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ORIGINAL ARTICLE

ASSESSMENT OF THE SYMMETRY OF LOWER LIMB PRESSURE FORCE ON THE RUDDER OF THE ANTI-G FORCE MANEUVER TRAINING STAND

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Introduction: Modern combat aircraft increase the psychophysiological demands placed on pilots. This necessitates continuous improvement of methods for assessing fitness for flight duty, supported by specialized flight simulators.

One such simulator, developed with the participation of the Military Institute of Aviation Medicine, is the stationary flight simulator named SymuLBNP.

In the presented study, a criterion of 10% threshold was proposed for evaluating the symmetry of lower limb pressure force on the rudder pedals of the diagnostic and training stand for Anti-G maneuver training, which may be applied in future research using the SymuLBNP simulator.

The aim of the study was to evaluate the symmetry of lower limb pressure force on the rudder pedals of the diagnostic and training stand for Anti-G maneuver training, recorded during scheduled pilot training in aviation medicine, as a factor potentially influencing the results of measuring lower limb pressure force on the rudder pedals of the SymuLBNP simulator.

Method: The study utilized pressure force measurement data on the rudder pedals of the diagnostic and training stand, recorded during routine pilot training in aviation medicine.

The statistical analysis was conducted on the measurement results of a group of 258 men aged 18 to 25 years. Differences between the pressure force exerted by the left lower limb and the right lower limb were examined.

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Results: The analysis of the lower limb pressure force measurements on the pedals of the diagnostic and training stand revealed a statistically significant ($p = 0.05$) asymmetry in the pressure force applied to the rudder pedals by the lower limbs.

Based on the analysis of additional parameters describing the obtained results, a criterion was adopted stating that if the value of the symmetry index does not exceed 10%, it can be assumed that the pressure forces exerted by the pilot on the rudder pedals with the left and right lower limbs are symmetrical and will not significantly affect the assessment of the muscular component of the Anti-G maneuver performed on the SymuLBNP simulator.

Keywords: aviation medicine, LBNP, AGSM, muscle strength symmetry, loading symmetry index

INTRODUCTION

Since December 1903, when the Wright brothers performed the first controlled powered flight [15], aircraft have been built that achieve record-breaking speeds and accelerations [1]. However, it turned out that the human body is not adapted to tolerate high-magnitude accelerations sustained over extended periods [14]. This issue primarily affects military aircraft pilots, who must endure accelerations many times greater than the force of gravity, lasting from several to over a dozen seconds [9]. The acceleration value divided by the acceleration due to gravity defines the "G" load.

The effects of G-forces on the human body depend on their magnitude, duration, and direction of action. The human circulatory system is particularly vulnerable to G-forces acting along the body's longitudinal axis, defined as the "head-to-foot" direction. The most common effect of G-forces on the circulatory system is the cessation of cerebral circulation, leading to G-force induced Loss of Consciousness (G-LOC). An insufficient supply of oxygenated blood to the head results in disturbances and potentially cessation of the functions of the visual system and the brain.

One way to reduce the impact of G-forces on the pilot's body is to increase intrathoracic pressure, while simultaneously invoking isometric tension of the major muscle groups of the lower limbs, abdominal muscles, and shoulder girdle muscles [19]. Both of these mechanisms are referred to as the Anti-G Straining Maneuver (AGSM). The respiratory component of the AGSM resembles the performance of the Valsalva maneuver, which involves increasing thoracic pressure by attempting to exhale with a closed glottis [9,26]. A correctly performed AGSM allows for an average increase in G-tolerance of approximately 1 to 2 Gz [28].

In the process of learning and training the execution of AGSM, it is essential for the pilot to acquire and consolidate the ability to properly regulate skeletal muscle tension and intrathoracic pressure. This enables the sustained maintenance of arterial blood pressure at the level of the head, thus ensuring continuous cerebral blood flow during the exposure to high-magnitude G-forces.

The training in correct AGSM execution is conducted during pilot instruction in aviation medicine at the Military Institute of Aviation Medicine, using a diagnostic and training stand for Anti-G maneuver training, followed by training in the human centrifuge a dynamic flight simulator generating accelerations similar in character and magnitude to those encountered during actual aircraft flight [18].

AGSM learning and training with the use of the diagnostic and training stand which enables measurement of lower limb pressure force on two immobile rudder pedals includes the following components:

a) execution by the pilot, while seated in the diagnostic and training stand, of a diagnostic test of maximal muscle strength (Maximal Voluntary Contraction, MVC) exerted with the feet on the rudder pedals. The purpose of this test is to familiarize the pilot with the measurement result of their own maximal force, aiding in self-assessment of strength capacity. The MVC test enables the determination of a reference force value for evaluating physical effort during subsequent training stages,
b) familiarization of the pilot with perceived exertion and accompanying fatigue during an exercise of exerting pressure on the rudder pedals with force equal to 70% of MVC. The aim of this exercise is to allow the pilot to assess the perceived difference in exertion intensity relative to that experienced during the MVC test,
c) execution by the pilot, at the diagnostic and training stand, of respiratory component training of the Anti-G maneuver, combined with an exercise involving foot pressure on the rudder pedals with a force specified in the train-

ing program. The value of this force falls within the range of 20% to 40% of MVC. During each repetition, the pilot is observed by an instructor who evaluates the correctness of the performed training.

AGSM learning and training using the Anti-G maneuver training stand is conducted under stationary conditions. For this reason, its main focus is the training and coordination of the muscular and respiratory components of the Anti-G straining maneuver. The respiratory component of the AGSM is limited to emphasizing the breathing phases. This limitation is guided by trainee safety, as excessive increases in blood pressure under conditions of Earth's gravity could result in the rupture of blood vessels at the head level.

Training in the human centrifuge is conducted under actual acceleration conditions, with acceleration many times greater than Earth's gravitational acceleration, which necessitates the proper execution of the AGSM, including both the muscular and respiratory components. However, a pilot's self-assessment of lower limb pressure force on the rudder pedals may differ from the actual pressure force values recorded by the centrifuge system. This discrepancy may result from disturbances in proprioceptive sensation within the musculoskeletal system caused by G-forces in some pilots [4].

In an effort to improve the effectiveness of aviation medicine training, the Military Institute of Aviation Medicine has initiated the development of a diagnostic and training system that enables the complete execution of AGSM under stationary conditions at Earth's gravity. This work was initiated as part of the Priority Research Directions of the Ministry of National Defence for the years 2017–2026. In accordance with contract No. DOB-BIO-12-05-001-2022 signed with the National Centre for Research and Development, a project entitled: "Development of a system for assessing the fitness of flying personnel for flight duty based on registration of circulatory system parameters during flight and under simulated G-force exposure conditions (SymuLBNP)" is being carried out. As a result of this project, a simulator of an aircraft, used by the Polish Air Force, was designed. This simulator was equipped with a Lower Body Negative Pressure (LBNP) system. The AGSM diagnostic and training system is one of the functional components of this simulator.

The construction of the SymuLBNP simulator cabin enables the measurement of lower limb pressure force on the rudder pedals. As in the case of an aircraft or a human centrifuge, the rudder is treated as a bidirectional lever mounted on an axis perpendicular to the floor of the simulator cabin, allowing the pedals to move forward and backward from the neutral position within a range of approximately 5 cm.

The human body is not symmetrical [22]. Measurements of various anthropometric parameters reveal also individual dynamic asymmetry [12,27], referring to quantitative differences in these features [13,21,29]. Scientific reports indicate a variable degree of lower limb strength asymmetry [5,30], which tends to decrease with age. Measurement results of rudder pedal pressure force under G-force conditions, conducted in the context of other research, revealed asymmetry in the pressure force applied to the fixed pedals of the human centrifuge [6,7].

It was therefore deemed purposeful to conduct a study on the possibility of utilizing lower limb pressure force measurements on the rudder of the Anti-G maneuver training stand to assess the nature of pilot exertion during the execution of a complete AGSM, based on force measurements from the SymuLBNP simulator's rudder system. This required defining a criterion by which the pressure forces applied to the rudder by the left and right lower limbs could be regarded as symmetrical.

Objective

The objective of the study was to evaluate the symmetry of lower limb pressure force on the rudder pedals of the diagnostic and training stand for Anti-G maneuver training, recorded during scheduled pilot training in aviation medicine, as a factor with potentially significant influence on the results of measuring lower limb pressure force on the rudder pedals of the SymuLBNP simulator.

Research hypothesis

During the test of force the studied population of pilots, there are no statistically significant differences in the pressure force applied by the right and left lower limbs on the rudder of the diagnostic and training stand used for Anti-G maneuver training.

MATERIAL AND METHODS

The study utilized measurement data collected routinely during the scheduled aviation medicine training of pilots.

For the purposes of this study, the following data were used:

1) Index number and anonymized personal data of the trainee,
2) Descriptive statistical parameters of the trainees,

3) Results of the pressure force measurements applied by the lower limbs on the left and right rudder pedals at the Anti-G maneuver training stand.

Material

The material used in the study consisted of lower limb pressure force measurement results recorded at various stages of aviation training for pilots of high-maneuverability aircraft undergoing aviation medicine training.

All military high-maneuverability aircraft pilots participating in such training were required to fully meet the medical standards for flights in air and in flight simulators, as certified by the relevant Regional Military Aviation Medical Board. All participants met these requirements.

The characteristics of the group of pilots participating in the training are presented in Tab. 1. In this group, based on the Shapiro–Wilk and Lilliefors tests at a significance level of p = 0.05, the data distribution was not confirmed to follow a normal distribution.

Tab. 1. Characteristics of the studied group.

Number of people N = 258	**Age**	**Body mass**	**Body height**	**BMI**
	[years]	[kg]	[m]	[-]
M±SD	21.1±2.2	75.6±9.2	1.790±0.057	23.57±2.50
Min.	18	54	1.63	18.2
Max.	25	112	1.98	33.3
W (Shapiro-Wilk)	0.918	0.976	0.988	0.972
P value (Shapiro-Wilk)	< 0.001	< 0.001	0.026	< 0.001
D (Lilliefors)	0.150	0.062	0.079	0.068
P value (Lilliefors)	< 0.001	0.026	0.001	0.009

Fig. 1 Method of measuring lower limbs pressure force on the rudder pedals of the diagnostic-training stand (Source: Military Institute of Aviation Medicine).

Method of measuring force on the Anti-G Straining Maneuver training stand

The measurement of lower limb pressure force simultaneously with the left and right leg on the rudder pedals of the diagnostic-training stand for Anti-G Straining Maneuver (AGSM) training (Fig. 1) was conducted during the routine aviation medicine training of pilots, in accordance with the Specialist Training Manual [20].

Before the exercise, each pilot performed a 5-minute warm-up. Next, the pilot took a seat in the AGSM training station chair and placed his feet on the rudder pedals. After stabilizing the pilot using a five-point harness, the instructor adjusted the seat's distance from the rudder pedals so that the knee flexion angle was, in the pilot's assessment, identical to the position adopted during airplane flight.

The first task was the diagnostic force test Maximal Voluntary Contraction, in which the pilot applied pressure with both lower limbs on the immobile rudder pedals, aiming to generate maximal force and maintain it for 5 seconds. Based on this measurement, reference values of maximal force (Fr) for each lower limb were determined. These values were calculated as the mean from the interval containing the highest recorded force at the stand. The boundaries of this interval were defined based on a threshold criterion set at 99% of the highest recorded maximal force [24] at the stand. Subsequently, training in the execution of the AGSM was carried out according to a sequence programmed in the stand's software.

Methods of measurement result analysis

The reference values of maximal force of lower limb pressure on the rudder pedals of the Anti-G Straining Maneuver training stand, determined during the MVC test, were used in the analysis as the force values exerted by the lower limbs on the rudder. The analysis was aimed at assessing the symmetry of the reference force values exerted by the left and right lower limbs on the rudder pedals.

Calculations of the analyzed indicators and angles were performed using Microsoft Excel 2016. To assess the symmetry of the reference force values exerted by the left and right limb on the rudder pedals, a graphical analysis of the computed values was also conducted [3].

Statistical analysis [25] was carried out using the "jamovi" software, version 2.3.28.0 ("The jamovi project 2024"), a free and open-source data analysis and statistical testing software [16], as well as the "Python" application using the "ChatGPT" interface.

At a significance level of p = 0.05, the normality of the data distributions was verified using the Shapiro–Wilk test [23,31] and the Lilliefors test, a modification of the Kolmogorov–Smirnov test.

Using the Wilcoxon signed-rank test for dependent samples, the statistical significance of the difference in reference force values between the right and left lower limb was tested for p = 0.05.

The rc statistic, representing the effect size [10] —in this context, the strength of association between variables in the Wilcoxon test—was also calculated. The accepted value ranges of the rc index are presented in Tab. 2.

Tab. 2. Effect size for the Wilcoxon test.

Value of the rc index	Interpretation
$0.0 < r_c \le 0.1$	weak effect
$0.1 < r_c \le 0.3$	moderate effect
$0.3 < r_c = 0.5$	strong effect

The Pearson correlation coefficient r was calculated between the reference force values of pressure exerted on the rudder of the Anti-G Straining Maneuver training stand by the left and right lower limb. The scale for interpreting the correlation coefficient values was adopted according to J. Guilford's classification of the strength of correlation dependency, presented in Tab. 3 [17].

Tab. 3. Classification of the strength of correlation dependence according to J. Guilford

Value of the correlation coefficient	Strength of correlation dependence
$\|r_p\| = 0$	no correlation
$0.0 < \|r_p\| \le 0.1$	negligible correlation
$0.1 < \|r_p\| \le 0.3$	weak correlation
$0.3 < \|r_p\| \le 0.5$	moderate correlation
$0.5 < \|r_p\| \le 0.7$	high correlation
$0.7 < \|r_p\| \le 0.9$	very high correlation
$0.9 < \|r_p\| \le 1.0$	nearly perfect correlation
$\|r_p\| = 1$	perfect correlation

The analysis of the symmetry of reference force values of lower limbs pressure on the rudder pedals of the Anti-G straining maneuver training stand in the studied group was conducted based on the assessment of symmetry defined by the Symmetry Index and the Symmetry Angle [2]. The Symmetry Index is derived by normalizing the difference between the parameter values of the right and left limbs relative to the taken into account parameter value of one of the limbs or the arithmetic mean of the parameter values of both limbs.

The values of the Symmetry Index (SI) were calculated using the formula proposed by Robinson [11,29,32].

$$SI = 2\frac{X_P - X_L}{X_P + X_L} \cdot 100\% \quad (1)$$

where:

X_P – parameter of the right limb, here: reference force of right lower limb pressure (FrP);

X_L – parameter of the left limb, here: reference force of left lower limb pressure (FrL).

The values of the Symmetry Angle were calculated based on angular measures determined in a Cartesian coordinate system [32]. The angles were determined using the reference force values of the left and right lower limbs, which were assigned to a two-dimensional coordinate system. The reference force values of the right lower limb (XP) were assigned to the x-axis (abscissa), and the force values of the left lower limb (XL) were assigned to the y-axis (ordinate). The points (XP, XL) determined in this way for each subject defined lines forming angles with the horizontal x-axis. The angle of inclination of each line was calculated using the following formula:

$$\alpha = arctg\frac{X_L}{X_P} \quad (2)$$

where:

α – angle of inclination of the line,

X_P – parameter of the right limb, here: reference force of right lower limb pressure (FrP);

X_L – parameter of the left limb, here: reference force of left lower limb pressure (FrL).

Similarly to the approach proposed by Zifchock and co-authors [32], it was assumed that for the condition XL = XP, the angle α = 45°. Any other value of angle α indicates asymmetry, which is described by the Symmetry Angle. Since the analyzed forces had the same direction and their values were assumed to be positive, the following formula was adopted to calculate the Symmetry Angle (SA):

$$SA = \frac{\left(45^\circ - \arctan\left(\frac{X_L}{X_P}\right)\right)}{90^\circ} \cdot 100\% \quad (3)$$

where:

X_P – parameter of the right limb, here: reference force of right lower limb pressure (FrP);

X_L – parameter of the left limb, here: reference force of left lower limb pressure (FrL).

An evaluation of the analyzed values of the Symmetry Index and the Symmetry Angle was also performed based on a classical measure of feature dispersion, using the coefficient of variation of the analyzed parameter [29]. The coefficient of variation (VS) for the examined feature in the studied group was calculated according to the following formula:

$$V_S = \frac{SD}{X_{śr}} \cdot 100\% \quad (4)$$

where:

Xśr – arithmetic mean of the sample values of the examined feature;

SD – standard deviation of the sample.

The classification intervals for the coefficient of variation (VS) are presented in Tab. 4.

Tab. 4. Coefficient of variation (VS) of the analyzed feature.

VS value [%]	Feature variability classification
$0.0 < V_S \le 20$	low
$20 < V_S \le 40$	moderate
$40 < V_S \le 60$	high
$60 < V_S$	very high

RESULTS

Results of the measurement of rudder pressure force on the Anti-G maneuver training stand

The results of the force measurements on the Anti-G maneuver training stand, obtained by the participants, were subjected to statistical analysis at the significance level of p = 0.05.

Tab. 5. Results of measuring force of left (FrL) and right (FrR) lower limb pressure on the Anti-G straining maneuver training stand.

Number of people N = 258	FrL	FrP
	[N]	[N]
M±SD	3046±1369	2948±1245
Median	2858	2870
Min.	1002	846
Max.	6294	5870
W (Shapiro-Wilk)	0.948	0.959
P value (Shapiro-Wilk)	< 0.001	< 0.001
D (Lilliefors)	0.110	0.085
P value (Lilliefors)	< 0.001	< 0.001

The Shapiro–Wilk test [23] of the distribution of the reference force values applied to the rudder pedal by the left lower limb (n = 258), W = 0.948, p < 0.001, and by the right lower limb (n = 258), W = 0.959, p < 0.001, indicates in both cases a violation of the normality assumption. Likewise, the analysis using the Lilliefors test demonstrated that the pedal forces applied by the left lower limb (n = 258), D = 0.110, p < 0.001, and by the right lower limb (n =

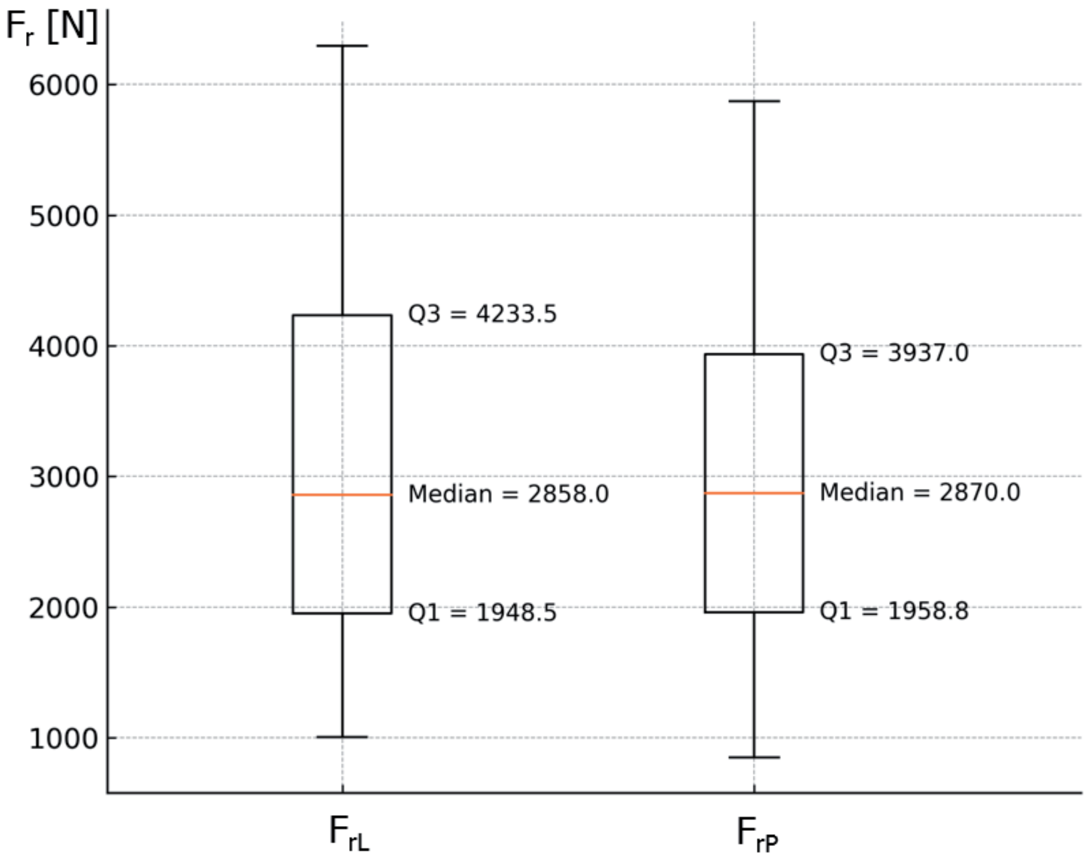

Fig. 2. Reference force values applied by the lower limbs to the rudder pedals of the Anti-G maneuver training stand: FrL, FrP – reference force of the left and right lower limb respectively (own elaboration).

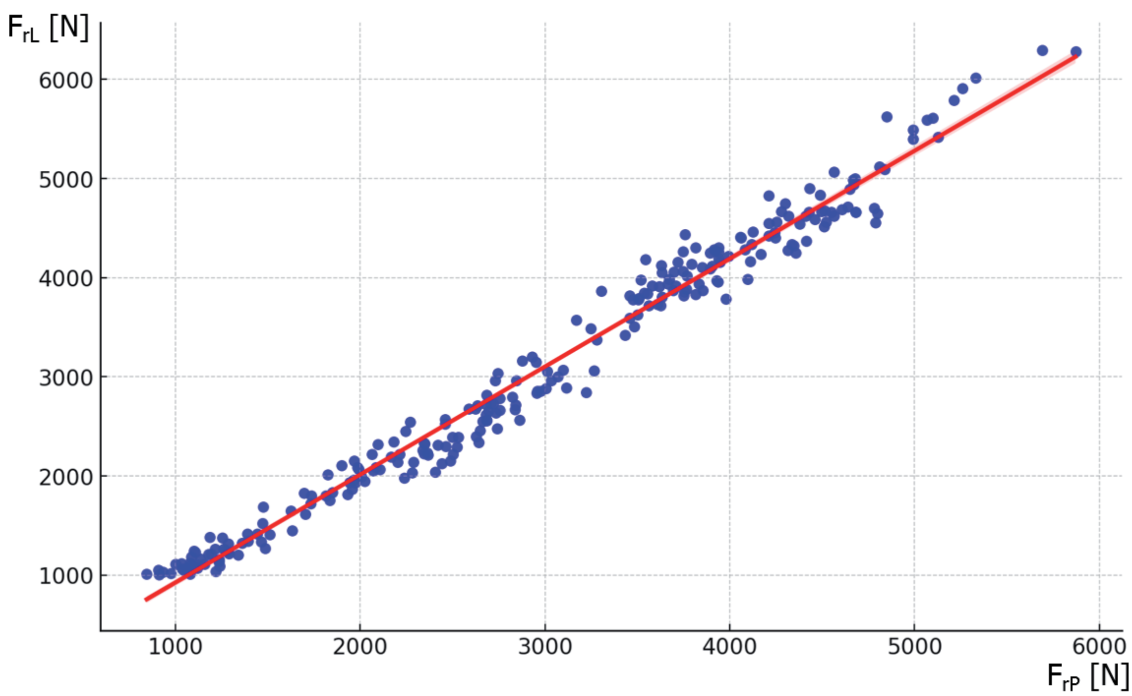

Fig. 3 Scatter plot of reference force values applied by the lower limbs to the rudder pedals of the Anti-G maneuver training stand: FrL, FrP – reference force of the left and right lower limb respectively (own elaboration).

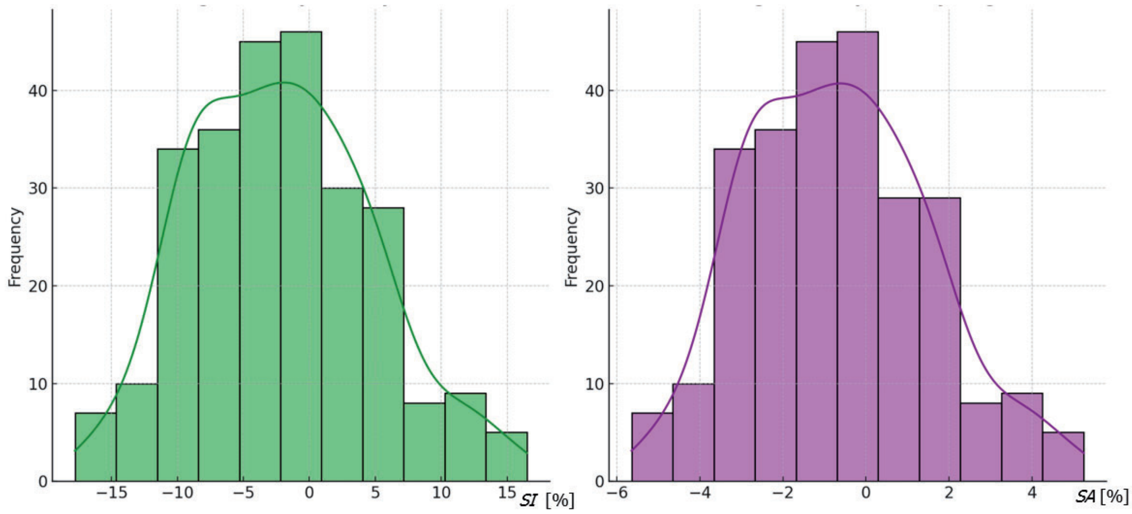

Fig. 4. Histograms of the Symmetry Index (SI) and Symmetry Angle (SA) values of the reference force of lower limbs pressure on the rudder pedals at the Anti-G straining maneuver training stand (own elaboration).

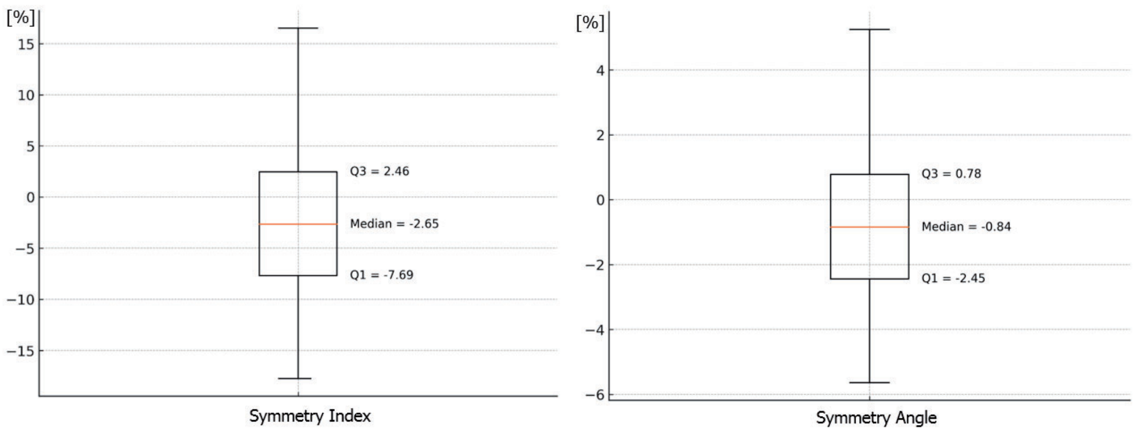

Fig. 5. Values of the Symmetry Index and Symmetry Angle of the reference force exerted on the rudder pedals of the Anti-G maneuver training stand (own elaboration).

258), D = 0.085, p < 0.001, do not follow a normal distribution.

The Wilcoxon signed-rank test for dependent samples revealed a statistically significant difference between these variables (n = 258), W = 16.00, p < 0.001. The effect size, estimated using the r statistic, was 0.39, which suggests a moderate effect size.

To compare the distributions of the reference force values FrL and FrP, box plots were generated (Fig. 2). No significant outliers were observed.

The Pearson correlation coefficient r was calculated to examine the relationship between the reference force applied to the rudder pedals by the left lower limb (F_{rL}) and the right lower limb (F_{rP}). The analysis showed, according to J. Guilford's scale, a very high to nearly perfect correlation between F_{rL} and F_{rP} , with r = 0.991, p < 0.01.

A scatter plot of the reference force values applied by the lower limbs to the rudder pedals of the Anti-G maneuver training stand was prepared (Fig. 3). A regression line equation was determined. The standard error area indicated in the graph is barely noticeable due to its very small values.

An analysis of the symmetry of the reference force values applied by the left and right lower limbs to the rudder pedals was conducted based on the Symmetry Index and the Symmetry Angle. Histograms of the Symmetry Index and Symmetry Angle values are presented in Fig. 4.

To verify the assumption of normal distribution for the Symmetry Index and the Symmetry Angle values at the adopted significance level of alpha = 0.05, the Lilliefors test was applied. The results indicate that the distribution of Symmetry Index values does not significantly differ from normal: n = 258, D = 0.052, p = 0.13. Similarly, the distribution of Symmetry Angle values does not significantly differ from normal: n = 258, D = 0.052, p = 0.13.

Tab. 6. Characteristics of the symmetry of reference forces exerted by the left and right lower limb on the rudder pedals of the Anti-G maneuver training stand.

Characteristic	Mean	Mdn	SD	Min.	Max.	D(258)	P value	V_s
	[%]	[%]	[%]	[%]	[%]	[-]	[-]	[%]
SI (FrP - FrL)	-2.11	-2.65	6.88	-17.8	16.5	0.052	0.13	-328
SA (FrP; FrL)	-0.671	-0.843	2.19	-5.64	5.24	0.052	0.13	-312

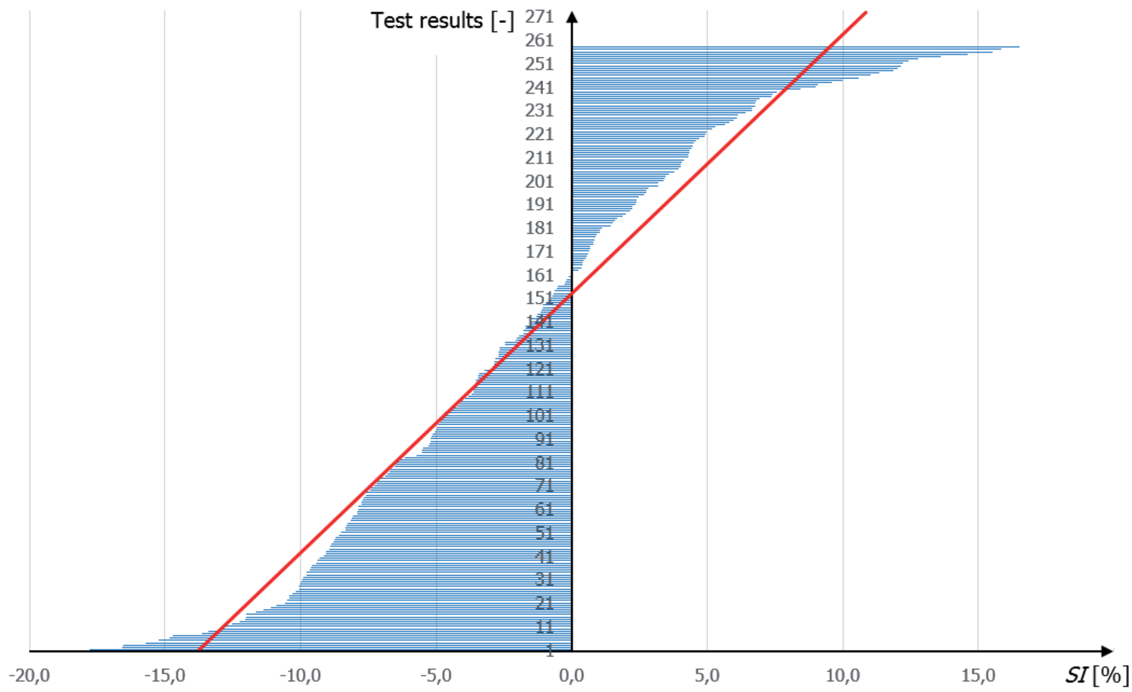

Fig. 6. Values of the Symmetry Index (SI) of the reference force exerted by the lower limbs on the rudder pedals of the Anti-G maneuver training stand (own elaboration).

Box plots of the Symmetry Index and Symmetry Angle values were also developed and are presented in Figure 5. The plots indicate data asymmetry.

The mean and median of the Symmetry Index (Fig. 5) are asymmetrically positioned and show a left-sided shift in their values. The asymmetrically distributed Symmetry Index values between the first and third quartiles do not exceed 8%. No outlier observations were identified among the data.

Similarly, the mean and median of the Symmetry Angle (Fig. 5) are asymmetrically positioned and show a left-sided shift in their values. The asymmetrically distributed Symmetry Angle values between the first and third quartiles do not exceed 3%. No outlier observations were identified among the data.

The results of the assessment of the normality of the distribution of the Symmetry Index and Symmetry Angle values, conducted using the Lilliefors test, as well as the results of other analyses of the symmetry characteristics of the reference force values applied with the left and right lower limbs on the rudder pedals of the Anti-G maneuver training stand, are presented in Tab. 6.

The values of the statistics calculated for the symmetry features, presented in the above table, indicate higher values of the reference force exerted on the rudder pedals by the left lower limb compared to the right lower limb. This justifies the conclusion that there is a left-sided asymmetry in the force exerted by the lower limbs on the rudder pedals of the stand within the analyzed measurement results.

A graphical analysis of the Symmetry Index values of the lower limb force exertion was conducted, as shown in Fig. 6. This analysis confirmed the presence of left-sided asymmetry in the force exerted by the left and right lower limbs on the rudder pedals of the stand.

DISCUSSION

Aviation training is a process that includes, among other things, training in aviation medicine, which covers topics such as aviation medical training and learning to perform the Anti-G maneuver. An integral element of the Anti-G maneuver is the tensing of skeletal muscles, primarily the muscles of the lower limbs, abdomen, and shoulder girdle [8]. As a result of tensing the muscles of the lower limbs, pressure is exerted on the rudder pedals. During the learning process of performing the Anti-G maneuver at the Anti-G maneuver training stand, an MVC test of the lower limb muscles is conducted. Based on this test, a reference force value is calculated, which is used to program the load magnitude in later training at this stand.

The results of the measurements of the force exerted by the lower limbs on the rudder pedals of the stand, subjected to statistical analysis aimed at determining the symmetry of the pressure force on the pedals and evaluating the possibility of using lower limb force measurements on the rudder pedals, showed a statistically significant asymmetry of the force exerted by the lower limbs on the rudder pedals for $p = 0.05$.

However, the effect size value $r = 0.39$ obtained in the Wilcoxon test indicates a moderate strength of the statistically demonstrated difference in the force exerted by the lower limbs on the rudder pedals.

Based on the calculated Pearson correlation coefficient $r = 0.991$, $p < 0.01$, a strong positive relationship was found between the reference force exerted on the stand rudder pedals by the left lower limb FrL and the right lower limb FrP. This result, without distinguishing a stronger lower limb, confirms the concurrency of the direction of the lower limb force exertion.

The distinction of a statistically stronger lower limb was made based on the values of the symmetry features: the Symmetry Index and the Symmetry Angle. Different values of these features, such as mean and standard deviation, calculated for the same reference force values exerted by the lower limbs on the rudder pedals, shown in Tab. 6, result from the different methods of calculating the Symmetry Index (formula no. 1) and the Symmetry Angle (formula no. 3). The Lilliefors normality tests conducted on the distributions of the Symmetry Index and Symmetry Angle values gave similar results. The variability coefficient (VS) values of both features are also very similar.

Histograms of the distribution of the calculated values of the Symmetry Index and the Symmetry Angle of the reference force exerted by the lower limbs on the rudder pedals at the stand, presented in Fig. 4, show a high degree of similarity.

The values of the Symmetry Index and Symmetry Angle of the reference force exerted by the lower limbs on the rudder pedals of the stand, presented in box plots (Fig. 5), similarly illustrate the magnitude of the asymmetry caused by higher force values exerted by the left lower limb compared to the right lower limb.

Taking into account the similarity of the symmetry assessment results of the lower limb force exertion on the rudder pedals of the diagnostic-training stand obtained using the Symmetry Index and Symmetry Angle, and the fact that in the literature the Symmetry Index [29] is most commonly used in symmetry research, the graphical analysis used the Symmetry Index values presented in Fig. 6. This chart confirms the similar distribution of index values for negative values, related to the left lower limb, and positive values, related to the right lower limb. No information was found in the literature concerning a developed scale for assessing the symmetry of lower limb force exertion on measurement platforms [13]. However, in some publications, arbitrary threshold values for symmetry indices adopted for analysis are applied [5].

Based on the obtained results, the Symmetry Index was adopted as the criterion for assessing the symmetry of the lower limb force exerted on the rudder pedals of the Anti-G maneuver training stand. At this stage of measurement result analysis, the principle was adopted that if the value of the Symmetry Index does not exceed 10%, it can be assumed that the force values exerted by the pilot on the rudder pedals with the left and right lower limbs will not significantly affect the assessment of the muscular component of the performed Anti-G maneuver at the SymuLBNP simulator.

CONCLUSIONS

1) Hypothesis, which assumes that "During the force test of the studied pilot population, there are no statistically significant differences in the force exerted by the lower limbs, right and left, on the rudder pedals of the diagnostic-training stand for Anti-G maneuver training," was rejected.
2) The objective of the study, which was to assess the symmetry of the force exerted by the lower limbs on the rudder pedals of the diagnostic-training stand for Anti-G maneuver training recorded during the scheduled pilot training in aviation medicine as a factor potentially significantly influencing the measurement results of the force exerted by the lower limbs on the rudder pedals of the SymuLBNP simulator was achieved.
3) At the preliminary stage of research using the SymuLBNP simulator, a comparative assessment of the physical effort of pilots can be conducted if the Symmetry Index of the force exerted by the lower limbs on the rudder pedals of the diagnostic-training stand for Anti-G maneuver training does not exceed the value of 10%.

Final remarks

During the course of this work, a measurable and acceptable criterion for assessing the symmetry of the force exerted by the lower limbs on the rudder pedals of the diagnostic-training stand for Anti-G maneuver training was proposed, based on the values of the Symmetry Index, taking into account that:

- a high correlation was found between the force exerted by the left and right lower limbs on the rudder pedals of the stand,
- the effect size value r obtained in the Wilcoxon test of significance of differences indicates a moderate effect size of the statistically demonstrated difference in force exerted by the lower limbs on the rudder pedals,
- the Symmetry Index values, distributed between the first and third quartiles, do not exceed 8%.

The adopted threshold value of 10% for the Symmetry Index as the assessment criterion will be verified during further studies on the SymuLBNP simulator and may be subject to change.

AUTHORS' DECLARATION

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