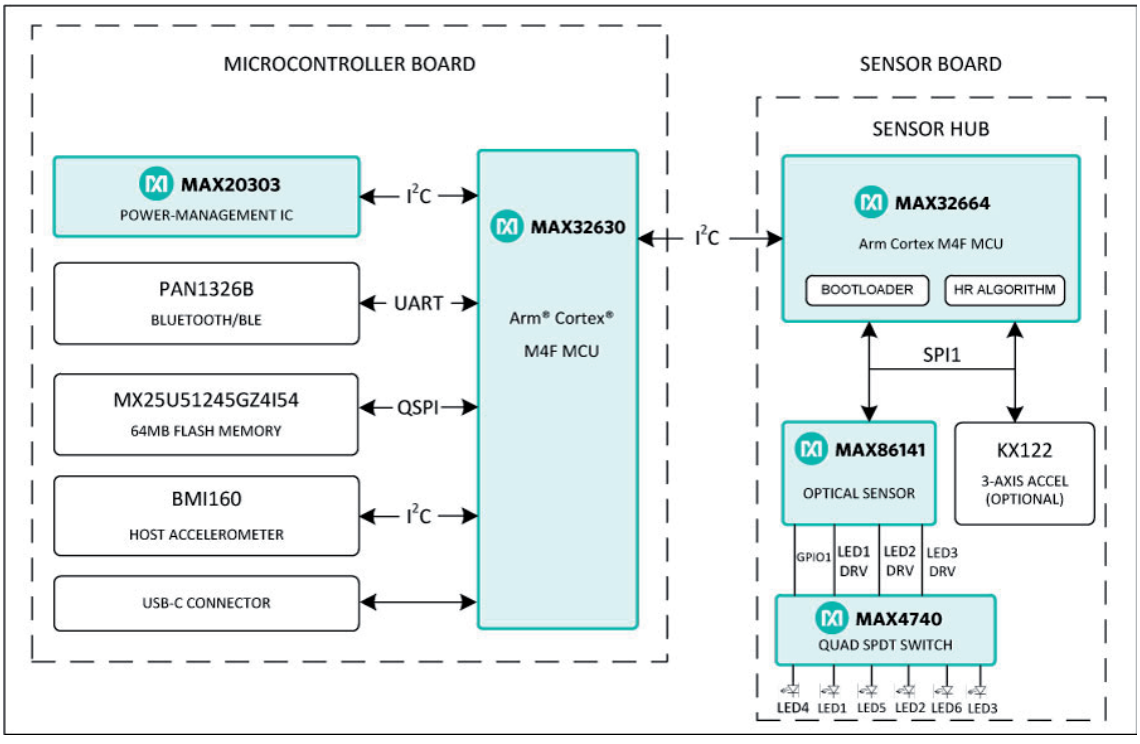

Fig. 1. Schematic diagram of the recorder platform from Maxim Integrated Products [47].

parameters SPO_2, HR, HRV (heart rate variability) and acceleration in a three-axis coordinate system. A MAX86141 sensor using photoplethysmography (PPG) technology is used for medical measurements. The BLE system, PAN1326B, is responsible for wireless connectivity to the platform. The manufacturer also declares the ability to calculate a sleep quality algorithm. A schematic diagram of the platform is shown in Fig. 1. Depending on the needs of potential users of the remote patient monitoring system, it is possible to extend the presented platform with additional sensors or design another solution based on available technologies.

DATA PROCESSING

Currently, there are two leading microcontroller architecture solutions the use of which allows for making a personal recorder for a remote patient monitoring system. These solutions are implemented in ARM (by Advanced RISC Machines) and PIC (by Microchip) integrated circuits [7,26]. The two companies' architecture solutions enable energy-efficient operation of the microcontroller and its integration with BLE (Bluetooth Low Energy), GPS and eSim (embedded-SIM) modules. Although the solutions of both companies provide energy-efficient operation of devices based on the use of their microcontroller architecture, the size of the recorder will be directly affected by the number of sensors used and, consequently, the size of the power source (battery).

MEDICAL SENSORS

Photoplethysmography (PPG) sensors can be used to measure HR and SPO_2. Sensors using this measurement technology have already been used by designers at WIML, in the EvaCopNet project. The sensors were located in a band worn on the wrist of the hand. The results of testing wrist bands with sensors of this type in experiments conducted under field conditions were very good for SPO_2 measurement and promising for HR measurement. Given the advances in the design of these sensors, it seems reasonable to use them to measure SPO_2. Table 4 shows examples of commercially available PPG sensors that can be used in the recorder design [28,2,25].

The designers' long experience shows that the best HR measurement results can be achieved by using electrodes placed on the chest. For this purpose, an elastic band with electrodes embedded in it that adjusts its shape to the chest surface is used, with a HR measurement module connected to it. The table below shows examples of commercially available HR measurement systems that can be used to make an HR measurement module attached to a band with their marks shown in Table 5 [42,43].

To assess body position, MEMS (microelectromechanical system) sensors, for example accelerometers, are used (Table 6).

Tab. 4. List of PPG sensors.

Mark	Measurement capability	Dimensions	Manufacturer
OB1203 [28]	SPO2, HR	4.2mm×2mm×1.2mm	RENESANS
ADPD144RI [2]	SPO2, HR	5.1mm×2.9mm×1.45mm	Analog Devices
MAX86150 [25]	SPO2, HR	5.6mm×3.3mm×1.3mm	Maxim Integrated Products

Tab. 5. List of HR measurement systems.

Mark	Measurement capability	Dimensions	Manufacturer
AD8233 [1]	HR, ECG	2mm×1.74mm×0.15mm	Analog Devices
MAX3003 [24]	HR, ECG	5mm×5mm	Maxim Integrated Products
TIPD116 [37]	HR, ECG	no data	Texas Instruments

Tab. 6. List of MEMS sensors.

Mark	Measurement capability	Dimensions	Manufacturer
ADXL372 [3]	3-axis accelerometer	3.3mm×3.1mm×1.14mm	Analog Devices
KX122-1037 [22]	3-axis accelerometer	2mm× 2mm×0.9mm	KINONIX

PATIENT LOCATION

Currently, useful technologies that can be used in patient location recorders are BLE and GPS technologies.

GPS-assisted localization technology [11] will perform well outside of buildings, but a significant energy expenditure for its operation must be expected. This expenditure can be reduced by making software changes to its mode of operation at the expense of accuracy. The technology requires no additional investment in its application other than the cost of the GPS module itself.

Technology of localizing with the help of BLE beacons. Beacons are miniature transmitters that generate a unique code of information to be transmitted to mobile receivers. The technology allows the network to be extended to determine patient location inside buildings. The energy expenditure for its operation is small. However, the technology requires additional costs to install beacons in the rooms of a given facility.

A sort of sister technology to BLE beacons is ZigBee beacons, which can be successfully used interchangeably for indoor location. ZigBee is a communication technology that uses a different radio frequency than BLE, but is also characterized by low power consumption.

A monitoring system based on available sensors and telecommunication technologies can be realized in two versions: basic and extended.

BASIC VERSION OF THE SYSTEM

In its basic version, the system consists of two main components: a recorder in the form of a wrist band and a remote computerized data acquisition system. The basic version of a recorder can be equipped with:

- PPG optical sensor – used to measure heart rate and blood oxygenation,
- gyroscopic sensor – used to determine body position,
- BLE module – used for wireless communication with a computer equipped with a local information system,
- GPS module – used to determine the location,
- eSim module – used for wireless GSM communication with a remote information system,
- LCD touch screen – used to control the device,
- physical control buttons – used to control the device,
- battery with inductive charging loop – used to power the device.

EXTENDED VERSION OF THE SYSTEM

In the extended version, the system consists of five main components: a wrist band, a chest band, an arm patch, a smartphone, and a remote computerized data acquisition system.

The wrist band can be equipped with:

- PPG optical sensor – used to measure blood oxygenation,
- gyroscopic sensor – used to determine the position of the body,
- BLE module – used for wireless communication with: a patch (mounted on the arm) and a band (mounted on the chest), beacons and a smartphone,
- LEDs – used to indicate the operating mode of the device,
- button – used to call for help in emergency mode,
- battery with inductive charging loop – used to power the device.

Chest band:

- temperature measurement sensor – used to measure the temperature of the body surface under the band,
- electrical signal converter – used to measure the frequency of heart contractions,
- BLE module – used for wireless communication with the band,
- power module – replaceable battery.

Module in the form of an arm patch:

- sensor–- used to measure blood glucose level,
- BLE module – used for wireless communication with the band,
- power module – replaceable battery.

The use of additional modules in the extended version of the recorder allows to achieve many advantages over the basic version:

1. Relieving the energy burden of the wrist band module by moving HR measurement to a separate module, abandoning communication using eSim in favor of connecting to a smartphone using BLE.
2. Possibility to use additional modules equipped with sensors and own power supply: blood glucose level and HR measurement.

IT SECURITY OF PATIENT MONITORING SYSTEM

When designing the architecture of a patient monitoring system, special attention must be paid to security issues.

In the case of the basic version recorder, security issues are related to the stage of authenti-

cation and data transfer from the recorder to a remote information system. An eSim card operating on a 5G GSM network with IPv6-based addressing should be used to enhance security. This combination of applied telecommunication technologies and communication protocol, when properly implemented, can partially protect against, among others, the following types of attacks: spoofig (impersonation), man-in-the-middle (information interception), DDoS (distributed denial of service) [15].

For the extended version of a recorder, security issues are related to the vulnerability of the Bluetooth technology to hacking attacks and external interference. When using Bluetooth or Zigbee wireless communication technologies, one has to take into account increased financial expenditures incurred for constant updating of internal software, to which security improvements will be introduced, along with disclosure of further vulnerabilities reducing the security level [38]. The BLE communication protocol between system components should be encrypted (using, for example, RSA or AES protocol) and the data format should be protected (classified) [40].

An equally important consideration is the security aspects of the remote information system used to acquire data from the recorders.

AUTHORS' DECLARATION:

Study Design: Marcin Piotrowski, Mirosław Dereń. **Data Collection:** Marcin Piotrowski, Mirosław Dereń. **Manuscript Preparation:** Marcin Piotrowski, Mirosław Dereń. The Authors declare that there is no conflict of interest.

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TECHNICAL NOTE

AIR FORCE EXPERIENCE INFLUENCES A PILOT'S VISUAL PERCEPTION: PRELIMINARY RESULTS

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Abstract: The objective was to characterize visual scanning of a jet fighter cockpit by pilots with different air force experiences using the eye movement monitoring method and flight simulator under G-Force.

Total, 36 pilots with various experiences in piloting MIG-29 participated in the study. Pilots performed basic manoeuvres required for patrolling the air space, including taking off, turning, landing. Experiments were conducted using an human carrying centrifuge with the MIG-29 flight simulator mode. The visual scene was divided into 22 ROI affiliated to cockpit's instrument and out of widow area. Eye-tracking was performed with The GLASSES portable google sensor manufactured by Sensomotoric Instruments GmBH (SMI, Tetlow, Germany). ANOVA of total dwell time and average fixation duration recorded in each flight phase were run to evaluate statistical significance between the expertise at 95% confidence ($p<0.05$).

Significant differences in total dwell time and fixation duration on selected ROI were revealed between pilots various experiences, i.e. while patrolling air space regarding attitude director indicator (ADI) and exhaust gas temperature (EGT). The median duration of fixation was also significantly different on altimeter while turning. Fixation duration on airspeed indicator, EGT, IPV were unique for each group during approach landing. Also, the total duration time on the altimeter and ADI were significantly different.

Keywords: eye-tracking, visual perception, jet-fighter pilot training, aviation experience

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INTRODUCTION

Expert pilots' gaze behaviour differs from fewer experience counterparts [1]. Although it could be generalised that experienced expert pilots made more fixations with shorter dwell time than the cadets, it is essential to carefully interpret perception studies in aviation. For example, a different study [3] showed that expert pilots had longer dwell times to relevant ROIs than the novice, related to better decision-making.

Svensson et al. showed the importance of the balanced visual scanning of fighter pilots, who made shorter fixations to the head-down tactical display and alternated more frequently between the tactical display and the outside world, maintaining the best flight performance [4].

It is essential to underline that expert pilots do not always rely on shorter fixations while sampling aviation relevant information in a cockpit [3]. Experts' longer duration of the expert pilots was associated with more accurate decision-making than fewer experienced pilots.

Interestingly, experience development at the early stages of training might strongly impact the visual perception of airman cadets [2]. Private pilot's license and over 50 hours of flight time made more fixations to a navigation map and kept altitude better than cadets with experience between five and 15 hours of flight time.

This study aims to evaluate visual scanning metrics of pilots with different Air Force experiences while flying MIG-29 under G-force. The primary metrics evaluated were total dwell time and median fixation duration at a particular cockpit instrument and display area.

METHODS

Total, 36 pilots with various experiences in piloting MIG-29 participated in the study. The fewer experience subjects of 12 have on average 40h of air force training on the jet fighter, whereas the other 11 who spent over 860h in MIG-29 were considered experts. The intermit 13 pilots have a mean of 515h flighting MIG-29. All participants gave written informed consent to all procedures prior to the study. All procedures had been approved by the Institutional Review Board of the Military Institute of Aviation Medicine, Warsaw, Poland and have been performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

The pilots performed basic manoeuvres required for patrolling the air space, including taking off, turning (Fig. 2), and landing (Fig. 2). Experiments were conducted using an human carrying centrifuge with MIG-29 flight simulator mode. The vision system of the simulator provides a wide field of view (120x70°) and high-resolution images required to visualise the terrain and aerial situation in all lighting and weather conditions.

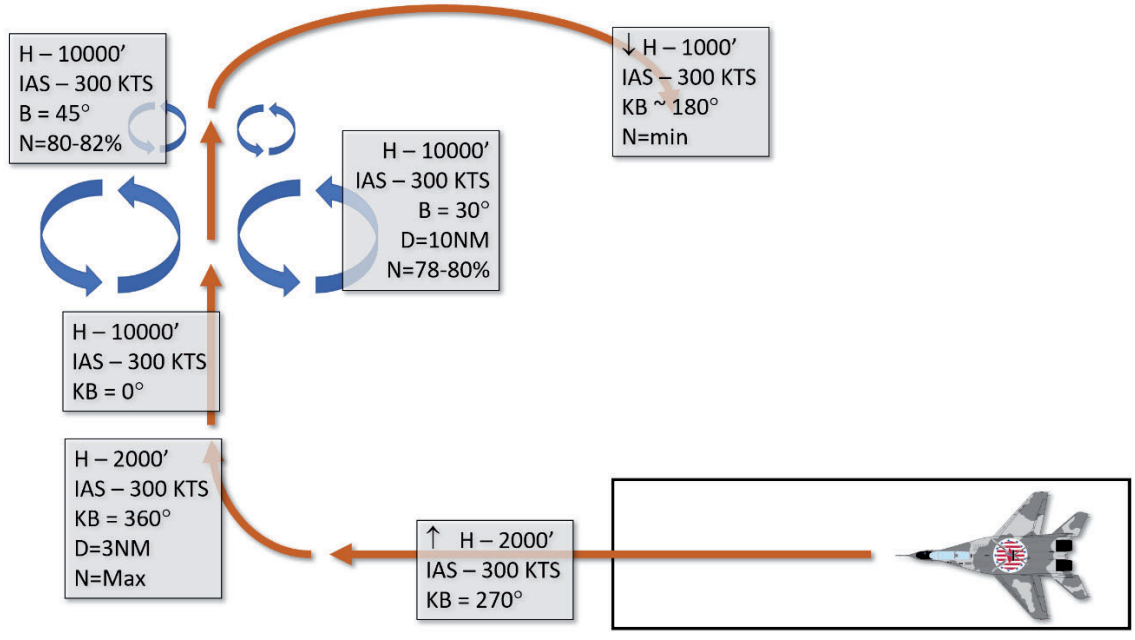

Fig. 1. Patrolling air space task profile starts on the ground and requires taking-off and ascending 2000m before the initial turn, after which additional climb to 10000m with 300 knots. Pilots circled over the designated area four times performing 360 degrees left, and right turns with different radius.

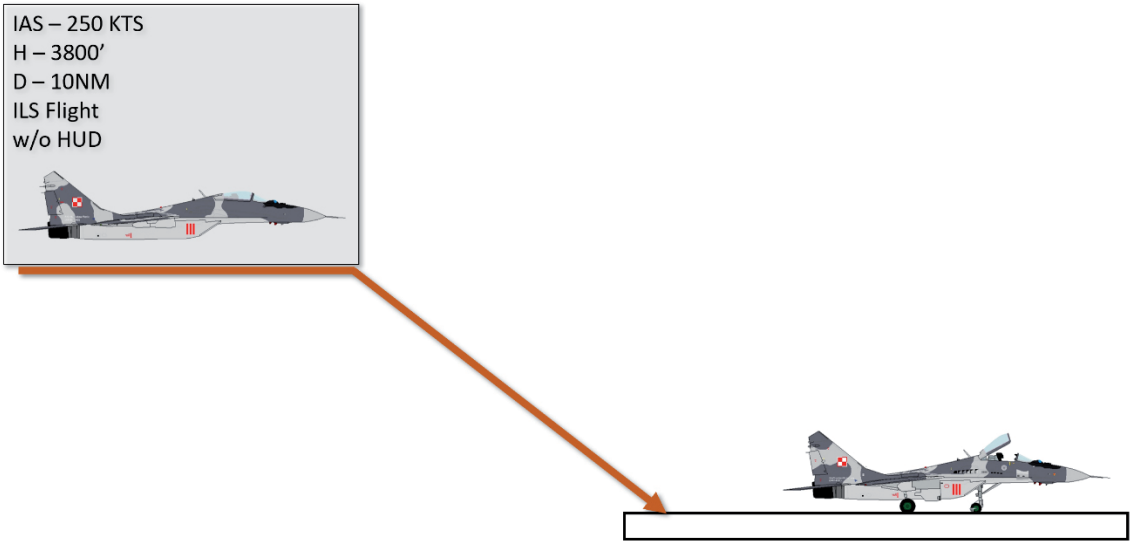

Fig. 2. Approaching the landing task profile starts with the initially indicated airspeed (IAS) of 250 knots at 3800m altitude h. Pilots used the instrument landing system (ILS) flights without HUD.

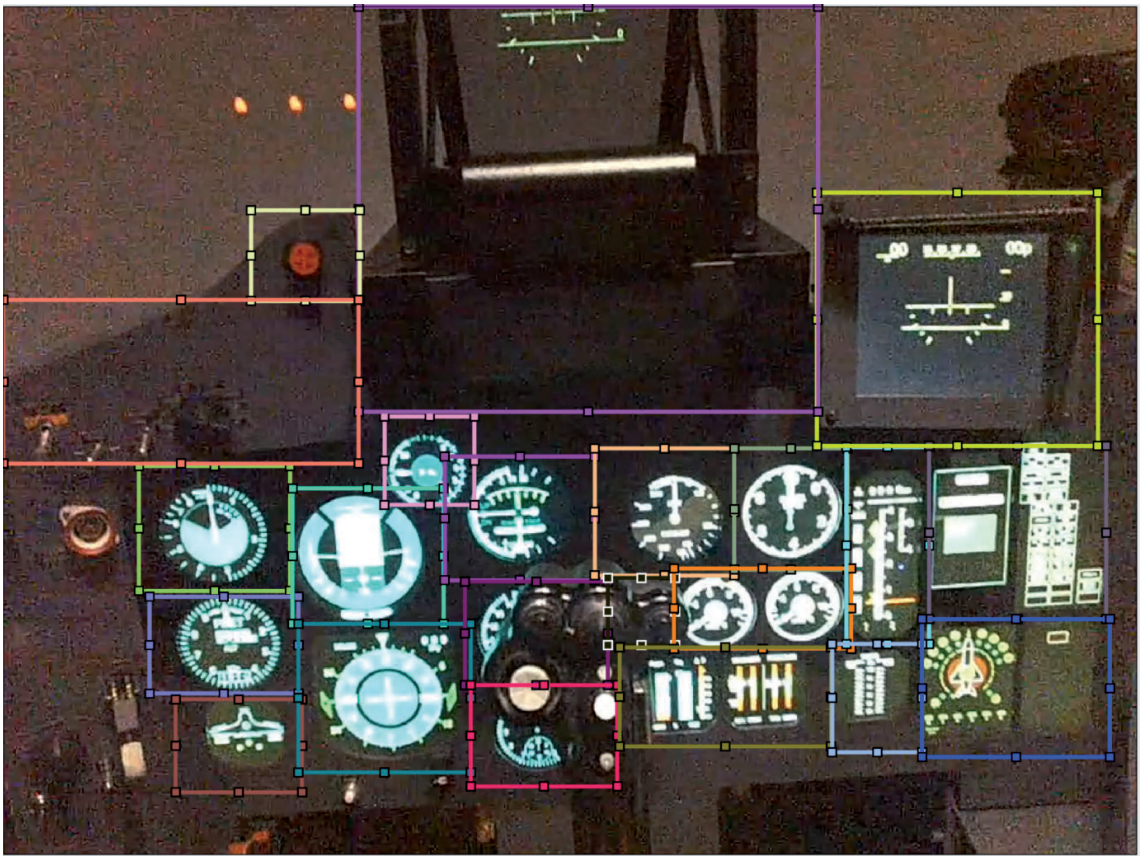

Fig. 3. A total of 22 ROIs covers the most relevant cockpit instruments and out of the window area of MIG-29, i.e. Airspeed, Altimeter, Pilot approach display, Attitude Director Ind, Navigation Instr, G-force Ind, Vertical Velocity Ind, Mach speed Ind, Clock, Radio Altimeter Ind, Flares amount, Engine tachometer, Exhaust Gas Temp Left-Right Engine, Oxygen & Hydraulics, Fuel, Ramp pos, Ekran03BITE/CAS display, Radar warning, IPV1, ILS31HUD, Air to Ground, and Aiming & navigation.

The visual scene was divided into 22 ROI affiliated to the cockpit's instrument and out of widow area (Fig. 3). Eye-tracking was facilitated with The GLASSES portable google sensor manufactured by Sensomotoric Instruments GmBH (SMI, Tetlow, Germany).

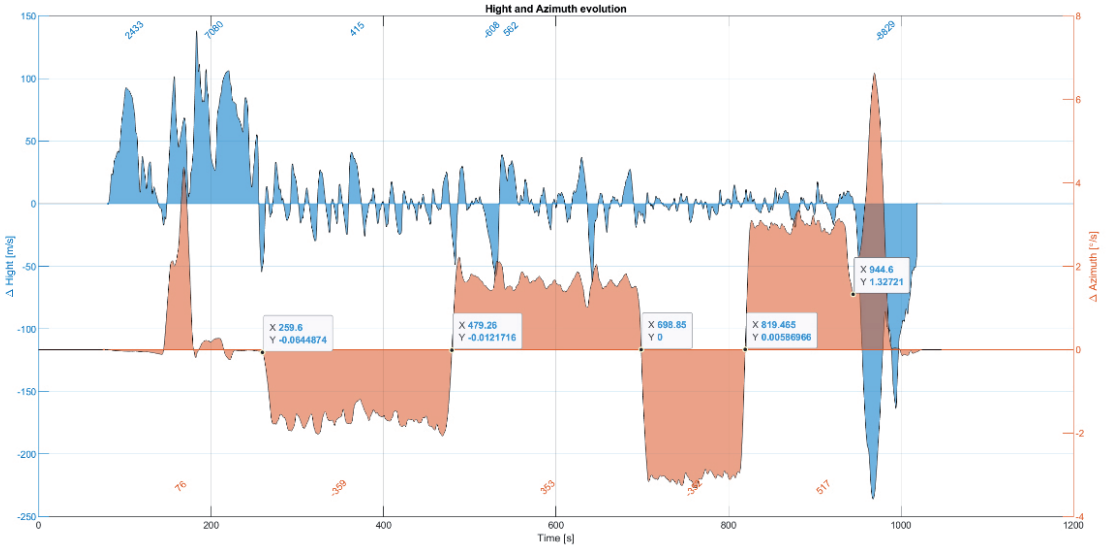

Fig. 4. An example of processed and analysed flight parameters while a pilot patrolled air space according to the task profile.

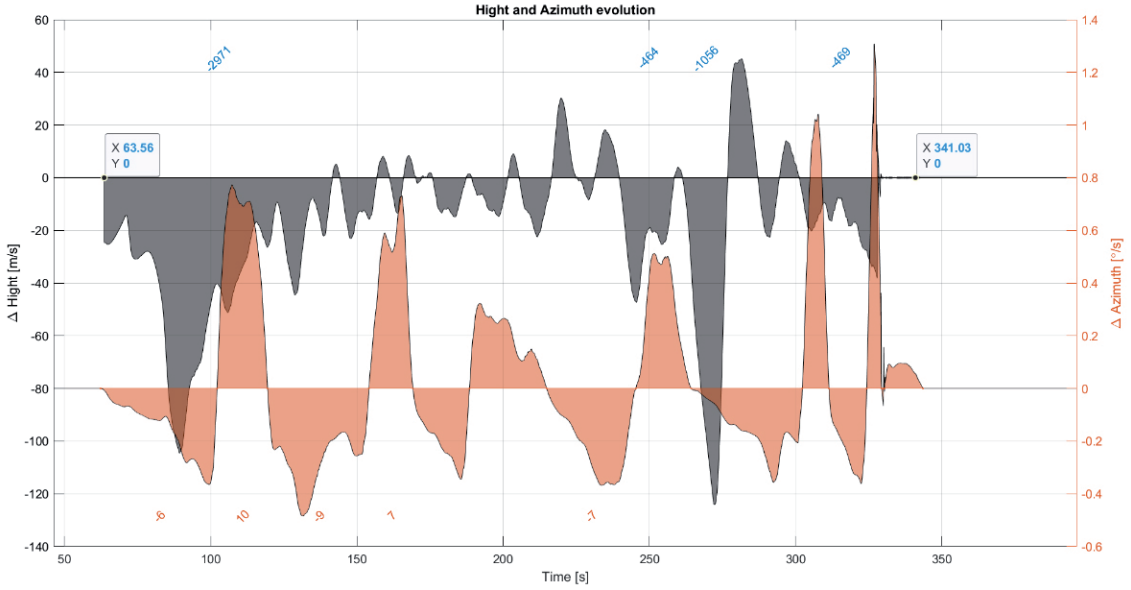

Fig. 5. An example of processed and analysed flight parameters during approaching landing to the instructed task profile.

Flight parameters of altitude, longitude and latitude were recorded during the flight simulation. Postprocessing analysis enables calculating the height and flight direction changes during patrolling (Fig. 4) and landing (Fig. 5).

One-way ANOVA of total dwell time and average fixation duration recorded in each flight phase were run to evaluate statistical significance between the expertise at 95% confidence ($p<0.05$). The normality of distributions were evaluated with Kolmogorov-Smirnov Test.

RESULTS

Pilots with various experiences spent significantly different amounts of total dwell time and made fixations on selected ROIs with different duration. Airspeed was dwelled relatively longer by the intermit group during take-off (Fig. 6). The percentage of dwell dedicated to the altimeter, attitude director indicator (ADI), engine tachometer, exhaust gas temperature (EGT), ILS31HUD and airspeed varied between pilots' groups during turns (Fig. 6).

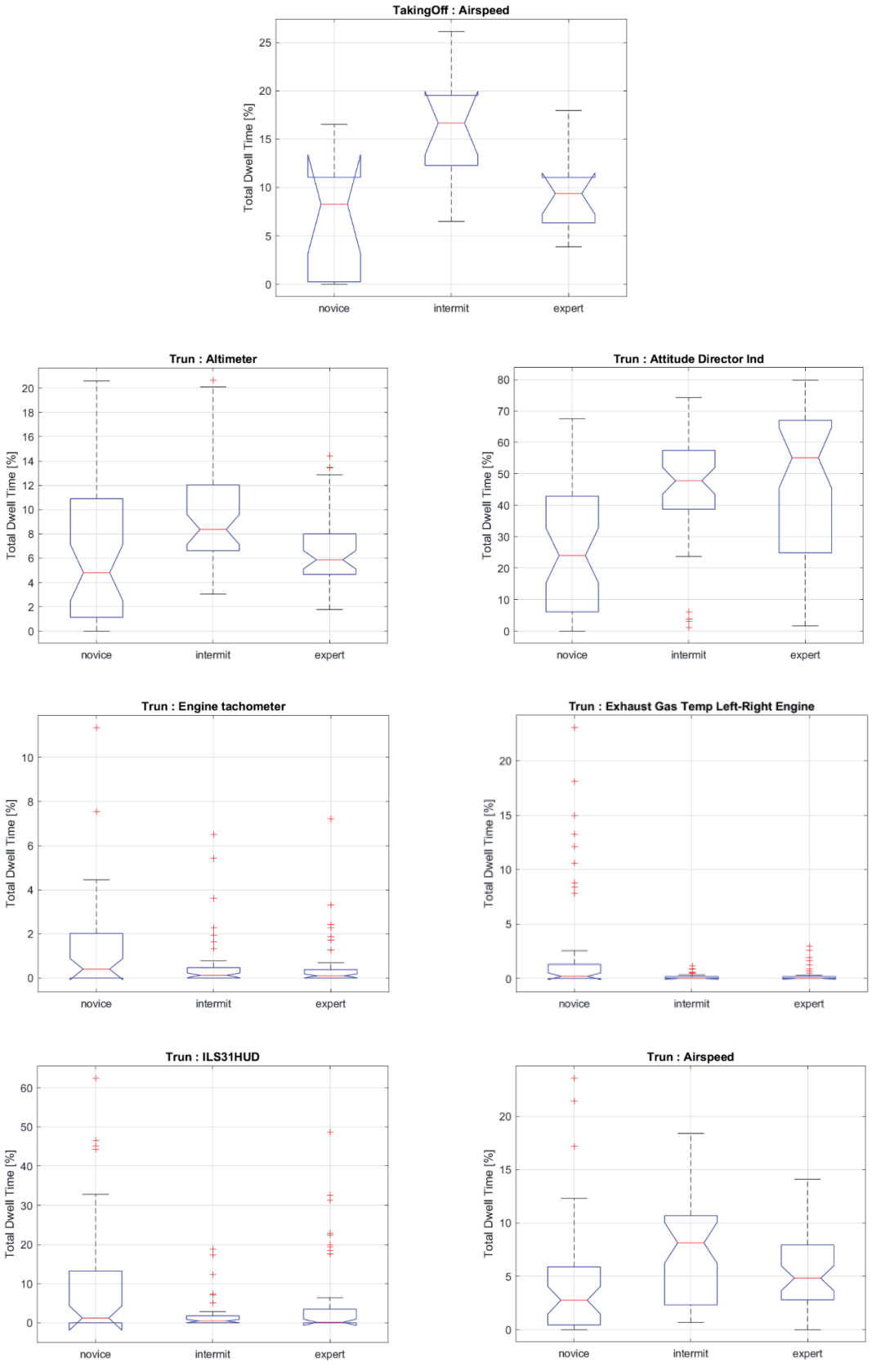

Fig. 6. Boxplots of total dwell time for selected ROIs during take-off and turning, when ANOVA revealed statistically significant difference at $p<0.05$.

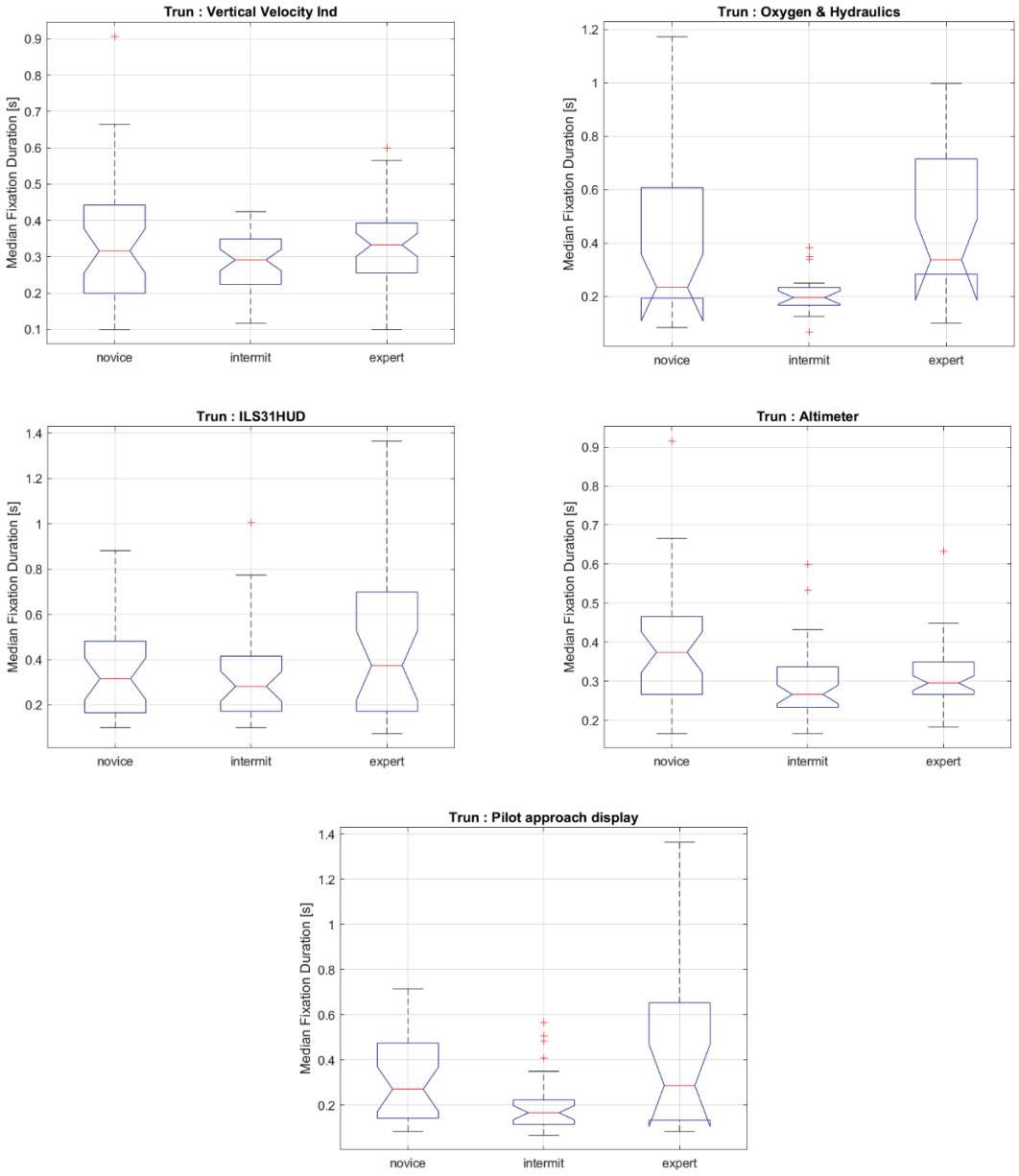

Fig. 7. Boxplots of median fixation duration [s] for selected ROIs while turning, when ANOVA revealed statistically significant difference at $p<0.05$.

Similarly, median fixation duration was different while changing aircraft direction on vertical velocity indicator, oxygen and hydraulics, ILS31HUD, and altimeter (Fig. 7).

Approaching landing conducted by pilots with different aviation experiences were characterised by a significant difference in total dwell time dedicated navigation instrument and median fixation duration on exhaust gas temperature, airspeed, andIPV1 (Fig. 8).

DISCUSSION

Pilots sampled aviation relevant information distinguished to their experience range. It confirms that visual perception evolved in training. However, there is no simple paradigm applied to it, i.e. experts made shorter fixations etc. In contrast, novices, intermit, and experts implemented different visual scanning strategies at taking-off, patrolling, and approaching landing.

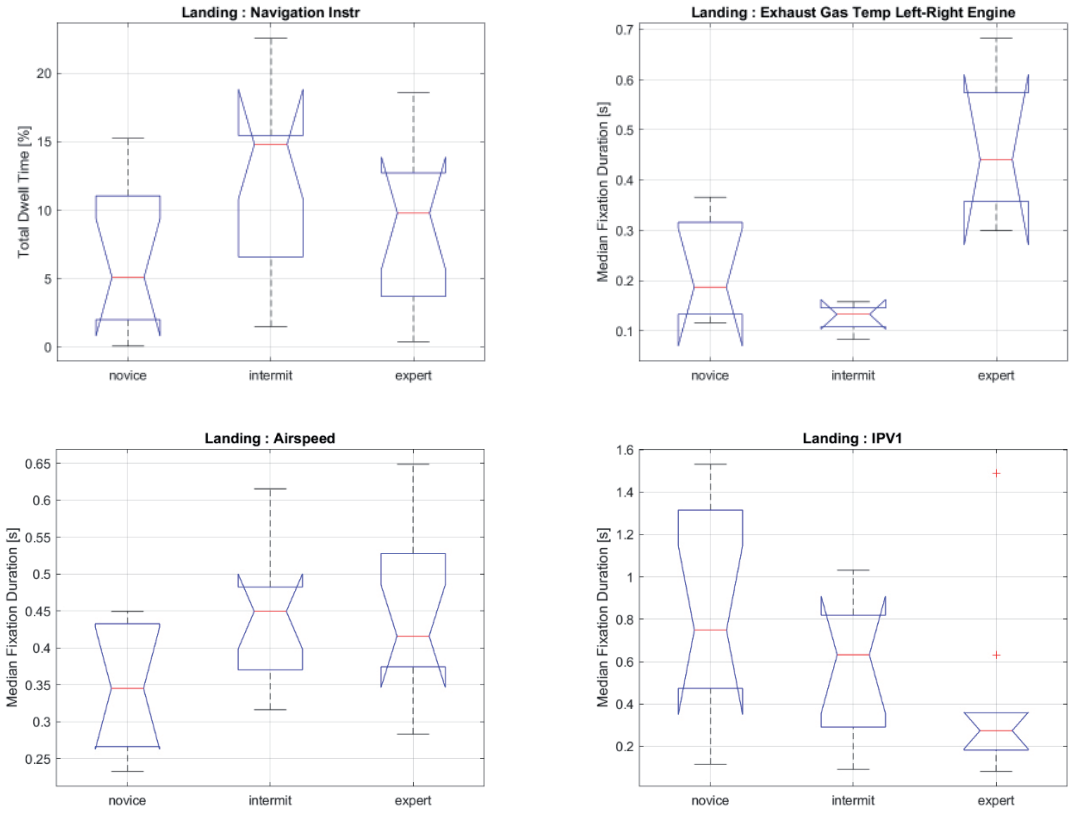

Fig. 8. Boxplots of total dwell time [%] and median fixation duration [s] for selected ROIs during take-off and turning, when ANOVA revealed statistically significant difference at $p<0.05$.

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Study Design: Mariusz Pietrzyk, Krzysztof Kowalczuk, Michał Janewicz, Ewelina Zawadzka-Bartczak, Lech Kopka; **Data Collection:** Mariusz Pietrzyk, Krzysztof Kowalczuk, Michał Janewicz, Ewelina Zawadzka-Bartczak, Lech Kopka; **Manuscript Preparation:** Mariusz Pietrzyk, Krzysztof Kowalczuk, Michał Janewicz, Ewelina Zawadzka-Bartczak, Lech Kopka. The Authors declare that there is no conflict of interest.

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TECHNICAL NOTE

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ADAPTATION OF WUK-90 HIGH ALTITUDE PRESSURE SUITS FOR REHABILITATION PURPOSES

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Abstract: Integrating discoveries in military technology into civilian applications represents one of the most common combinations, since these include the technologies developed to, among other things, improve the bodily functions in extreme conditions. In addition, aviation technology is characterized by such parameters as lightness, ergonomics and durability. Adaptation of flight or space suits represents the application of solutions that in their original purpose were dedicated to enhance human capabilities under altered pressure and gravitational conditions. These suits, when properly adjusted, can be used in the rehabilitation of patients with neurological or orthopaedic deficits. The purpose of this publication is to show the most commonly adapted solutions based on HAP suits and space suits, as well as to demonstrate the process of adapting HAP (High Altitude Protection) suits of WUK 90 type (Type 90 High Altitude Pressure Suits) for therapy purposes. In rehabilitation applications, these suits are suitable for adaptation in therapy where the technical parameters of the devices allow to explore completely different therapeutic possibilities. Such devices, however, require adaptation to the needs of disabled people with orthopaedic injuries or mental disorders and specific conditions for rehabilitation, as was the case with the WUK suit, which after introducing technical modifications and adaptation solutions was given the name R-WUK (abbreviated from the Polish name "Rehabilitacyjny Wysokościowy Ubiór Kompensacyjny" (Rehabilitation High Altitude Pressure Suit).

Keywords: WUK suit, R-WUK suit, ATLANT suit, ADELI suit, suit therapy, HAP suit

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INTRODUCTION

The use of military technology solutions for civilian purposes represents a certain regularity. Elements of technological solutions that directly or indirectly derive from military applications are quite often found in other areas of everyday life, be it automotive, emergency medicine or clothing. This is associated with far greater funding for the development of solutions to increase the chances of human survival in extreme conditions, to raise the physiological capabilities of the body, or to reduce the advantage of the enemy. In this regard, at the forefront of modern solutions in the field of health and life protection are solutions from aviation technology, which are characterized by strength, lightness, ergonomics, as well as reliability. These elements provide inspiration for adapting technical solutions in everyday life. These were the very attributes that that have brought these solutions to rehabilitation, where lightness and durability of materials, design reliability and specificity of application play an important role. Yet sometimes the inclusion of space or aerospace technology comes nowhere near its principal application, e.g. space suits or G-suits designed to counteract the effects of prolonged lack of gravity or to counteract G-force or protect against the effects of reduced atmospheric pressure [17] have found their way into rehabilitation. The purpose of this article is to show the process of adapting HAP suits of the WUK-90 type (High Altitude Pressure Suits) for rehabilitation purposes as well as to show the most commonly adapted solutions based on HAP suits and space suits.

The first attempts to create pressure suits for aviators date back to 1934, and their creator was American pilot Wiley Hardeman Post, who went down in aviation history as a pioneer of stratospheric flight. The design itself resembled a classic diver's more than a pilot's outfit [14,10]. Work on clothing to reduce the negative effects of increased G-forces as well as thin atmosphere intensified during World War II. During this period, two directions of solutions clashed, the essence of which can be summarized as pneumatic and hydrodynamic directions. Water-based suits, due to their weight, lost the race to air-based suits at the time [3]. However, the greatest development of this type of clothing was forced by the use of jet propulsion in aviation, which was characterized by an increase in G-forces and an increase in the ceiling of combat aircraft. Spacesuit solutions developed in the period of space conquest where attempts were made to go into open space as well as to keep astronauts in a state of microgravity for a long time represent yet another category.

Space suit (Fig. 1) was primarily aimed at preventing loss of muscle and bone mass in cosmonauts, which, in a state of reduced or no gravity, made long-term space flight impossible. In addition, these factors made it necessary for cosmonauts to undergo rehabilitation after returning to earth [18]. The introduction of pressure solutions, or forcing muscles to work to prevent atrophy, has reduced this problem, allowing for longer space flight times. The assumptions of appropriate muscle tension and its correction, which was made possible by the PENGUIN suit, formed the basis for the adaptation of these suits for rehabilitation purposes (Fig. 2).

Fig. 1. PENGUIN space suit [5].

The introduction of the use of spacesuits in therapy is to be traced back to the measures taken by the Russians with regard to cosmonauts who were in a state of microgravity for an extended period of time. The suits used in the rehabilitation of cosmonauts were designed to enhance muscle strength. This aspect attracted the attention and interest of the physiotherapist and led to the idea of using spacesuits in the therapy of patients with disabilities, especially those with cerebral palsy. These efforts led to the adaptation of the inner part of the PENGUIN-type space suit and the creation of a commercial version called the ADELI suit [3]. This suit (Fig. 3) is based on a system of elastic bands and pulleys that enhance the patient's ability to move in a controlled manner. The main goal

Fig. 2. PENGUIN suit elastic bands and pulleys system [5].

Fig. 3. ADELI rehabilitation suit [3].

inspiring the adaptation of the suit for rehabilitation purposes was the possibility of strengthening muscle movement or counteracting uncontrolled muscle tension, which in the case of cerebral palsy patients prevents the execution and learning of correct movement patterns [13]. These suits have resulted in accelerating as well as enhancing the effects of the rehabilitation process. The solutions used in the ADELI suit have lived to see many similar developments around the world, such as THERASUIT or SPIDERSUIT.

Fig. 4. ATLANT rehabilitation suit [4].

Adaptations were also made to HAP-type flight suits, which were given the trade name ATLANT. Their construction is similar to the WUK suit based on a winch pull suit design [9]. This suit (Fig. 4), due to its design, allows only very limited movements or exercises. These limitations are due to the structure of the suit itself, as the winch-type structure used is inflated pneumatically and this results in limited mobility in the limb joints. In addition, the authors of the ATLANT suit used a head position regulator hooked up to the suit to prevent the head from drooping. This system significantly limits the flexion of the trunk or limbs, creating a kind of frame, which has a significant impact on the on the applicability of physiotherapy techniques for patients with neurological deficits. The main field of application according to the originators of the ATLANT suit is the therapy of patients with cerebral palsy [8].

Another problem associated with the use of suits of this type is the physiological response of the body to increased pressure, which results in increased blood pressure and increased heart rate [1,2]. This problem is not addressed in the process of using the ATLANT rehabilitation suit.

ADAPTATION OF WUK-90 FOR REHABILITATION PURPOSES

The WUK-90 is a High Altitude Pressure Suit, which was developed for aviation by Lucjan Golec, PhD, at the Military Institute of Aviation Medicine [16]. Its task is to brace the body and prevent or reduce the movement of blood between the pilot's head and the rest of the body. At the same time, the suit is intended to provide protection for the pilot's body from the atmospheric pressure drop factor in the event of sudden cabin decompression or if the pilot leaves the cabin at high altitudes. Large changes in the pressure range carry the risk of lung tissue expansion or even rupture, so there is a need for external chest compression to balance intrapulmonary pressure [15]. Second, at even higher altitudes – around 18-19,000 m (60–62,000 ft.) the risk of boiling body fluids is present. At a pressure of about 47 mmHg water, and thus body fluids begin to boil at human body temperature, which would quickly lead to tissue destruction [10]. The design of WUK suits allows for an increase in G-force tolerance of about 1.5-2 G.

Approval was obtained from the Ministry of Defence and the Air Force Command for the use of WUK-90 suits for research and rehabilitation purposes. They were made available by the 23rd Tactical Air Base. In addition, research approval No. 13/2015 has been received from the Bioethics Committee on Human Research at the Military Institute of Aviation Medicine on "The use of WUK High Altitude Pressure Suits in the therapy of patients with neurological deficits" as well as the subsequent extension No. 11/2021 "The use of WUK High Altitude Pressure Suits and NEURES suits in the therapy of patients with neurological deficits and psychiatric disorders."

The main task within the framework of the undertaken research was to adapt the WUK-90 suits for the purposes of the undertaken research and to prepare them for conducting therapy given the different scope of application of the WUK suits in the normal way as well as the specifics of working with neurological patients. It consisted in adapting the pneumatic system in such a way that kinesitherapy could be conducted while keeping the structural system of the system intact (Fig. 5).

The adapted suit features ¼-inch valves that allowed pressure to be applied to the suit. Closing valves were used to ensure the tightness of the system. This made it possible to disconnect the suit from the external power supply and perform

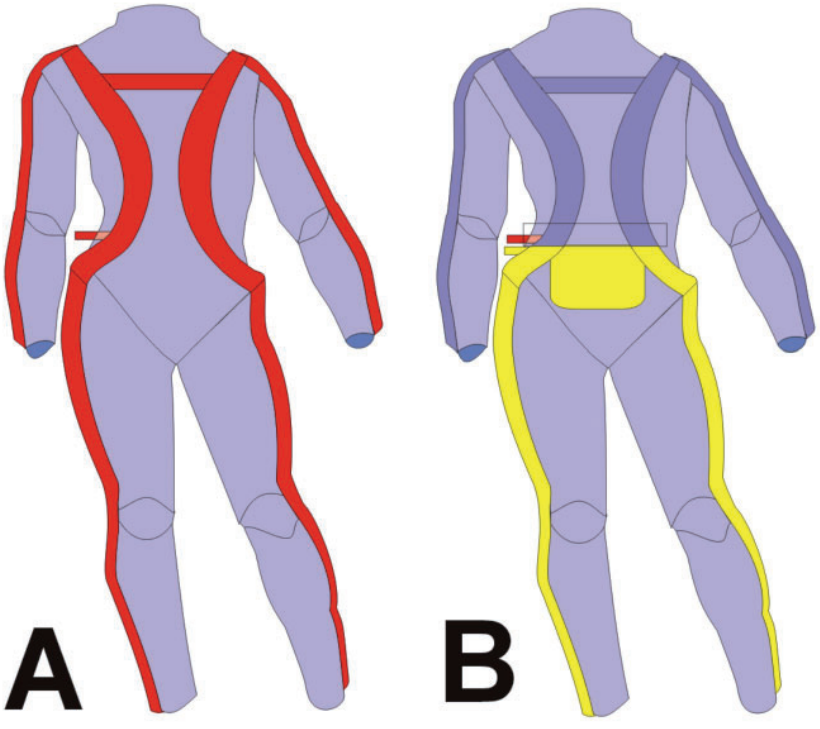

Fig. 5. Pneumatic system of the WUK-90 suit (A – altitude circuit, B – G-force circuit).

exercises without a permanent connection to the pneumatic system limiting the patient's mobility (Fig. 6).

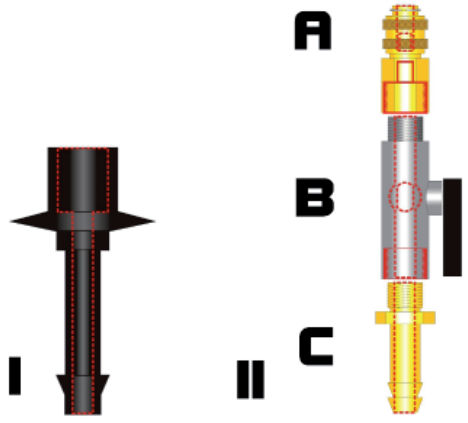

Fig. 6. Replacement of pressure connectors in the WUK-90 suit (I – the system used in the WUK-90 suit, II – the system used in the R-WUK suit, A – quick connector ¼", B – shut-off valve ¼", C – plug ¼").

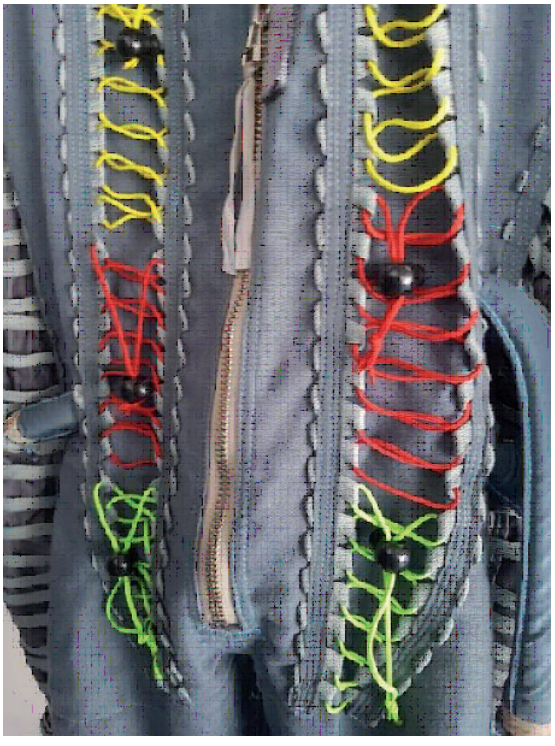

Fig. 7. R-WUK suit lacing (multi-segment section with colour division).

The WUK-90 suit has a lacing system designed for individual adjustment by the pilot. It allows for a one-time, yet long-lasting suit adjustment (provided there is no change in weight), performed by the technician. Individual fitting takes about 2-3 hours each time, which, given the rehabilitation process, is too long a time and would prevent or at least significantly limit the use of the WUK-90 suit in conducting research. The time deficits involved in conducting rehabilitation have necessitated changes allowing the suit to be quickly fitted to the patient, as well as to be subsequently untied. To this end, single-segment sections were converted into multi-segment sections and, for easier lacing, they were divided by colour (Fig. 7). In addition, the lacing was finished with an adjuster. These changes made it possible to reduce the suit fitting time to 5 minutes. After the modifications, the WUK-90 suit was named R-WUK, abbreviated from the Polish name "Rehabilitacyjny Wysokościowy Ubiór Kompensacyjny" (Rehabilitation High Altitude Pressure Suit).

Fig. 8. The compressor for filling the R-WUK suit.

A separate issue was to design a pressure supply that would allow easy filling of the suit's pneumatic system. For this purpose, a compressor with a pressure gauge has been developed, powered by 230V as well as a 12V battery (Fig. 8).

Hoping to obtain information on the pressures that the suit exerts on the pilot's body at specific values of pressure in the pneumatic system, an inquiry was made to the Air Pol Legionowo Company being the manufacturer of these pressure suits. It turned out that this manufacturer had never conducted such research. Since the issue of exerted pressure is crucial to the safety of using WUK-90 suits in rehabilitation, it was decided to conduct empirical studies on healthy patients while conducting other research.

A two-wire arm cuff with an attached mercury manometer and a "bulb" was used to conduct the

study. The gauge's measuring range was from 0 to 300 mmHg. The cuff was placed in the front of the WUK on the forearm between the lacing of the suit and the pressure hoses.

The study involved 17 subjects, on whom the pressure exerted by the suit on the patient was measured. The experiment was conducted while studying the safety of the suits on control patients [1]. The test consisted of inflating the cuff to a level of 15 mmHg and then applying pressure to the main circuit. The cuff reading was given in 10 mmHg increments starting at a value of 20 mmHg. Higher readings than 0.9 KPa in the pneumatic system exceeded the research value of interest due to the scope of aviation use.

The manufacturer's technical documentation indicates that the maximum pressure in the pneumatic system must not exceed 1.98 KPa [6]. However, when WUK-90 suits are used in combat conditions, this value rarely exceeds 0.9 KPa. An important factor is the temperature range of application of WUK-90 suits, which is from -50oC to +50oC. This factor is strange to say the least because the manufacturer states the altitude range of use of the suits from 0 to 40,000 meters, but temperatures in this altitude range vary from -70oC to +60oC [12]. This parameter for R-WUK suits has been narrowed down to the ambient temperature of the therapeutic procedures performed, which take place at temperatures of min. +18oC to +30oC. These assumptions indicate a significant reduction in the critical values of the use of R-WUK suits, which in the case of new designs will not require sophisticated technological solutions. It is important to determine the service life, i.e. the maximum operating time of the suit at 3 years or 200 hours, which in the case of R-WUK suits is irrelevant, since failure of the pneumatic system causes only interruption of session [6] and does not endanger the patient in any way.

An additional limitation of the use of the WUK-90 and therefore R-WUK adaptive version of the suits is their size, the main element of which is the patient's height and BMI. For pilots, it is possible to use special sizes, i.e. tailor-made suits (for a specific pilot). R-WUK rehabilitation suits are designed for patients with standard BMI, and their height sizes range from 160 to 185 cm. In the case of normal human development, it eliminates patients under 13 years of age and patients over 185 cm tall [7].

CONCLUSION

The designs of the suits, which originated in aviation or aerospace, make it possible to adapt them for the purpose of conducting therapy with patients who have various deficits resulting from neurological, orthopaedic or psychiatric disorders. The parameters resulting from the design of the WUK-90 suits, as well as the adapted version of the R-WUK, are details that affect the conduct of therapeutic activities, reducing the time to prepare the equipment for operation and improving ergonomics. Elements that limit the motion range or changes in physiological parameters of the body that endanger the patient must be taken into account and incorporated into the design of the new suit, which will fulfil the specifics of conducting physical therapy of neurological patients or patients with mental disorders. Research work with the R-WUK suit made it possible to carry out studies to determine the methodology of working with the patient, to delineate operating parameters, to develop safety rules, to specify the level of risks and, in particular, contraindications to therapy [1,2]. At the same time, research on the R-WUK suit has made it possible to delineate the area of major disease entities for which suit therapy can be effective or will produce the desired therapeutic effects.

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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