S H O R T C O M M U N I C A T I O N

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Distance visual acuity in air force pilots and student pilots when exposed to + Gz acceleration in human centrifuge

Oštrina vida na daljinu kod pilota borbene avijacije i studenata pilota izloženih + Gz ubrzanju u humanoj centrifugi

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Abstract

Background/Aim. High speeds that modern aircraft develop during take-off, flight and landing place an additional strain on the organ of vision. Owing to its considerable practical implementation in air combat, the effect of +Gz acceleration on the organ of vision is considered increasingly important for research. Substantial changes in visual functions may occur during high acceleration onset rates. However, it is important for a pilot to maintain visual acuity in order to be able to monitor new functional displays for rapid orientation, scan the configuration of terrain, display of weapons systems and enemy aircraft and deal with additional issues of the complexity of spatial orientation. The aim of the investigation was to establish whether distance visual acuity in air force pilots and student pilots is affected when exposed to +Gz acceleration. **Methods**. The study was performed on a defined population consisting of 95 respondents from 21 to 45 years of age divided into two groups. The first group included 65 air force pilots and the second group comprised of 30 student pilots, all of whom were exposed to an acceleration of +5.5 Gz. The testing was performed in a human centrifuge, which mimics conditions of real Gz acceleration, in the Department of Biodynamics in Aero Medical Institute (Zemun, Serbia). We examined the obtained differences in distance visual acuity before and after exposure to acceleration. **Results**. After the testing, all respondents in the group of air force pilots had distance visual acuity of 1.0, while in the group of student pilots a statistically significant difference in distance visual acuity was observed after being exposed to +Gz acceleration. **Conclusion**. Transient changes in distant visual acuity were more pronounced in the group of student pilots in comparison with the changes in visual acuity in the air force pilots when exposed to the same acceleration values (+5Gz acceleration). Since change in distance visual acuity is the most sensitive physiological indicator when exposed to high acceleration, individual physiological pilot training in the human centrifuge increases tolerance to accelerations, which is important for flight safety in both peacetime and combat conditions.

Key words:
acceleration; aerospace medicine; pilots; students; visual acuity.

Apstrakt

Uvod/Cilj. Velike brzine prilikom poletanja, tokom letenja i prilikom sletanja modernih letilica predstavljaju dodatni napor za organ vida. Zbog njihove velike praktične primene u vazdušnoj borbi, uticaj +Gz ubrzanja na organ vida je veoma važan za istraživanje. Kod visokog početnog stepena ubrzanja mogu se javiti značajne promene u vidnim funkcijama. Pri tome je važno održati oštrinu vida kako bi mogli da se prate novi funkcionalni displeji za brzu orijentaciju pilota, konfiguracija reljefa terena, prikaz oružanih sistema i protivničkih aviona i uspešno savladaju svi dodatni zahtevi orijentacije u prostoru. Cilj rada je bio da se utvrdi da li postoji uticaj na oštrinu vida na daljinu kod pilota borbene avijacije i studenata pilota usled izlaganja +Gz ubrzanju. **Metode**. Ispitivanje je sprovedeno na definisanoj populaciji, 95 ispitanika starosti od 21 do 45 godina podeljenih u dve grupe. Prvu grupu činilo je 65 pilota borbene avijacije, a drugu 30 studenta pilota. Svi ispitanici su bili izlagani ubrzanju od +5,5 Gz. Ispitivanje je vršeno u Odeljenju za biodinamiku Vazduhoplovno medicinskog instituta (Zemun, Srbija), na humanoj centrifugi u kojoj postoje uslovi realnog Gz ubrzanja. Posmatrali smo dobijene razlike u oštrini vida na daljinu pre i nakon izlaganja ubrzanju. **Rezultati**. U grupi pilota borbene avijacije, svi ispitanici su posle testa imali oštrinu vida na daljinu 1.0, a u grupi studenata uočena je statistički značajna razlika u

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oštrini vida na daljinu nakon izlaganja +Gz ubrzanju. **Zaključak**. Prolazne promene oštrine vida na daljinu, veće su kod studenata pilota nego kod pilota borbene avijacije kada su izloženi ubrzanju istih vrednosti (+5Gz ubrzanju). Budući da je promena oštrine vida na daljinu najosetljiviji fiziološki pokazatelj u uslovima izlaganja visokom ubrzanju, individualna fiziološka trenaža pilota u humanoj centrifugi poboljšava toleranciju na ubrzanja što je važno za bezbednost letenja u mirnodopskim uslovima kao i u borbenim manevrima.

Ključne reči:
ubrzanje; medicina, vazduhoplovna; piloti; studenti; vid, oštrina.

Introduction

Visual acuity (VA) is the ability of the eye to distinguish separate objects of observation in the outside world and is defined as the ability of the eye to see two separate points at the smallest angle. VA is better if the observed angles are closer and if the visual angle of each eye is smaller. It is dependent on the dioptric apparatus of the eye, transparency of the media, health of the retina, especially the central part of the yellow spot, the visual pathway and the central nervous system. VA of 1.0 is characteristic only of the centre of the foveola [1].

The ability to differentiate between two separate points is characteristic of the whole field of vision but it decreases significantly as the distance from the foveola increases. If a picture is formed outside the foveola, VA decreases sharply, so in the horizontal meridian it is 0.1 already at 20 degrees. VA is tested by an optotype. Most optotypes are designed in the way that the symbol to be recognised is formed of segments, the visual angle of which is 1’, and that the whole figure comprises five segments. All optotypes are based on the fact that normal central VA understands the size of the picture on the retina of 0.004 mm and the visual angle of 1’, and that the histological structure of the macula, especially its central part – the foveola, enables quick noticing of the object of observation. The mean diameter of the plug in the macular area is 0.004 mm, which is also the distance between two plugs separated by a third. This angle is at the same time the smallest angle separating the two observed points, it is invariable and is 1’ of the visual angle [1].

Optotypes must be standardised so that obtained results can be compared. The contrast between the black optotype symbols on the bright surface should be 80–90%, and the brightness of the background 85 cd/m^2. The optotype symbols must be at a minimum distance of 3 cm. The Landolt Optotype is considered physiologically as the most accurate. It is a circle drawn within a 5’ square, the thickness of its circular line being 1’. There is a 1’-long gap at one point on the circular line, forming a 1’ x 1’ opening in the shape of a square that faces different sides. The ratio between the size of the test and the size of the inner circle, thickness of the circular line and dimensions of the gap is 5 : 3 : 1. Constructed in this way, it is black on a white base. The Landolt ring is the only device that can test the real minimum separabile. In European countries, VA is most often expressed in linear decimal values from 0.05 to 1.0. VA testing results must be written clearly, comprehensively and always in the same manner, and contain the following elements: vision – right eye (VOD) or vision – left eye (VOS) score for the examined eye and VA without sight correction (sc), expressed in decimals (0.50) or fractions (30/60).

In aviation physiology, spatial disorientation can be overcome most efficiently by means of physiological training [2]. Massive human and material losses compelled aviation physiology scientists in the 1920s to focus on investigating physiological mechanisms that may be a cause of crash and try and find solutions or at least mitigate the problem. Training is based on theoretical knowledge of the physiological effects of speed and acceleration, as well as of factors that increase or reduce the body’s tolerance to the effect of dynamic flight factors [3]. Training is carried out in the human centrifuge, the aim being to enable the pilot to improve his tolerance to acceleration in the conditions of real G load, as well as learning about his body’s potential response to excessive G stress [4]. Practically, the device is a combined gravity-altitude laboratory which simulates various flight conditions (+Gz load) and conditions of high-altitude flying (lower atmospheric pressure) with gradual or sudden change in cabin altitude (explosive compression). The structure of the device allows the maximum possible acceleration of up to +30Gz, but where people are involved, the given acceleration goes up to +9Gz, and with technical material up to +25Gz.

Air force pilots flying supersonic planes of the third, fourth and fifth generations, may be exposed to high values of +Gz load even while performing regular flight tasks. The most sensitive part of the organism to positive acceleration is the cardiovascular system. Blood as liquid tissue moves and retracts into lower body parts and, as a result, symptoms and outages of different organ systems occur, such as visual effects or loss of consciousness [5].

In flight, accelerations occuring due to changes in flight direction of high-speed planes exceed the normal gravitational force and cause various changes in the functioning of the whole organism, particularly the visual function. Exposure to +Gz acceleration brings about worsening of vision before any disorder of consiousness takes place [6]. Exposure to an acceleration of +4.5 Gz usually leads to a complete loss of vision – the “black curtain”. At lower rates of acceleration, it causes loss of peripheral vision while central vision is maintained – the “grey curtain”. Rates of acceleration causing loss of peripheral vision differ largely from person to person, and depend on the brightness of both the visual field and the object of observation, as well as on the degree of fatigue. Visual disorders occurring due to positive acceleration are caused by retinal ischemia [7]. The eye receives blood by means of the central retinal artery (*arteria centralis retinae*). Intraocular pressure is normally 22 mmHg and for blood to circulate in the retina the pressure in the retinal artery must be above 20 mmHg, so that blood flow can be maintained. When exposed to positive acceleration, the pressure inside the eye is reduced by about 22 mmHg *per* 1 G, and an increase in acceleration leads to an interruption in the supply of oxygen to the retina, causing visual disorders known as the "grey and black curtains". The "grey curtain" is a result of progressive reduction in blood flow in the blood vessels of the retina, while the "black curtain" is caused by complete stalling of blood flow in the blood vessels of the retina. The "grey curtain" is the first sign of non-compensated G stress and is a common symptom known to any air force pilot. One study claims that 98% of pilots in the Royal Air Force of Australia have experienced this phenomenon [8]. With an increase in acceleration up to +4Gz and +5Gz, the pressure in the *arteria centralis retinae* decreases below the level of intraocular pressure, which causes a complete loss of vision, and the "black curtain" occurs when arterial pressure in the eye drops below 22 mmHg. The pilot's consciousness is still unimpaired and he is capable of maneuvering the plane, using radio connection and communicating with flight control. There is an interval of 4–6 s from the interruption of retinal blood flow until a complete loss of vision occurs, which is conditioned by an oxygen reserve in the retinal artery. Recovery of vision occurs as soon as the oxygen reserves are replenished and the pressure in the retinal artery rises above 20 mmHg. The "black curtain" has been observed in 29% of pilot respondents in the Royal Air Force of Australia [8]. A study involving Brasilian Air Force states that 20% of their pilots have experienced a complete loss of vision [9]. Examining the eye bottom by ophthalmoscope, one notices that the arteries and arterioles are pale, completely empty. The interval between a sudden drop in pressure and loss of vision is 4–6 s thanks to a small reserve of oxygen that is diluted in the extravascular retinal fluid. Vision is only restored when this oxygen reserve in the retina is replenished and when the pressure of the oxygen diluted in the extravascular fluid rises above the minimum necessary for normal functioning of vision. Exposure to acceleration also causes reduced eye movement, which in some research papers is taken as a highly reliable indicator of partial or complete loss of vision [10]. The "grey" and "black curtain" are deemed a subjective experience by individual pilots.

Methods

The research included 95 pilots from 21 to 45 years of age. All of the respondents were highly selective, had no history of ocular diseases or system disorders, they were provided information about the scientific research and each of them filled in and signed a consent form to participate in the research. Depending on the years of flying experience and flight hours, the pilots were classified into two groups: a group of air force pilots, comprising of 65 pilots, and a group of 30 student pilots. Both groups were exposed to an acceleration of +5.5 Gz.

We observed the prevalence of exposure to positive acceleration, examining the effect of acceleration on distance VA in these two groups of respondents. The investigation was conducted in a gravity-altitude laboratory (human centrifuge).

We examined the obtained differences in distance VA at a particular rate of acceleration between the two group of respondents, thus obtaining our own significant indicator of the condition of visual functions at the beginning of professional career and after years of flying. Before testing in the centrifuge, the respondents were checked by methods that are part of the standard medical-psychological expertise procedure, and underwent control check-ups to establish whether there were any pathological conditions that could affect the pilots' tolerance to acceleration (increased body temperature, upper respiratory track infections, or a subjective feeling of the pilot himself). Two hours before the testing, the respondents were asked to have a light meal. One should always consider the adrenalin reaction instigated by apprehension in the face of possible failure of testing, by being subjected to testing, as well as accompanying disturbances of the vegitative function. Safety of respondents and their comfort in the cockpit must never be compromised.

The respondents were exposed to prolonged acceleration in the centrifuge, from 9.00 to 11.00 in the morning. A linear increase in acceleration test was used with both groups of respondents, meaning that acceleration was increased up to +5.5Gz without anti–G protection, the acceleration gain being 0.1 G/s. The first step in testing was exposing the respondents to an acceleration of +2Gz increasing to +5.5Gz, and then reducing it back to +2Gz. While being exposed to increases in acceleration from +2Gz to +5. Gz, the respondents were required to respond to the light signals in the cockpit by pressing the stick switch. If the respondent did not press the switch, the acceleration decreased. After a one-minute intermission, the respondent would leave the centrifuge cabin.

The pilots' distance VA was tested upon entering and exiting the cabin. It was carried out by a subjective method using the Landolt optotype. The testing was carried out monocularly, the right eye first, and then the left, at the distance of 6 m from the optotype (direct method of testing VA). The investigated pilots were tasked with naming the position of the ring opening (Latin letter "C"), starting with the biggest to the smallest. The size of the opening and the test as a whole are designed in such a way that if the pilot has normal VA, he should be able to see clearly all the symbols from a certain distance, meaning, see the biggest symbols from the distance of 60 m, to the smallest ones that he would be able to notice from the distance of 6 m. VA was expressed in decimal numbers. If VA is normal, a pilot can see the tenth line on the optotype and that is expressed as 1.0.

Results

Before the test, all the respondents, both in the student pilot group and the group of air force pilots, had distance VA of 1.0. After the test of linear increase in acceleration, a statistically significant difference in VA ($p = 0.000$) was noticed in both groups. In the group of air force pilots all of the respondents also had distance VA of 1.0 after the test. In the student pilot group, after the test, in 66.7% of cases

Table 1

Visual parameters in student pilots and air force pilots

Distance visual acuity		Student pilots n (%)	Air Force pilots n (%)	*p*
Before the test	1.0	30 (100)	65 (100)	/
After the test	0.8	3 (10.0)	0 (0)	
	0.9	7 (23.3)	0 (0)	0.000*
	1.0	20 (66.7)	65 (100)	
p		0.002†	/	

*** – statistically significant difference between student pilots and air force pilots;**
† – statistically significant difference before vs. after the test within observed groups of respondents (χ^2-test).

distance VA was 1.0, in 23.3% it was 0.9 and in the remaining 10% it was 0.8. By analysing the frequency of respondents with a difference in distance VA before and after the test, a statistically significant difference ($p = 0.002$) was noticed in the student pilot group (Table 1).

Discussion

Aviation medicine includes a wide range of tasks, the end goal of which is continuous creation of measures and procedures which would best equip the pilot for flight and performance of duties he has been entrusted with, at the same time reducing risks to life, health and material resources to a minimum. In aviation medicine, the journey from theory to practice is somewhat longer since any research calls for complex technical innovations and high level of security for their verification [11]. The pilot profession is a job involving optimum mental and physical fitness, full personal integrity and excellent health. It is one of few professions in which work capacity is under permanent scrutiny. Pilots are a highly selective population that undergoes regular controls throughout their flight experience, as any functional deficiency might compromise the safety of flight [12]. In the field of physiology of acceleration, notable variations in tolerance to G acceleration have been noticed. Most pilots start their flight experience with a grey curtain at +3Gz to +3.5Gz and near loss of consciousness at +4.5Gz to +5.0Gz, while there are those who lose consciousness immediately upon acceleration exceeding +3.0Gz, as well as those who tolerate +7.0Gz and +7.5Gz accelerations [13]. Apart from medical significance, high sensitivity to G acceleration also has a high operational significance in military aviation because, when a pilot takes command of the plane, there is a potential risk to his life, the lives of the crew and the plane. In comparison with other systems of the human body, the circulatory system is the one most significantly affected by positive G acceleration. Progression of symptoms, from a minimal reduction in vision to a black curtain, to loss of consciousness, is to be expected due to the reduction of blood flow in the upper body parts. If acceleration is high enough to cause a black curtain or other visual symptoms, it will manifest itself a few seconds after arterial pressure has reached its lowest value [11]. As the system pressure rises, vision may be restored, but full recovery is delayed for a few seconds until circulation has been restored thanks to the oxygen reserve in the retina in the period of anemia. In the works by Feigl et al. [13] and Tsai et al. [14], it is shown that after being exposed to +Gz acceleration, the depth of the eye chamber increases and energy reserves in the retina and the central nervous system enable the brain and the visual apparatus to keep on functioning for a few seconds longer after blood flow to the brain has been cut off. This enables tolerance to sudden high increases in G acceleration over a short period of time, usually for about 5 seconds [15]. With high acceleration onset rate, significant changes in visual functions may occur. However, maintaining distance visual acuity is of considerable importance for a pilot to be able to orientate himself in space rapidly, visually scan the configuration of the terrain, display of weapons systems and enemy aircarft and deal with additional issues of the complexity of spatial orientation [3]. Tolerance to +Gz accelerations, and the ensuing changes in visual acuity, may be compromised if pilots do not experience high +Gz accelerations over a longer period of time [16]. This is why there is a question of how much air combat training a pilot needs in order to maintain good tolerance. It is a known fact that a pilot who flies in air combat conditions at least once a week tolerates +Gz acceleration better than pilots who do this once in two weeks or once a month [17, 18]. When exposed to an acceleration of +5,5Gz, the air force pilots showed greater tolerance to acceleration compared to the student pilots, as there were statistically significant distance visual acuity differences. We have not found any similar data in available literature.

Conclusion

There was a considerable degree of transient loss of distance visual acuity in the student pilots in comparison with the air force pilots upon exposure to high +Gz acceleration. In the student pilots, a transient reduction in distance visual acuity occurred upon exposure to a +5Gz acceleration, whereas visual acuity of the air force pilots remained unchanged before and after exposure to the acceleration of the same value. One of the most sensitive physiological indicators when exposed to high acceleration is a change in distance visual acuity. Individual pilot training in the human centrifuge mimicking real G acceleration conditions improves tolerance to acceleration and brings about only minor changes in visual acuity upon exposure to acceleration. In this way, pilots become familiar with their body's response to increased G accelerations, which is important for flight safety both in peacetime and combat conditions.

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