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The impact of 40-hour specialized training of female cadets of the Polish Air Force University on the tolerance of +Gz accelerations

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C Statistical Analysis
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Dictionary:

ASGM – Anti-G Straining Manoeuvres (AGSM). Include several seconds of isometric contractions of skeletal muscles with additional tension of the abdominal muscles and with a simultaneous attempt to exhale air.

SAGI – Special Aviation Gymnastics Instruments is used to describe a set of instruments such as: looping, single aero wheel and triple aero wheel, the so-called gyroscope.

Linear program in a human centrifuge – allows to determine the acceleration value that causes the first symptoms of circulatory system decompensation, thus assessing the body's tolerance limit for maximum acceleration. The acceleration rate is 0.1 G/s.

HPA – High-Performance Aircraft such as MiG-29, F-16, M-346 Master, FA-50

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Abstract:

Background and Study Aim: The ability to perform a specific physical task requires numerous activities from people. This depends on the type and intensity of effort directed towards a specific goal. In the military pilot's professional work involving body adaptation to endure extreme +Gz acceleration values and maintaining situational awareness at the peak of their occurrence is one of the key elements. The aim of the study was knowledge on the impact of 40-hour specialized training including a set of isometric-breathing exercises on the tolerance level of +Gz accelerations among female cadets of the Polish Air Force University.

Material and Methods: The study involved 18 cadets, including 8 female cadets (experimental group) and 10 male cadets (control group) of the Polish Air Force University. The age of the surveyed cadets ranged from 20 to 22 years. The medical examinations of the group cadets were carried out twice before (study I) and after (study II) the implementation of the 40-hours long specialized physical training in a sample of female cadets and after standard physical education program in male cadets. In both studies, the tolerance limit of +Gz accelerations was determined in a human centrifuge, according to a linear program, and before each study, somatic features were measured.

Results: Before the applied training in the experimental group the tolerance level to +Gz accelerations was 5.78±0.12 G while after the training the participants improved their tolerance to +Gz accelerations by 7.19±0.58 G. The difference between the experimental group and control turned out to be statistically significant at a significance level of 0.05. The standard physical education program in the male cadets did not improve their tolerance to +Gz accelerations.

Conclusions: The 40-hours long specialized training in female cadets contributed to the improvement of the tolerance to +Gz accelerations and it seems reasonable to introduce this solution permanently into the physical education program for female cadets at the Polish Air Force University.

Keywords: the human centrifuge, intensity of effort, isometric-breathing exercises, training on SAGI, military pilots

1. Introduction

The increase in the technical capabilities of aircraft and the introduction of High-Performance Aircraft (HPA) (MiG-29, F-16, M-346 Master, FA-50) capable of operating at sustained high acceleration rates, have confronted aviation physiologists with an entirely new situation. This issue becomes particularly important during flights on the modernist fifth-generation aircraft (F-35). It is possible to achieve incomparably higher accelerations on such aircraft than in the past. Unfortunately, such capabilities, although excellent from the point of view of combat, often pose a great danger to the crew [1]. The development of an appropriate level of the pilot's body resistance to specific flight factors (accelerations, altitude hypoxia, air sickness) requires specialist influencing tactics. New training solutions are constantly sought to increase body resistance to flight physical factors [2].

The ability to perform a specific physical task requires numerous activities from people. This depends on the type and intensity of effort directed towards a specific goal. In the military pilot's professional work involving body adaptation to endure extreme +Gz acceleration values and maintaining situational awareness at the peak of their occurrence is one of the key elements [3]. The effect of accelerations contributes to body fluid movement, hypoxia of the central nervous system (CNS) and cognitive disorders. Blood flow in the pilot's body is caused by changes in the speed, direction and tilt of the aircraft in relation to the ground. This leads to hypoxia of the cerebral vessels, which, in turn, affects perceptual-motor processes and results in the ability to receive and process information and to undertake adequate sensorimotor reactions to a given situation during the implementation of tasks in the air [4]. In order to counteract the multiple +Gz accelerations occurring during real flights, the pilot performs special exercises that are aimed at retuning old movement habits to new technical and tactical skills, necessary when piloting High-Performance Aircraft [2]. Currently, the forms and methods of operations in this area are constantly evolving. In individual armies (Air Forces), complex goals regarding psychophysical preparation are achieved in different ways [5, 6, 7].

In the available literature, little attention has been paid to female cadets training. Since the year 1999, when the Air Force Academy (since the year 2018, the Polish Air Force University) began to qualify women for jet pilot studies, the phenomenon of a sudden loss of consciousness, due to the generated high increase in +Gz accelerations, has been encountered [8]. At the Polish Air Force University, in order to prevent the above-mentioned phenomenon, cadets studying piloting, prior to starting practical training in the air, complete a 40-hour specialist training (programme) called Fitness-Physical Conditioning Preparation for Flight Duties [9-11]. This training leads, among other things, to learning special manoeuvres known as Anti-G Straining Manoeuvres (AGSM) (M-1, L-1), which significantly increase the tolerance to +Gz accelerations by 1.5-2.5 G [12, 13]. A specialized training on Special Aviation Gymnastics Instruments (SAGI) was supplemented with an appropriate set of isometric-breathing exercises, allowing to reduce flight related fatigue. Specialized training on SAGI does not have a significant direct effect on +Gz tolerance, but it has a stimulating effect, mainly on the balance system and the autonomic nervous system [14, 15]. A set of isometric-breathing exercises, in turn, as a form of targeted training, allows you to prepare the body for effective performance of AGSM and to maintain cerebral circulation in exposure to extreme +Gz acceleration values [16, 17]. Moreover, it should be emphasized that the system of pilots' conditioning to prepare

them for flights at the Polish Air Force University is constantly being improved based on the new scientific research [13, 18, 19, 20].

The aim of the study was knowledge on the effect of 40 hours of specialized training including a set of isometric-breathing exercises on the level of +Gz acceleration tolerance, among female cadets of the Polish Air Force University. Therefore, in this study, an attempt was made to experimentally confirm the hypothesis that including a 40-hour specialist training in the fitness preparation process in female cadets improves the tolerance to +Gz accelerations.

2. Materials and Methods

Participants

The study involved 18 cadets, including 8 female cadets (experimental group) and 10 male cadets (the control group) from the Polish Air Force University in Dęblin. The age of the subjects ranged from 20 to 22 years (in the experimental group: 20.63±0.52 years and in the control group 21.30±0.67 years). The detailed anthropometric data obtained from both groups are included in Table 5. The study participants were divided into two groups: a group of female cadets undergoing a 40-hour specialist training (experimental group) and a group of male cadets undergoing a standard physical education program (the control group). The cadets participating in the study constituted a homogeneous comparative material, as both groups were studying to be a jet pilot and were selected by the Regional Military Aviation and Medical Commission in Warsaw, where they received the highest health category for HPA. The Bioethics Committee approved the project of the medical experiment at the Military Medical Board, based on resolution No. 177/20 dated 20.11.2020.

Study Design

The examinations of cadets were conducted twice, before (study I) and after (study II) the implementation of a 40-hour physical training in both groups (the experimental group and the control). In both studies, the tolerance limit of +Gz accelerations in the human centrifuge was determined according to the linear program [21] and each time, before each test, somatic characteristics (body mass, body height) were measured and, based on measurement results the Body Mass Index (BMI) was calculated.

Assessment of acceleration tolerance +Gz

The assessment of tolerance to +Gz acceleration was performed on a dynamic flight simulator which is a human centrifuge, by AMST-Systemtechnik GmbH, which is part of the equipment of the Aeromedical Training Department of the Military Institute of Aviation Medicine in Warsaw (Fig. 1). The tests were carried out in the morning, after breakfast, according to a linear program that included determining the tolerance limit of +Gz accelerations in a human centrifuge using the so-called slowly increasing acceleration approach at a rate of 0.1 G/s (Fig. 2). The criteria for the tolerance limit of +Gz accelerations include loss of the peripheral vision field within the range of up to 50° or a functional disorder in the recorded indicators, mainly the circulatory system. Responses to visual stimuli (registration of changes in the peripheral field of vision) and vocal contact with the flight physician conducting the study indicated that the subjects maintained situational awareness. The centrifugation time did not comprise deceleration of the human centrifuge from its individual maximal value to its stop [21]. The tests in the human centrifuge were

conducted by a flight doctor working at the Aeromedical Training Department of the Military Institute of Aviation Medicine in Warsaw.

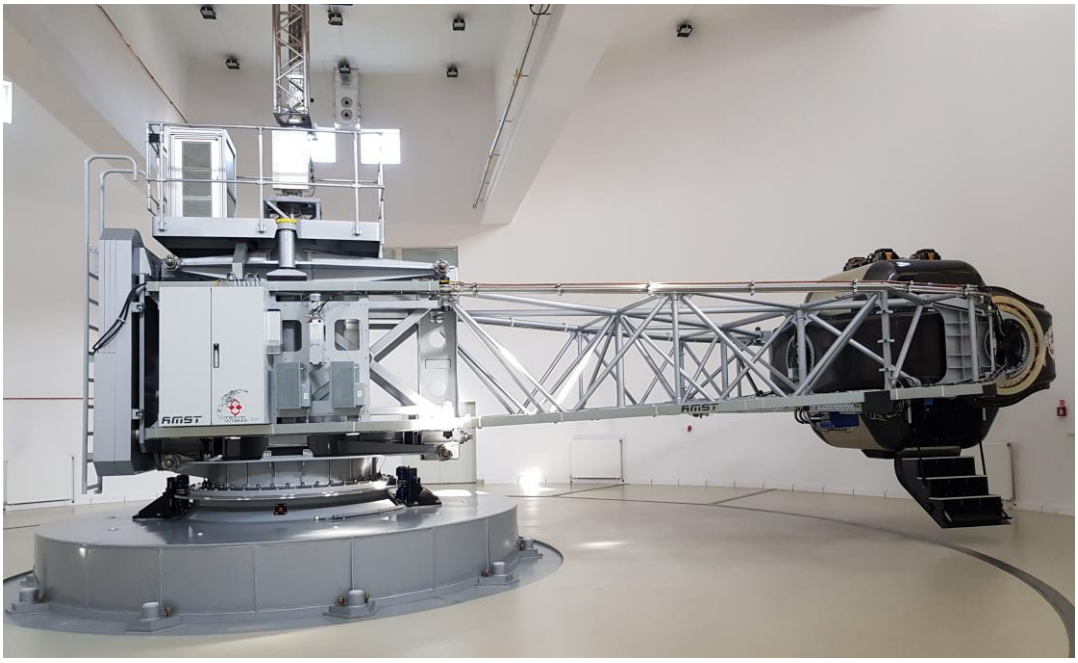

Figure 1. The human centrifuge at the Military Institute of Aviation Medicine in Warsaw (Poland).

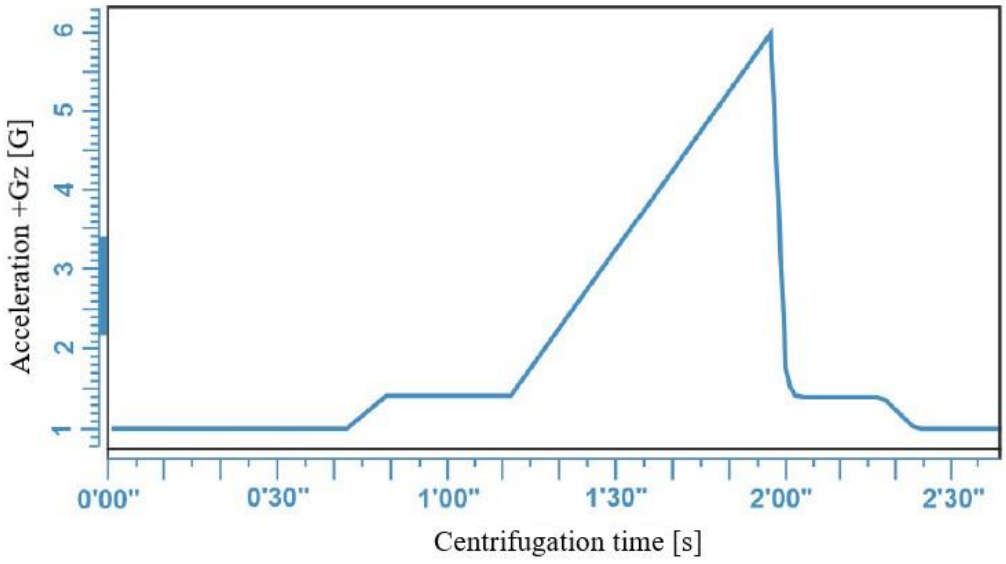

Figure 2. Acceleration program – linear program.

40-hour specialist training

A 40-hour long specialist training was conducted in the experimental group between October and December. It lasted a total of 40 teaching hours (1 teaching hour = 45 minutes). The training took place twice a week on Tuesdays and Thursdays (2 · 90 minutes). A detailed description of the exercises can be found in the aforementioned publications [11, 17]. The specialist training consisted in adding a set of isometric-breathing exercises (22 exercises) (Table 1) to the exercises on SAGI (exercises on a gyroscope, single aero wheel, looping), which were conducted each time

after the exercises on SAGI. The time of performing individual exercises of the isometric-breathing set was initially twenty seconds and was increased by five seconds during each subsequent week of the training.

Table 1. Set of isometric-breathing exercises.

Exercise numbers	Name of the exercise
1	Alternate raising of lower limbs up
2	Alternate raising of the lower limbs at an angle of 30 degrees with hip raise
3	Raising of the straightened lower limbs to the vertical position
4	Raising of the lower limbs at an angle of 45 degrees to the ground
5	Inverted pike with the legs leaning against the ground
6	Shoulder stand
7	Trunk bend forward with grasping the ankle joints
8	Loud exhalations with the glottis partially closed
9	Trunk and head bending backward
10	Backward bend of the torso
11	From the prone position, an alternate raise of the lower extremities
12	From the prone position, raising both lower limbs together upward
13	Backward bend of the tense trunk with grasping the ankle joints bent lower limbs
14	Backward bending of the trunk with the upper limbs resting behind on the forearms
15	Bowing the trunk backward to lie backward
16	Forward trunk bend with the forehead resting on the floor
17	Forward trunk bend with backward arm raise and stopped breathing
18	Plank
19	Hip raise with the lower extremities resting on the floor
20	Standing on the head and forearms
21	Raising the lower limbs at 90 degrees angle to the torso on a gymnastic ladder inclined at 45 degrees to the ladder
22	Sit up straight on a gym bench tilted at 45 degrees with the feet hooked to a ladder rung

Standard physical education program at Polish Air Force University

The standard education training program was carried out in the control group between October and December. For the aim of this study, this program was shortened to 40 teaching hours (1 teaching hour = 45 minutes) (Table 2). The training was carried out twice a week on Tuesdays and Thursdays (2 · 90 minutes). It included the topics of team games, field athletics, gymnastics, instrument gymnastics (sport equipment exercise, exercises on Special Aviation Gymnastics Instruments) and swimming. The classes were conducted with great intensity and variety, in order to increase the functional capabilities of the body to use greater loads in next training sessions. A detailed description of the workouts can be found in the mentioned publication [13].

Training sessions for both groups were conducted at the Physical Training Centre of the Air Force University in Dęblin under the supervision of lecturers, in order to ensure equal accommodation and catering conditions.

Table 2. Standard physical education program at Polish Air Force University.

Number of hours	Topic
5	Team games
5	Field athletics
5	Gymnastics
20	Instrument gymnastics (SAGI)
5	Swimming

Statistical analysis methods

The collected test results were subjected to statistical analysis using the R computing package. Two comparisons of the experimental group with the control group were carried out. The first comparison concerned the average results of the assessment of +Gz acceleration tolerance limit and centrifugation time in both groups (the experimental group and the control group) before (study I) and after (study II) the implementation of 40-hour training in both groups. Additionally, changes in the +Gz acceleration tolerance limit between studies I and II and the difference in time spent in the human centrifuge during study II and study I were verified (Table 4). Then, comparisons were made of the average results obtained from both groups regarding somatic indicators (body mass, body height) between two research situations. The change in BMI between the I and II study was also analysed.

The assumption of distribution normality is one of the basic assumptions determining the selection of a statistical test for comparisons of two groups is. P-values from the Shapiro-Wilk test and the Kolmogorov-Smirnov test with Lillefors correction (Table 3). Due to the failure to meet the assumptions of the normality of the analysed variables, it was decided to use the Mann-Whitney test, which is a non-parametric equivalent of the student's t test for independent samples. In statistical tests, a significance level of 0.05 was accepted. A detailed discussion of the results is provided later in the article.

Table 3. Test results corresponding to normality of the distribution in the analysed variables.

Variable	Shapiro-Wilk test (p-value)	Lillefors test (p-value)	Result
BMI change (experimental group)	0.0399	0.0134	distribution different from a normal one
BMI change (control group)	0.6090	0.5692	normal distribution
Changing time in a centrifuge (experimental group)	0.0001	0.0009	distribution different from a normal one
Time change in the centrifuge (control group)	0.8830	0.8433	normal distribution

3. Results

The analysis of the average results of the assessment of +Gz acceleration tolerance limit and centrifugation time (Table 4) showed that in study II a statistically significant increase in the average value of +Gz acceleration tolerance limit was noted in the experimental group (7.19±0.58 G), as compared with the control group (6.11±0.28 G). The comparison of the mean values corresponding to the time spent in the centrifuge was similar, as a statistically significant increase in centrifugation time was noted in study II, in the experimental group (71.88±5.79 s) as compared with the value obtained in the control group (61.10±2.85 s).

Table 4. Means, standard deviations and medians (in brackets) obtained from the assessment of +Gz acceleration tolerance limit and centrifugation time determined in both studies carried out in both groups (the experimental group and the control group).

Indicator	Experimental group (n=8)		Control group (n=10)	
	Study I	Study II	Study I	Study II
Acceleration +Gz [G]	5.78 ±0.12 (5.70)	7.19 ±0.58 (7.00)	5.98 ±0.09 (6.00)	6.11 ±0.28 (6.00)
Centrifugation time [s]	57.75 ±1.16 (57.00)	71.88 ±5.79 (70.00)	59.80 ±0.92 (60.00)	61.10 ±2.85 (60.00)

A comparison of accelerations is mathematically equivalent to comparing time spent in a centrifuge. In the case of differences between the acceleration tolerance limit +Gz the values obtained from study II and study I and in the time spent in the centrifuge, there are grounds for stating (p-value equal to 0.0004) that the distribution in the experimental group and the control group are different. In particular, the median values obtained in the experimental group are higher than the median results in the control group, and this difference is significant at the statistical level of 0.05. This indirectly proves the effectiveness of the applied training program (Table 4).

Contrary to the results of the +Gz acceleration tolerance limit test, the measured somatic indicators (body mass, body height, BMI) in the study group did not significantly change from the statistic point of view (Table 5).

Table 5. Mean values and standard deviations of body mass, body height and BMI determined in both studies, in both groups (the experimental group and the control group).

Indicator	Experimental group (n=8)		Control group (n=10)	
	Study I	Study II	Study I	Study II
Body height [cm]	168.25 ±2.71	168.25 ±2.71	177.90 ±5.82	177.90 ±5.82
Body mass [kg]	57.75 ±2.96	57.13 ±2.23	75.30 ±8.78	75.00 ±6.57
Body Mass Index (BMI) [kg/m^2]	20.40 ±0.96	20.18 ±0.75	21.30 ±0.67	23.66 ±1.09

In the case of the comparison of changes in BMI, there are no grands to claim that the distributions of changes in body mass, body height or BMI (p-value equal to 0.5564) in the experimental and control groups are statistically significantly different.

4. Discussion

Determining the +Gz acceleration tolerance limit in a human centrifuge is one of the basic tests qualifying pilots for flights on High-Performance Aircraft. Research on the +Gz acceleration tolerance limit in a human centrifuge is a valuable source of information about the psychophysical condition of pilots and candidates for military service, and their physical preparation [22]. In this study, the main goal was to determine the threshold beyond which the body of female cadets was no longer able to meet the challenge of exposure to hypergravity environment. Unfortunately, there are no reports in the available foreign literature on the specialized training of female cadets, which has been conducted for many years at the Polish Air Force University. The 40-hour specialized training called Fitness-Physical Conditioning Preparation for Flight Duties includes training on SAGI (exercises on a gyroscope, single aero wheel, looping) and a set of isometric-breathing exercises (included in the training of female cadets for the purposes of research for this article). Training on SAGI reduces sensitivity to angular and centripetal accelerations, vestibular organ habituation, eye-hand coordination and spatial orientation. The specificity of workouts on these instruments also impacts the central nervous, muscular and cardiovascular systems through forced exercises performed in the longitudinal, transverse and sagittal axes [15]. Isometric-breathing exercises, in turn, are aimed at teaching (improving) proper breathing by increasing abdominal pressure and muscle endurance as a preparation for performing AGSM manoeuvres (M-1, L-1). They allow maintaining cerebral circulation under the influence of linear accelerations in the +Gz axis and thus, increasing their tolerance to such accelerations [16].

The available foreign literature contains increasingly more reports on the new forms of a focused and specialized physical training for pilots, aimed at increasing the tolerance to +Gz accelerations [7, 23]. Balldin prefers, among others things, isometric and speed training. He emphasizes that isometric training focuses on strength increase in specific muscle groups that are involved in maintaining body position and the process of physiological compensation for acceleration. Speed training, in turn, affects the speed of muscle contraction in exposure to acceleration. These forms of training are important for a quick and effective performance of AGSM manoeuvre [24]. Additionally, the form of such training is mainly focused on the development of specific muscle groups, which include the thigh muscles (quadriceps and adductor muscles), the gluteal muscles, and the lower leg and abdominal muscles [23]. It should also be emphasized that, during such training, a participant does not need to tense the abdominal muscles strongly, but only keep them a little tense. When performing aviation tasks, the pilot should be able to independently assess the degree of effective muscle tension in an appropriate proportion to the applied acceleration. This is due to the fact that acceleration values during flights or other aircraft evolutions (turn, loop, half-loop, spin, roll) are constantly changing, which may contribute to rapid muscle fatigue and exhaustion of their metabolic reserves [25, 26]. As early as in the 1980s, Tesch and colleagues found that physical training of selected muscle groups, supplemented with respiratory muscle exercises, causes an increase in the tolerance value for +Gz accelerations. This form of training should involve development of muscle strength in the entire body and include isometric exercises.

Besides, it should provide the opportunity for the improvement of Gz specific breathing patterns. As a result, the outflow of blood from the upper to the lower parts of the body is hindered [27]. Therefore, a specially targeted physical activity should become one of the basic elements of the training program, not only increasing the tolerance to acceleration, but also preventing health problems in pilots. It has been shown that 12 weeks of a focused physical training for British Royal Air Force pilots, the so-called Aircrew Conditioning Program (ACP) does not affect the tolerance to +Gz accelerations in the version without muscle tension and the so-called relaxed G tolerance (RGT) reduces the physiological load (strain) when tensing the so-called straining G tolerance (SGT) muscles. Moreover, it improves the ability to tolerate multiple +Gz accelerations [6]. Currently, the United States Air Force applies a special comprehensive training program for pilots of HPA, the so-called The Fighter Aircrew Conditioning Program (FACP). It (the comprehensive program) includes the following elements: cardiovascular fitness development, improvement of muscle strength and endurance, development of balance and stabilization and flexibility. It also justifies the purposefulness of such training. The high efficiency of the cardiovascular system ensures the ability to tolerate multiple repetitions of high values of +Gz accelerations. Improvement of muscle strength increases the effectiveness of AGSM manoeuvres. An adequate muscular endurance, in turn, ensures the ability to perform multiple isometric muscle contractions, reducing this way muscle fatigue. Balance and stability concerns ensuring the appropriate position of the pilot's body in the cockpit by exercising the deep abdominal and back muscles, providing better conditions for AGSM manoeuvre performance. Flexibility, however, allows for a full and pain-free range of motion, improves the effectiveness of AGSM and reduces the risk of injuries [23].

The results of +Gz acceleration tolerance limit test performed in the human centrifuge, in both groups (the experimental and the control group), revealed a significant improvement. In the experimental group, the progress was visible in the case of all studied female cadets and ranged from 1.1 to 2.6 G. On average, the female cadets in this group improved their results from 5.78±0.12 G (study I) to 7.19±0.58 G (study II). The percentage improvement between study I and study II exceeded 24%. However, in the control group, only 2% improvement was noted between study I and study II. The favourable changes in the experimental group suggested a high functional efficiency of the circulatory system, since, during the studied period, the means and methods of preparation for conditioning in female cadets were changed and modified, and aimed at speed and strength ability development (necessary during AGSM manoeuvre performance). However, during the same period, only a standard physical education program, was carried out in military schools, in the control group. Progress was also noted in the time spent in the human centrifuge, in both groups. In study II, the experimental group of female cadets achieved the result of 71.88±5.79 s while the control group of male cadets achieved the result of 61.10±2.85 s. Therefore, the degree of improvement in both groups between study I and study II were as follows: experimental group 24%, control group 2%. The improvement in centrifugation time in the human centrifuge was certainly influenced by intensive, systematic training, which was conducted four hours a week (2 · 90 minutes) in the period between October and December in both groups. However, our research confirmed the thesis that 40 hours of specialized training, supplemented with a set of isometric-breathing exercises in the experimental group and omission of this training in the control group provides measurable benefits leading to improvement in +Gz accelerations and the centrifugation time in female cadets, in a human centrifuge.

Due to the above, today it is difficult to talk about a uniform, generally accepted concept of specialized training for female cadets. Further progress in this matter seems to be possible only as a result of an integrated cooperation with representatives of many scientific disciplines who address the issue of the +Gz acceleration tolerance in pilots of High-Performance Aircraft.

Limitations of the study

In this research, the experimental group consisted of only 8 female cadets, which is a small research group. However, it should be emphasized that from 1999 to 2023, a total of 142 graduates completed military studies at the Polish Air Force University in various fields, including only 13 in the field of jet pilot (elite of military aviation). This number represents only 9,2% of all graduates who have so far managed to complete difficult military studies at the Polish Air Force University in Dęblin. The control group consisted of male cadets, as it was not possible to conduct research on a group of female cadets due to the small number of female cadets studying jet pilots. Despite this, the researchers managed to show the differences between various concepts of physical training and studies I and II. It is planned to continue research in the coming years to further verify the hypothesis presented in this study.

Perspectives

The problem of training pilots of High-Performance Aircraft in raising the tolerance of +Gz acceleration is becoming increasingly topical due to the action of high, prolonged acceleration, often reaching the limits of the tolerance of the human body. The technical development of aviation, has caused the aircraft a tool far beyond the physiological limits of the pilot's body, which consists of the complexity of tasks, the uniqueness of each flight and the dizzying dynamics of changing flight parameters. This fact has undoubtedly increased the demands placed on pilots. This applies to both mental abilities and psychophysical endurance. The advantage in favor of using the proposed training in female cadets is, first of all, the safety of flying personnel and reducing the effects of rapid fatigue. The pilot must not remain alone in his struggle with an environment that is different for him. Therefore, further research is only possible as a result of integrated cooperation of specialists from many scientific fields dealing with the issue of improving +Gz acceleration tolerance in pilots of High-Performance Aircraft.

5. Conclusions

1. The analysis of the results obtained from tests in the human centrifuge showed that 40-hour specialized training, including a set of isometric-breathing exercises, had a statistically significant impact on the tolerance to +Gz acceleration improvement of the tolerance to +Gz accelerations and the increase in the centrifugation time in female cadets in study II compared to study I in the human centrifuge.

2. The applied training program may be useful in health prevention for military pilots and in improving the tolerance of +Gz accelerations of female cadets. These exercises should be recommended as a permanent element of supplementary training in the adopted system (program) of Fitness-Physical Conditioning Preparation for Flight Duties potential.

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Data Availability Statement: The data supporting this study's findings are available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declared no conflict of interest.

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