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Multicriteria Comparison and Evaluation of Vestibular Apparatus Training Methods for Pilots

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Abstract

The phenomenon of spatial disorientation and illusions in flight has been addressed in civil and military aviation for decades. The possibility of training, especially the vestibular apparatus, which is involved in human spatial orientation, is of particular interest in training military pilots. This article aims to analyze and compare, using multicriteria analysis, the different methods for training the resistance of the vestibular apparatus at the University of Defence. In total, five different facilities were compared against nine criteria. The scoring showed comparable results for three of them: Rotation Cage Passive, 360 Swing, and Gyroscope. This analysis has shown that none of the devices cover the entire criteria area. Therefore, further research is required to find suitable combinations of these three devices to achieve the best results. However, the results have already highlighted the importance of preparing pilots prior to flight training and the possibility of preadaptation to a dynamic environment, thus making flight training more efficient.

KEY WORDS: *vestibular apparatus, training, aviation, simulator, military, spatial disorientation*

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1. Introduction

Balance, regulation of position, body movements in space, the perception of gravity, and angular and linear acceleration are significant for every pilot because their processing with possible suppression of false sensations is one of the basic conditions for a successful flight. The vestibular apparatus is involved in the above. This critical apparatus generates sensory perceptions. If not corrected by vision, it may generate perceptions that may not correspond to the real position of the pilot-aircraft system. The reactions of the apparatus, mostly of an unconditionally reflexive nature, may also induce various unusual sensations, unwanted emotions, and illusions, which may be fatal for the pilot. This is because the human body is adapted only for movement on the ground, and its senses cannot properly evaluate the sensations during flight in an aircraft. For this reason, every aircraft is equipped with flight and navigation instruments that indicate its actual position in space, regardless of the dynamic forces acting on it. Their use helps pilots to overcome the imperfections of human perception [1-5].

As part of the preparation of a student of the University of Defence (UoD), specialization military pilot, physical training takes place during the first three semesters before the start of practical flight training. This physical training takes place in the scope of four lessons per week and focuses on:

- Basic physical training (development of physical abilities and movement skills);
- Special physical exercise to increase the body's resistance to the adverse physical factors of flight.

In particular, the specialized training prepares students for initial flight training, which places increased demands on spatial orientation [6]. The flight training takes place in an intensive form of 2 to 3 flights per day in a briefing-flight-debriefing format with progressively more demanding individual flights. This training aims to provide primary flight training and test future pilots' competencies.

For this reason, aerobatic flights are included in the flight training after 30 hours to test spatial orientation skills and organism endurance as prerequisites for the possibility of becoming a fighter pilot [7]. In the context of the current increasing expenditure on armaments and the acquisition of new modern equipment by the Air Force [8], a high emphasis is placed on the training of personnel.

In the international field of military aviation, spatial disorientation training is described in the North Atlantic Treaty Organization Technical Report [1], where the ground-based and in-flight demonstration is described. The standards across different nations are concentrated mainly on demonstrations of vestibular apparatus false reception and the causes and consequences [9]. The devices used for demonstration vary from small to large full-flight simulators. The Polish Air Forces uses specialized training on instruments called Special Aviation Gymnastic Instruments, which consist of looping, aerowheel, and Gyroscope. The influence and effect of that training are described in [10-12] and were concentrated mainly on increasing fitness level and Gz toleration.

This article aims to analyze and compare, using multicriteria analysis, the different methods for training the resistance of the vestibular apparatus at the UoD. Thanks to regular training, students of the military pilot specialization prepare for adverse effects, such as kinetosis caused by irritation of the vestibular apparatus, learning to recognize flight illusions and to react adequately to them. In the special physical training classes, students perform physical exercises with changes in body position, such as various agility exercises, basic gymnastics, and exercises on gymnastic equipment (trampoline, rings, trapeze, etc.). In order to strengthen the resistance of the vestibular apparatus of future pilots of the Czech Air Force to undesirable phenomena of motion sickness and vestibular illusions, the UoD has a training simulator 360Swing, Gyroscope by company Ad-Libitum, Poland, and rotation cage.

2. Method of investigation

At the beginning of the study, the analytical hierarchy process [13] was performed to identify the individual criteria according to which each training method is compared. In total, nine criteria for comparison were identified within the expert team:

- C1 Maximum acceleration values;
- C2 Similarity to flying in an airplane;
- C3 Simultaneous irritation of multiple semicircular canals;
- C4 Variability of training;
- C5 Involvement of cognitive functions;
- C6 Necessity of mastering the technique;
- C7 Current health status;
- C8 Possibility of leisure training;
- C9 Equipment maintenance needs;

C1 criterion examines the highest values of the resultant linear acceleration vectors and the highest values of angular accelerations achieved during measurements on devices using the GoPro HERO 9 camera. The box plot in Figure 1 shows the statistical evaluation of the acceleration pattern.

C2 evaluates the similarity of the magnitude of linear acceleration on the trainer to the aircraft's actual flight. Given the profile of airplane flight, which usually involves simultaneous irritation of multiple semicircular canals, this needs to be considered in the ground preparation in criterion C3.

Criterion C4 represents the possibility of exercise variation, therefore, in how many directions of the body axes (and around them) we can perform movement. During the flight in the aircraft, the pilot must frequently perform other activities besides piloting that require full concentration. In ground training, these activities may be simulated by exercises involving cognitive functions, and this option is assigned a criterion C5. Some forms of training require trainees to have previous experience or mastery of the technique of performing individual exercises (e.g., putting a cage into a rotary motion). The need for prior instruction is reflected in criterion C6. Due to injury and subsequent recovery, the trainee may not always be able to perform a complete workout.

Therefore, criterion C7 affects the ability to exercise even when the exerciser's physical performance is not optimal after injury or illness.

Criterion C8 considers the possibility of performing some exercises outside the special physical training classes or the possibility of exercising a larger group of exercisers simultaneously. For some devices, regular maintenance takes them out of service for a period of time and makes it impossible to train them, as illustrated by criterion C9.

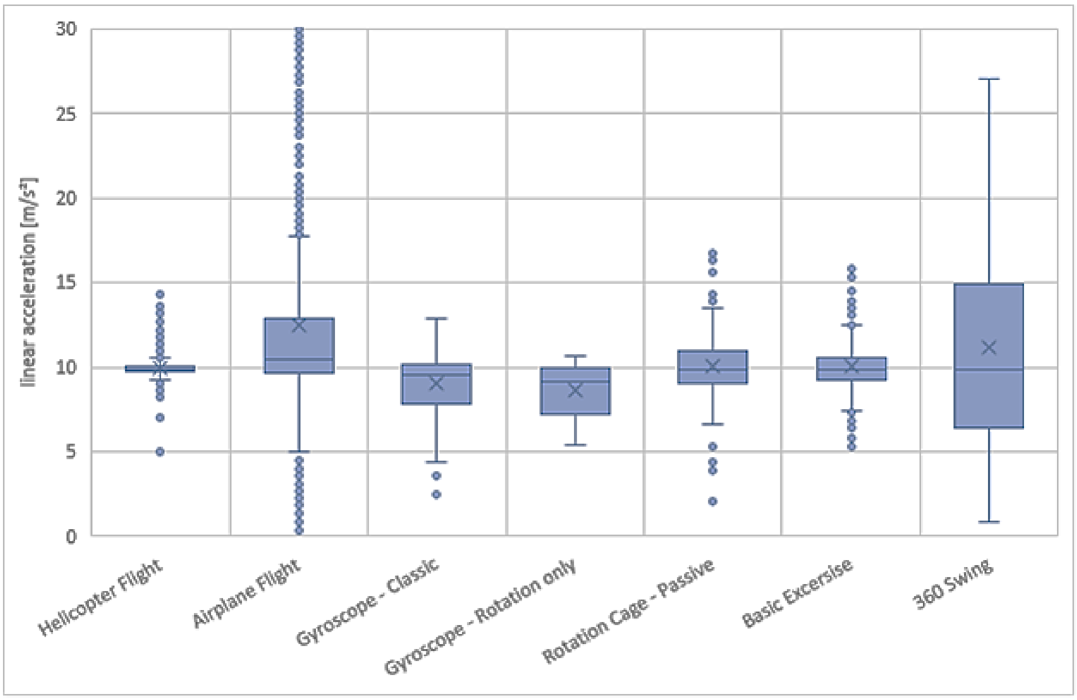

Fig. 1. Measuring of the acceleration vector.

Table 1.

Saaty matrix for criterions

	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9	G_i	v_i
C_1	1.00	3.00	4.00	5.00	5.00	6.00	7.00	8.00	9.00	4.59	0.31
C_2	0.33	1.00	2.00	5.00	6.00	7.00	7.00	8.00	9.00	3.46	0.24
C_3	0.25	0.50	1.00	5.00	4.00	6.00	7.00	8.00	8.00	2.66	0.18
C_4	0.20	0.20	0.20	1.00	2.00	4.00	4.00	7.00	8.00	1.34	0.09
C_5	0.20	0.17	0.25	0.50	1.00	3.00	5.00	5.00	7.00	1.09	0.07
C_6	0.17	0.14	0.17	0.25	0.33	1.00	2.00	4.00	2.00	0.56	0.04
C_7	0.14	0.14	0.14	0.25	0.20	0.50	1.00	2.00	2.00	0.40	0.03
C_8	0.13	0.13	0.13	0.14	0.20	0.25	0.50	1.00	3.00	0.30	0.02
C_9	0.11	0.11	0.13	0.13	0.14	0.50	0.50	0.33	1.00	0.24	0.02
									SUM	**14.65**	**1**

Weights were then determined for each criterion using the Saaty matrix [14]. The evaluation of the importance of each criterion was carried out by the authors' team and the resulting values, including the geometric mean Gi and the standardized weights vi, are shown in the Table 1.

3. Investigation Results

The result of the comparison is a table of the individual criteria, scored and compared according to the criteria weights. Devices and methods currently available in the UoD environment were included as alternatives:

- A1 Gyroscope;
- A2 Rotation Cage passive;
- A3 Rotation Cage active;
- A4 Basic Gymnastics;
- A5 360 Swing.

The individual scores of these variants without weighting are shown in the spider diagram in Figure 2. The rating of the variants according to the criteria is on a scale of 1 - 5, where a value of 5 is awarded to the best-rated variant according to the criterion, and a value of 1 is awarded to the lowest-rated variant. The training method with the highest numerical rating is considered the closest to the need for increasing resistance of the vestibular apparatus under UoD conditions.

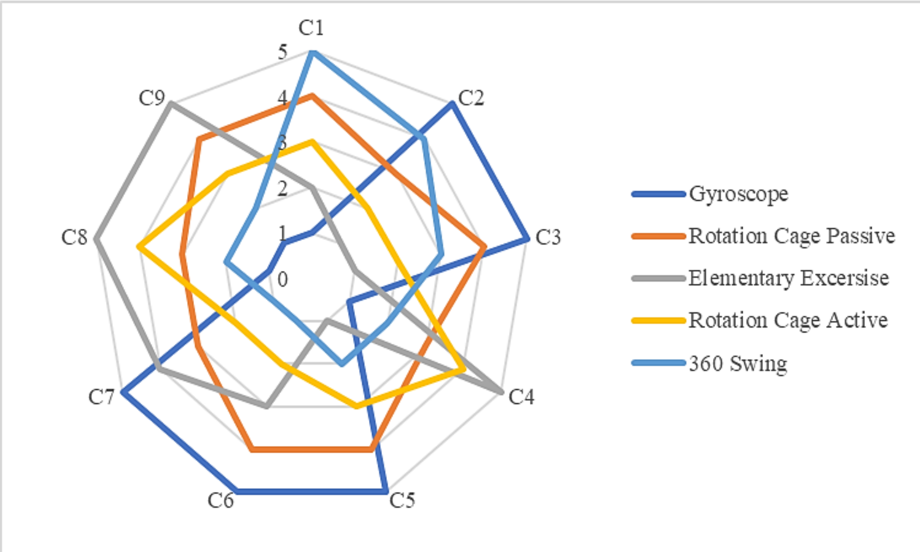

Fig. 2. The spider diagram.

The final calculation and achievement A of the resulting values using equation (1):

$$A_i = \sum v_i \cdot C_i \tag{1}$$

The results where were taking into account both the scores and the weighting of the criterion, is shown in Table 2.

Table 2.

The scores and the weighting of the criterion

Training device	Result
Gyroscope	3.23
Rotation Cage Passive	3.62
Elementary Excersise	1.99
Rotation Cage Active	2.63
360 Swing	3.53

Criteria directly related to vestibular stimulation (maximum acceleration values, similarity to flight environment and multiple semicircular irritation) had the highest weight (more than 0.15). This is due to the targeted focus on pilot training. On the other hand, the criteria allowing leisure training or training during recovery had the least weight. These criteria should be mentioned however they do not have a major impact for comparison. The final evaluation shows that the Rotation Cage Passive exercise scored highest. Maximum acceleration values for the passive exercise on the fixed double circle were the second highest, and the similarity to airplane flight is average. This exercise is also very suitable for the present irritation of semicircular canals. The practitioner alone performs almost no movement, can turn his head in various ways, and thus simultaneously move the endolymph in several ducts. However, stiffening the body during the exercise is essential to avoid injury. The variation in training is rated average because the double-circuit design partially restricts the trainee's movement, and the trainer only allows movement in two directions. However, both the 360 Swing and Gyroscope exercises achieved similar results. During the gyroscope exercise, the acceleration values reached are the smallest compared to other training methods. However, the actual course of these accelerations (especially the resultant linear acceleration vectors) is the most similar to the course of acceleration during an airplane flight. In addition, more semicircular canals are stimulated during the training because the motion of the Gyroscope is relatively random.

During the 360 Swing, the highest acceleration values were measured, and the profile of these accelerations was very similar to the acceleration profile during flight in an airplane. Simultaneous stimulation of multiple semicircular canals is limited due to the active nature of the exercise. However, the practitioner can tilt the head unrestrictedly once the technique is mastered. The training variability is limited because the cage design only allows forward, backward, and sideways rotation.

The involvement of cognitive functions is only passable, as the trainee is primarily focused on spinning the turntable in the initial phase, and it is not possible to observe the taskmaster during the transition over the top. The turntable exercise places the highest demands on prior experience of all the other methods, as the acquisition of the turning technique on this trainer is demanding, and many trainees manage to turn the turntable for the first time only after several hours of special physical training.

4. Conclusions

Despite the above evaluation, none of the alternatives overwhelmingly outweighed the others in absolute numbers and individual criteria. This fact is illustrated in the spider diagram, see Fig. 2, which shows the distribution of the scores in each criterion, not including the weights that would distort the resulting area.

Another potential limitation is the subjective processing of most of the criteria, apart from acceleration measurements and comparison with flight dynamics, so it would be beneficial to introduce other objective criteria in the future, such as heart rate variability measurements. In conclusion, the best training results can be achieved by appropriately combining all the above methods. Finding a suitable combination of methods is also a direction for future research. To have a practical impact, it would be necessary to firmly embed the new training program into the pre-pilot training period. This opportunity presents itself in the form of incorporation into physical training classes in the October-March period, as flight training is usually initiated with the start of the summer season and more favorable weather conditions.

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