SHORT COMMUNICATION

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The effect of acceleration on color vision

Uticaj ubrzanja na kolorni vid

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Abstract

Background/Aim. Over 80% of all information a pilot receives during the flight is visual with color perception being one of the most important visual functions for managing an aircraft. The reception of color is of high significance in aviation due to the importance of signal tracking on instrument panels as well as the importance of visual stimulus and environment signs. There is no sufficient number of papers and studies that deal with this issue, although recent studies have shown that the connection between acceleration and color perception exists. The aim of this study was to demonstrate the correlation between pilot exposure to +Gz acceleration in human centrifuge and color perception before and after acceleration exposure. **Methods**. Subjects of the study were 40 military pilots, aged 35–45, with 10 and 20 years of flying experience. Pilots were exposed to +Gz acceleration (inertial force acts from head to feet) in the human centrifuge for pilot training with accelerations of +2Gz, +5.5Gz up to +7Gz. The tests focused on color perception before and after the exposure to the acceleration. **Results**. Out of 40 pilots examined for color vision, in 35 (87.50%) had normal results in color identification before and after +Gz; 5.00% (2 subjects) had two mistakes – reading number 5 instead of number 3, which falls within the normal trichomes, and reading number 16 instead of number 26. Three subjects (7.50%) gave their answers slower than the accepted response time. After the +7Gz exposure, 34 (85%) persons had normal results in color identification, 2 (5%) subjects made three mistakes – at numbers 5, 74 and 26; one (2.50%) pilot made four mistakes on numbers 5, 7, 74 and 26; 7.50% (3 pilots) of the subjects identified colors slower. **Conclusion.** Color perception in pilots is unstable on high +Gz accelerations. Exposure to +5.5Gz acceleration does not lead to significant changes in color perception, while exposure to +7Gz acceleration showed a significant percentage of reversible disturbance in color perception which lasted for 10 minutes.

Key words:
pilots; aerospace medicine; space simulation; acceleration; color vision.

Apstrakt

Uvod/Cilj. Preko 80% svih informacija u toku letenja kod pilota je vizuelno, a raspoznavanje boja je jedna od vidnih funkcija koja je veoma značajna za upravljanje avionom. U avijaciji je raspoznavanje boja značajno zbog praćenja signala na instrument tablama kao i obojenih vizuelnih stimulusa i znakova okoline. Za sada ne postoji dovoljan broj radova i istraživanja koja se bave ovim pitanjem, premda novije studije pokazuju da veza između ubrzanja i raspoznavanja boja postoji. Cilj našeg istraživanja bio je da se utvrdi da li postoji veza između izlaganja pilota +Gz ubrzanju (sila inercije deluje od glave do stopala) u humanoj centrifugi i promena u raspoznavanju boja pre i nakon izlaganja ubrzanju. **Metode.** Analizirano je 40 pilota vojnog vazduhoplovstva starosti od 35–45 godina, sa letačkim stažom između 10 i 20 godina. Piloti su izlagani +Gz ubrzanju i to +2Gz, +5.5Gz do +7Gz u humanoj centrifugi koja služi za trenažu pilota. Ispitivano je raspoznavanje boja pre i posle izlaganja ubrzanju. **Rezultati**. Od 40 pilota kod kojih je ispitivan kolorni vid, kod 35 (87,50%) pilota raspoznavanje boja pre i posle izlaganja +Gz ubrzanju bilo je normalno, dva (5,00%) pilota su imala dve greške, jedan je broj 5 čitao kao broj 3, što spada u normalne trihomate, a drugi je broj 16 čitao kao 26, a tri (7,50%) pilota su samo sporije davala odgovore. Nakon izlaganja +7Gz ubrzanju 34 (85,00%) pilota normalno je raspoznavalo boje, dva (5,00%) pilota je napravilo tri greške na brojevima 5, 74 i 26 i jedan (2,50%) pilot je imao četiri greške na brojevima 5, 7, 74 i 26, dok su tri (7,50%) pilota samo sporije raspoznavala boje. **Zaključak.** Raspoznavanje boja nije stabilno na visokim + Gz ubrzanjima. Izlaganje +5.5Gz ubrzanju ne dovodi do značajnih promena u raspoznavanju boja, dok je izlaganje +7Gz ubrzanju pokazalo značajan procenat u poremećaju raspoznavanja boja, koji je bio reverzibilan, jer je nakon 10 min raspoznavanje boja bilo u celosti normalno.

Ključne reči:
piloti; medicina, vazduhoplovna; pilotiranje, simulisano; ubrzanje; vid, kolorni.

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Introduction

Over 80% of all information a pilot receives during a flight is of visual character and color recognition is one of the most important functions for managing an aircraft. Color vision or color recognition is the ability to react to different spectral light regardless of its intensity.

Color recognition in aviation is of extreme importance due to monitoring the signals on the dashboard as well as monitoring the plane's surroundings while in flight. Normal color recognition is explained in trichromatic theory based on the fact that all visible colors can be formed by combination of 3 basic colors – red, green and blue. The development of modern aviation forces pilots into situation where they are exposed to loads that are nine, ten, twelve and more times greater than the gravity force on Earth [1–10]. Testing the color vision is one of the obligatory visual functions tested when selecting candidates for aviation services and is regularly controlled in every medical examination. Long lasting acceleration mostly occurs in air maneuvers of fighting airplanes. Such acceleration leads to effects on internal organs and tissues (effects such as torsion and retrievals), mostly in changes of liquid tissues, causing significant redistribution in the body. Physiologically, blood redistribution and increased blood pressure leading the blood from head to toes are the most important effects that +Gz acceleration has on human body, which lead to the poor perfusion in CNS and eye as its most sensitive part causing disturbances such as grey veil, tunnel sight, black veil. Poor perfusion causes hypoxia that negatively affects the cells of the eye [11].

Bad color perception can be caused by atmospheric conditions such as bright sun with blinding light phenomena, night, cloudy weather and especially misty weather. The fog makes the position signal difficult to see and the colors get reddish hue. From the avio-physiological point of view, forces of inertia are important due to their effect on the human body, and to which organism are exposed during acceleration.

Newer and modern aircrafts use colored displays, some of which are mounted onto the pilot's helmet, making color vision and correct interpretation of data even more important for safety and flight efficiency, especially in military air force and during combat. +Gz acceleration leads to decreased blood float in the brain, therefore causing a reduction of blood in the blood vessels of retina, leading to temporary changes in visual functions such as loss of central and peripheral vision, thus increasing the probability of losing the function of color recognition. We still do not have the possibility to follow the blood flow through the retina during +Gz exposure as well as its influence on color recognition.

This research is based on a survey of pilots in conditions of exposure to +Gz acceleration in human centrifuge used for pilot training for the high performance flying and strong G load aircrafts. The centrifuge is a combination of gravity and altitude laboratory, reaching accelerations up to 20Gz and simulating heights up to 30,000 meters. Training in the centrifuge aims to increase individual's abilities to ignore +Gz acceleration.

The research was done with simple exposure to only +2Gz acceleration and composite intermittent exposure to acceleration from +2Gz to +5Gz on the first day and +7Gz on the second day.

Aim of this research was determining if there was a connection between pilot exposure to +Gz acceleration in human centrifuge and the changes in color identification, measured before and after the exposure. This question was not a subject of a greater number of articles and studies, although newer studies [1] show that the connection between acceleration and color perception exists.

Methods

Subjects for this research were 40 military pilots age 35–45 with flying experience from 10 to 20 years. All the participants gave written consent for inclusion in the research. The pilots were exposed to +Gz accelerations of +2Gz, +5.5Gz and higher, up to acceleration of +7Gz in human centrifuge of the Institute of Aviation Medicine in Belgrade.

Color perception was examined before and after the +Gz exposure. Participants were exposed to the effects of long-term acceleration in the centrifuge and to coriolis effect in the time between 9 am and 11 am, two hours after meal. Model used was the experimental model EM-1, programmed to achieve constant radial acceleration of +2Gz, counterclockwise, and to perform head motion (active coriolis) after 30 seconds. Every head motion was made in one second, and the position was kept for 30 seconds after the change. The movements of the head were downwards (chin touching sternum), neutral head position, head on right shoulder forming 45 degrees angle and movement back to neutral position. After that movement, the device is slowed down to +1Gz, signal lamps for controlling the peripheral vision turn on and the acceleration starts in moderate grade of 0.1 G/sec up to the acceleration of +5.5Gz.

Pilot-subject was given a task to respond to light signals from the console within 0.9 seconds as an indicator of preserved peripheral vision. Console lights lighted up alternately on the dashboard. Afterwards, a warning of the same grade followed up to plateau of +2Gz, where immediately after reaching the acceleration of +2Gz, the before mentioned head movements were made.

On the second day of testing, the pilots were exposed to +5.5Gz acceleration and the effects of +7Gz acceleration while wearing Anti G suit. Pseudochromatic table Ishihara with 39 pages was used for testing color vision. Research was done in accordance with the instructions given for the test and carried out in the laboratory for altitude research.

All pilots tested for this research passed tests of color vision during their selective examination, by method of denomination and equalization. There are several tests for color vision research. Some tests are designed primarily for congenital i.e. inborn and some for acquired color perception deficits.

Tests were chosen based on its possibilities and procedures. Person performing the testing should be patient and have perfect knowledge of the method used, as well as normal color vision. These tests were based on decimation

method. The based principle was usage of small circles different in size, light and tonality. Circles were placed in specific positions to form various signs such as numbers and lines, easily noticed by normal trichomes. Ishihara test is placed 60 to 75 cm from eyes of the participant, and each page in the book is presented in 3 to 5 seconds with artificial light in a noise isolated room. Every subject had to read over 18 numbers to be considered as a person with normal color vision. Reading less than 9 pages would mean that there is a deficit in color perception.

Pilots have read Ishihara tables just before entering the centrifuge, immediately after exposure to +Gz acceleration and 10 minutes after leaving the centrifuge.

Results

Color identification tests showed that, out of 40 pilots tested for color vision, 35 (87.50%) pilots had normal color identification before and after +Gz exposure. Two (5.00%) pilots made 2 mistakes each, where one pilot read number 3 instead of 4 – which falls within normal trichomates, and the other pilot read 26 instead of 16. Three (7.50%) pilots gave slow answers after being exposed to +5,5Gz acceleration. On the second day, when the pilots were exposed to +7Gz acceleration, 34 (85%) out of 40 tested pilots had no changes in color recognition, two (5.00%) subjects made three mistakes reading numbers 5, 74 and 26. One (2.50%) subject made four mistakes while reading numbers 5, 7, 74 and 26. Three (7.50%) pilots gave slow answers.

Exposure to the +5.5Gz acceleration during the first day of testing did not show significant changes in color recognition before and after the exposure to +Gz acceleration. Exposing the subject to +7Gz acceleration caused a greater percent of mistakes and worse color recognition. Totally 85% of the tested pilots had normal color recognition. Even though the tested pilots were experienced and had good previous training, the results show that greater accelerations contribute to defects in color vision. The defects were reversible – ten minutes after the tests were done, color recognition in pilots was back to normal and no mistake was made when reading numbers on the Ishihara tables (Table 1).

Table 1

Number (%) of pilots making errors in color perception

Acceleration	Errors made, n (%)					
	0	1	2	3	4	slow reading
Before exposure to the acceleration +Gz	40 (100)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Immediately after exposure +5.5 Gz	35 (87.50)	2 (5)	0 (0)	0 (0)	0 (0)	3 (7.50)
Immediately after exposure +7 Gz	34 (85)	0 (0)	0 (0)	2 (5)	1 (2.5)	3 (7.50)
10 minutes after exposure to + Gz	40	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)

Discussion

In our study, when exposed to +5.5Gz acceleration, color vision was normal in 87.50% of cases; 12.50% of cases showed a change either in slower reading of Ishihara tables or in reading the numbers wrong. After the exposure to +7Gz acceleration, 85% of subject showed normal color vision; 7.50% of tested pilots read the numbers slower, and 7.50 of them showed a defect in color perception. Recent studies [2–4] showed that the acceleration has effects on color perception, which mostly occurs at high +G acceleration, particularly on +9Gz, where wrong answers were given in 7.7% of the cases. Retinal blood flow decreases during accelerations that high, but thanks to the good training, it returns to normal level. This ability is very important for military maneuvers where everything happens fast and under additional stress.

Expectations for the results of this research were that the effects of acceleration are mostly noticeable on +7Gz acceleration, due to cessation of blood flow through retinal blood vessels. Further researches are made to test the effects of blood flow and changes in the blood stream of retina on color vision [12].

Differences in the results of this and other researches can be explained as the consequence of using different methodologies. This research tested color vision using a method of discrimination with pseudoisochromatic Ishihara tables and the pilots were exposed to acceleration in human centrifuge which is used at the Institute of Aviation Medicine.

Persons with color perception deficiency either do not perceive the numbers or see completely different numbers which is typical for the anomaly. These different perceptions occur due to apparent pseudoisochromasia (false color equality). Ishihara tables are constructed in such a way to easily detect red and green color defects, and major disadvantage of this test is that it is not quantitative and cannot separate anomals from anops with certainty, cannot distinguish protanops (lack of noticing red colors) from deuteranops (lack of noticing green colors) and cannot separate people with defect in blue (trinatops) and yellow color from people with normal color recognition. All of the participants were tested with color recognition and denomination method during the first selective tests. Denomination method is used for determining whether the subject recognizes basic colors on Baynes lantern method of exaltation on Oculus HMC anomaloscope, because of its quantitative as well as qualitative analysis of eventual deficits in color perception. Method of denomination is indicated in certain professions and in this case the pilot profession serves to verify the sense of color in special conditions and circumstances. These are mostly persons working with signal utilities in a variety of light and weather conditions (scotopic, mesotopic, photopic conditions, fog, rain, etc.) Testing is done with special utili-

ties (lamps, lanterns) for better imitation of the before mentioned natural conditions. This test is reliable for extracting trichomates from persons with severe defect in color perception, but is not reliable for diagnosing the type of disorder and estimating its severity. The equalization test is also applied with selective examination which uses spectral colors and provides quantitative as well as qualitative analyses of eventual deficits in color vision. At the Institute of Aviation Medicine in Belgrade where one testing was done, Oculus HMC anomaloscope was used and the diagnosis with severity of the deficit was tested by determining AQ (anomaly coefficient) in subjects. All pilots exposed to +Gz acceleration in human centrifuge were determined AQ which was within normal limits (from 1,00 to 1,31). This research started with the assumption that all pilots have normal color perceptions and do not have a quantitative lack of color recognition. It is necessary to emphasize that color perception declines with decreasing brightness; first comes the loss of ability to distinguish red color, then green and at last, blue. The effect of reducing the lighting was not examined due to the tests being done under the same lighting conditions. High +Gz stress has two primary effects. The instantaneous effect is pressure drop at head level and it is proportional to G load; second primary, but somewhat postponed effect, is withdrawal of blood in legs and abdomen. Acute redistribution leads to a decrease in the inflow of venous blood to heart, reduced cardiac output and reduction of the blood pressure at the level of the heart that can further lead to blood pressure reduction in the head level. Physiologically, the ultimate effect on the level of visual function is loss of peripheral and central vision and loss of consciousness. It should be pointed out that energy reserves of the eyes and brain get exhausted in about 5 seconds since the start of lack of blood in the head of the pilot exposed to +Gz acceleration, and in that time the baroreciptoral reflex has not yet activated. In this case, the initial visual symptoms can be absent and could cause a current loss of consciousness which is the most dangerous for pilots. According to some authors [1, 5], in the conditions of greater +Gz acceleration, pilots see red colors as orange or yellow. Studies that dealt with comparative lighting relation, contrasts and color shades noted that changes in perceptions of greater +Gz acceleration, such as +9Gz, the pilots couldn't distinguish the color blue on the display, for they have seen it as white, and the color yellow as green. The ability to recognize colors decreases with decreasing lighting, first the ability to identify red color fails with light reduction, then the color green and at the lowest light, the color blue. Violet color has the longest photochromatical effect, i.e. it is also the longest seen color in low intensity lighting, therefore the modern airports use violet lamps for marking the runway for takeoffs and landings [13–20].

To improve the tolerance on +Gz in human centrifuge used for training and exercise of pilots, it is necessary to emphasize that lighting and contrast sensitivity in cabin are important for color perception, as described in some studies [6].

Conclusion

Color identification is not stable at high +Gz accelerations. Before any definitive conclusions on the perception of color can be reached, further researches should be made, testing the cockpit of the airplane where central and peripheral vision may have an impact. Testing on the Oculus HMC anomaloscope, that is, using the equalization method after leaving the centrifuge and immediately after the +Gz acceleration exposure could be applied in some of the researches to follow. At positive +Gz accelerations the force of inertia acts parallel to longitudinal axis of the body, in such a way that the pilot is pinched in the seat. Due to the great practical significance, especially in air battle, this acceleration attracts great attention and its effect on visual functions is constantly tested. Training in human centrifuge is also of great importance, because with increasing the individual exercise, the pilots are trained to tolerate high +Gz accelerations, which is of great importance in combat maneuvers and every form of training reduces the possibility of color blindness due primarily to loss of retinal blood stream for visual symptoms of tunnel sight, grey and black veil, and finally loss of consciousness.

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