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Original empirical article

FLACK'S TEST USED IN THE SELECTION OF DIVERS

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Abstract. *Flack test belongs to group of EKG stress tests. It is used to estimate functional adaptation of cardiovascular system to intensive stress by concomitant exposure to overpressure in the lungs (40mmHG) and apnea over 1 min. 627 male subjects have been tasted, at the age between 18 and 22 years. EKG was registered continuously at rest before exposure, during overpressure and apnea, and after test during recovery. Flack test is presented in a sitting position and it consists of three phases: (1) the phase at rest, (2) the phase of inspiratory apnea with overpressure in lung of 40 mmHg and (3) the phase of healing. Equipment needed for the test is: EKG apparatus, U tube partitioned in millimeters Hg till "O" sign and with rubber hose with mouthpiece at the end, rubber nose clamp and the test watch. There were 46,5% registrated changes of EKG (3.4% at rest phase, 42.4% in an apnea phase and 11% in a 3rd phase). The changes of P wave are recorded in 26.2%, QRS complex at 15.2%, ST segment at 3.8% and T wave in 7%. R/T phenomenon is registrated in 0.8% and assistolia in 0.33%. The value of Flack's test is in detection of hidden physiologic or pathologic abnormalities in young and healthy persons who intend to practice diving professionaly or sportly.*

Key words: *Flack's test, divers, EKG.*

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INTRODUCTION

Flack's test is one of the ECG stress tests. It is designed to assess the functional adaptation of the cardiovascular system to the intense stress of simultaneous action of overpressure in the lungs (40mmHg) and voluntary cessation of breathing for one minute.

The physiological events related to the continuation of breathing with overpressure in the lungs have been the focus of many researchers for more than 300 years. In the year 1850, at the Royal Scientific Society in Saxon, Leipzig, a German physician-physiologist Edward Friedrich Weber (1), (1804-1891), referred to a series of auto-experiments with drastic consequences. They resulted in changes in pulse rate, and states of consciousness during the voluntary interruption of breathing due to overpressure. In one of the experiments, he fainted with spasms of the limbs and retrograde amnesia. Weber concluded that the experiment would have ended fatally had it not been for the help of his assistants who described the changes. He believed that these changes are caused by increased intrathoracic pressure with consecutive compression of large blood vessels in the thoracic cavity, interruption to the flow of venous blood in the right heart and cardiac arrest. Weber examined previous research including, among other things, "Haller's Encyclopedic Elements", 1757-1766 and the reports of Valerius Maximus and Galen (1) who cite examples of voluntary breath holding and consequent apparent or real death with a previous loss of consciousness and convulsions of the extremities. He then concluded that the act of breathing is under the full control of will and is the subject matter of the ‘soul'. Weber, however, did not know that Morgagni (1) in "De causis sedibus e morborum," in the year of 1761, quoting his teacher Valsalva (1666-1723) said: "... With the closed glottis, and after a deep breath, if you are pushing a long exhalation, the pressure in the lungs disrupts the flow of blood and can disrupt the flow of the intrathoracic vessels."

The first time that the willful cessation of breathing with overpressure in the lungs was named the Valsalva experiment in Longet's Textbook, in the year 1869.

Einbrodt of Moscow (1) in 1860 performed the first experiments with the interruption of breathing in anesthetized animals, and noted a fall in blood pressure and heart rate. He concluded that the main cause of these changes during the Valsalva experiment was stimulation of the vagus nerve.

For the purposes of personnel selection for the Royal Air Force, Martin Flack (1), in 1920, developed a method of performing the Valsalva experiment and called it a test of "40 mmHg". Later, the test got its real name. In the test, pulse was followed by the frequency, the duration of the apnea and the subjective symptoms of the participants. These parameters became the standard for test evaluation. Of the subjective symptoms, he recorded the occurrence of dizziness, altered vision, nausea, headaches, and added them as adverse effects of the test. The heart rate can be limited to 144 hits per minute, a value above that is evaluated as poor adaptability of the cardiovascular system.

Kahn (1), in 1909, introduced electrocardiography for the first time in recording clinical observations during the Valsalva maneuver. His research, continued by Dawson and Hodges (1) in 1916 and 1920, determined that heart rate increases during a preliminary deep breath, falls to normal values during the test, with a brief increase after the end of the test.

Schlomka and Lammert (1), in 1935, provided base operation of electrocardiographic changes during the Valsalva maneuver. They divided the hearts into two groups: a healthy heart has a low T wave in the effort and reduced ratio of S / R. The reverse results represent heart failure. They also noted the frequent changes in P waves, but they were not considered pathological.

The influence of altered venous flow from the abdominal venous reservoirs activating abdominal presses and pressure changes in the abdominal cavity during the Valsalva maneuver was described by Bruck (1) in 1907. However, only Nordenfeld (1), in 1934, made a systematic study on the impact of this phenomenon on the physiological response of the cardiovascular system. For measuring pressure, he used three endobaloons raised in the esophagus, stomach and rectum. He found that the diaphragm plays an important role in changing the pressure in the abdomen and displacement of blood from the abdominal reservoir in systemic veins. If the diaphragm is out of contraction, the pressure in the abdomen is the same pressure in the thoracic cavity and then there is no additional inflow of blood into the right heart. The contraction of the diaphragm causes an increase in pressure in the abdomen and the squeezing of blood into the systemic venous circulation, which directly causes a heart response during the Valsalva experiment.

After World War II, studies of the Flack test continued in order for the assessment criteria to be equalized, and for the methodology of performance and basis for the interpretation of the "test of 40 mmHg" of M. Flack to be accepted. The final interpretation of the test methodology was given by French authors in the period between 1947 and 1952, led by Fabre. The Flack test, as such, in the selection of personnel for specific activities, is still applied today (4).

With the development of diving after World War II, Flack's test as a stress-test of the cardiovascular system, became a very popular test in the medical selection of divers. It is caused by a specific load of the cardio-respiratory system during diving, frequent short Valsalva maneuvers in the ascent phase, constant moderate excess pressure in the lungs in the ascent phase and maneuvers almost identical in the Flack test at the beginning of the dive with apnea.

THE PARTICIPANTS AND THE METHODS

The research was conducted in the period between 1995 and 2010 in the "HBO Medical Center", the practice of Underwater and Hyperbaric Medicine, Belgrade. Testing was conducted on healthy and young men. The Flack test is performed by a modified standard methodology (Zivkovic, 1987) (6). Physiological parameters were recorded and analyzed according to the stages of the test-control phase mode, the phase starting with apnea due to overpressure in the lungs, the flow of the apnea (first and last 30s) and the rupture of the apnea with recovery following the Flack test. The evaluation test was carried out by a combination of standard and analyses of morphological changes in the ECG.

A total of 627 participants were tested, males aged between 18 and 22. A detailed preparation of the participants was performed before the testing.

Flack's test was performed in a sitting position using a modification of standard procedure. Bipolar standard ECG electrodes were placed on all the participants and ECG recordings were made on I, II and III of the standard discharge at rest and during the test II standard derivation of the ECG was monitored. Then the participants were issued with rubber nose clips, and after a deep breath, blew through the rubber hose into the tube filled with mercury and maintained overpressure in the lungs at the level of 40 mmHg (Image 1). The overpressure phase in the standard test takes 60 seconds. Upon the termination of the apnea, a recovery phase follows, which is monitored for 30 seconds at least.

We used a standard paper speed of 2.5 cm / sec.

In terms of the statistical analysis of the results, we calculated the arithmetic mean (X), standard deviation (SD), standard error of mean (Sx) and percentage deviation of the arithmetic means of values obtained during the test and the recovery of the value found at rest (5).

Concluding assessments were made following the analysis of ECG records according to the criteria of Zivkovic et al. (6).

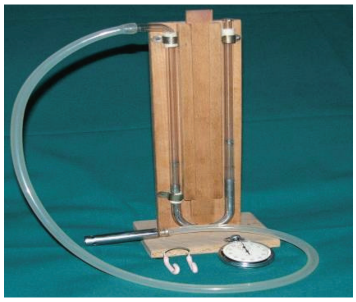

Fig. 1. Apparatus for Flack's test

THE RESULTS

The average age of the participants was 21.40 years, SD-1, 98 and SX-0, 29. Changes in the ECG records usually occurred during the test phase apnea in the case of overpressure in the lungs (in the case of 291 participants, or 46.5%), at rest occurred in the case of 21 participants or 3.4% and in the recovery phase in the case of 11% or 69 participants. The most common ECG change recorded was the altered P wave in the case of 164 participants or 26.2%. It appears as an altered P-wave nodal rhythm (in the first 30s 7.2%, from 30s to 60s 8.3% during the recovery phase of 6.2%) and P "pulmonale" was recorded in a significant percentage during the first 30s (4, 7%).

A total of 24 participants (3.8%) showed signs of a changed ST segment in the recovery phase.

A total of 95 of the participants (15.2%) had changes of the QRS complex and in 66.6% of these cases the cause of the altered QRS complex were extrasystoles. Based on their morphological characteristics, they all belonging to a group of polymorphic and multifocal extrasystoles. Extrasystoles with the R / T phenomenon were registered in 5 participants (0.8%). T wave changes were recorded in 44 of the participants (7%). Asystole occurred in 2 of the participants (0.33%).

In the case of 81 of the participants (13%) in whom tachycardia was registered during the entire test, altered electrocardiograms were also noted. In 40 of the participants (50%) extrasystole was recorded, while the rest had no significant changes in origin.

THE DISCUSSION

The final design of the Valsalva maneuver in the form of test that would allow the assessment of cardiovascular functional abilities and physical well-trained subjects was created by M. Flack (2).

Since 1920 and the first (1) attempt to obtain data from electrocardiograms, which would be essential for the elucidation of the physiological cause-effect aspects of the Valsalva test, ECG recording has increasingly been used in the analyses and evaluation of the stress response induced apnea with overpressure in the lungs. With the development of the ergometric test as a diagnostic test and as a test for assessing the physical abilities of the subjects in sports medicine, interest in static tests, such as Flack's test, was reduced. Analyses of the ECG during the Valsalva maneuver are more frequently used to clarify the physiological response of the heart than to define the application possibilities of selecting candidates for specific work effort.

Changes in the P wave and PQ segment. Schlomka and Lammert (1) were among the first who registered frequent changes in the P waves during the Valsalva maneuver, but they did not determine its pathological character.

In addition to monitoring heart rate during the assessment of Flack's test, the only essential component that Guillermo (7) found was the analysis of the P wave of ECG complexes. It is believed that the disappearance of P waves is a sign of extreme difficulty of the heart to adapt to stress, and that the persistent occurrence of a high P wave is of minor importance.

Bashour (7) in his classification of sinus node dysfunctions (sinus arrhythmia, wandering pacemaker, atrial fibrillation) cited the Valsava maneuver as the cause of functional dysfunction. It is believed to be the direct cause of acute dysfunction of vagal activation and that this condition can lead to syncope, known as idiopathic (vagal) syncope.

Jakopin et al. (7) during apnea and face immersion (parasympathetic stimulation) registered nodal rhythm in 70% of the participants.

Bigec et al. (7) following the ECG during rapid underwater swimming, registered early bradycardia within the fittest divers. It often progresses by changing the sinus guide for lower guides to the idioventricular rhythm without manifest signs of insufficiency of hemodynamics.

Zivkovic et al. (6), during Flack's test, registered morphological changes of P waves (walking center guide, loss and negativization of the P wave) in 26% of the participants. Mancia et al. (7) concluded that stimulation of baroreceptors inhibits the speed of the pulse of the atrioventricular node and the formation rate of pulses in nodes. This could intensify the appearance of AV blocks of varying intensity during Flack's test. Betina et al. (7), Zepilli et al. (7), Veneranda et al. (7), Botti et al. (7) and Notaristefano et al. (7) have thoroughly analyzed the pre-excitation syndrome in assessing the ability of sports activities. Pre-excitation is not sufficiently pronounced as a cardiac problem and a problem in sports medicine. Cases were recorded which caused dangerous arrhythmias and sudden death in young athletes with normal functional heart ability. They propose, as a way to determine the severity of the pre-excitation syndrome, using provocative working or non-working tests (where Flack's test already belongs), and by the principle of activation or inhibition of the sympathetic nervous system. From the overall sports activities, they belong to the group of high risk sports, or activities which include scuba diving, for which the occurrence of the pre-excitation syndrome is a contraindication. In addition, venture sports other adverse signs of the pre-excitation syndrome were ages below 16 and above 30, the presence pre-excitation during loading, the occurrence of arrhythmias and the presence of delta waves during loading.

In this study, for all of the phases of apnea with overpressure in the lungs, altered P waves were registered in the electrocardiographic complex (loss of walking ability, a negative P wave and P-pulmonale) regardless of the type of change and test stage within 44% of the participants. It was noted that the P wave changes occurred in almost uniform percentage throughout the phases of the overpressure.

Opinions on the diagnostic and prognostic value of the P wave deviation from physiological norms are divided even though most of them are considered benign. The discontinuous appearance of these changes is mainly due to the disbalance of the function of the sympathetic and parasympathetic nervous system and may be accepted as a benign phenomenon. Continuous reporting of these changes during the test and recovery is suspicious to the possibility of deepening the arrhythmia up to idiopathic syncope which is unacceptable for activities under the water. A prolonged and increasing P wave greater than 3 mm is usually a consequence of functional disorders of pulmonary circulation due to increased intrathoracic pressure, and should not exclude the possibility of increased pulmonary circulation of organic origin. A high rate of morphological change of the P wave was established during a prolongation phase of the apnea, with overpressure in the lungs. It is caused by intense activation of vagal baroreceptors by the rise in blood pressure due to the extension of Flack's test.

The study did not register a pre-excitation syndrome, which is contraindicated for high-risk sports. The extension of the PQ segment with no other morphological changes of the ECG complexes is the consequence of the vagus slowing the atrial impulse to the ventricular node. In the case of the AV block, the analysis of the ECG record, recorded during Flack's test, should distinguish whether it is organic or functional in origin.

Changes in the QRS complex. Flessas (7) analyzed the time during the contraction of the left ventricle and pre-ejection stage during THE Valsalva maneuver and found that ejection time is shortened from the third beat and reaches a minimum value around the fourteenth beat, while maintaining low levels until the end of the test. By the rupture of the apnea, from the third beat of the left ventricular, ejection time is prolonged until the final stabilization. The pre-ejection phase did not change in any phase of the Valsalva test. From the dynamics of the parameter that is monitored, he noted the ever-increasing sympathetic activity during the phase of the overpressure and rupture of the apnea.

In a selection of participants for flight crews, during the breath test with positive pressure, Davidovic et al. (7) noted the appearance of extrasystoles in the test with an overpressure of 15 mmHg within 45% , and Kelečević et al. (7) tested 111 participants and within 3% recorded the morphological changes of QRS complexes (extrasystole and AV block, first grade) which were described as deviations from the normal findings.

Barnini et al. (7) reported on electrocardiographic changes during a modified Flack's test. In the rest phase, they registered 4% of the abnormal ECG records. In the phase of the overpressure apnea, morphological changes and the appearance of extrasystoles were found in 89%, while in the recovery they registered extrasystoles in 3% of the participants. They concluded that the test has its value in the selection and control of divers. Bradycardia which occurred during the test was evaluated as a sign of good heart adaptability and physical fitness. They characterized the occurrence of polymorphic ventricular extrasystoles as contraindication for diving activities, and changes in the ST segment were assessed in the clinical significance of these changes.

Jakopin et al. (7) during the hold breath with face immersion in cold water registered the occurrence of supraventricular extrasystoles in 58% of the participants, where 80% were ventricular extrasystoles, and 37% had the extrasystoles in a salvo form.

They concluded that the stimulation of the parasympathetic nervous system and hypoxia face immersion in the final stage of the apnea, causes such a high percentage of cardiac arrhythmias. Sasel (7) also discussed the influence of the autonomous nervous system on the occurrence of arrhythmias. Based on the experimental results he concluded that vagal stimulation lowers the threshold of occurrence of ventricular extrasystoles and they mainly occur in periods of low heart rate. Only extrasystoles in pairs or in a salvo from a variety of focus are considered to be pathological.

Bigec et al. (7) registered extrasystoles in 33% of the participants during rapid underwater swimming and in 45% of the participants in cold water. In the case of three participants with extrasystoles (15%) the R / T phenomenon was registered.

Krgović et al. (7) during underwater swimming in shallow depths registered occurrence of ventricular extrasystoles in 8% of the participants, and occurrence of supraventricular extrasystoles in 25% of the participants. The appearance of extrasystoles was more common in terms of the preponderance of the vagus. Benign extrasystoles usually disappeared during physical exertion.

Zivkovic et al. (6), within the analysis of 500 ECG records, found morphological changes in the resting phase during Flack's test in 3.4% of the participants. During the apnea with overpressure in the lungs, morphological changes were expressed in 42.2% of the participants. Extrasystoles were found in the case of 11% and the R / T phenomena in the case of 0.8% of the participants. From all of registered extrasystoles 27% occurred at the end of the test (the rupture of the apnea) and 41% immediately after the end of the apnea. Pathological extrasystoles (multiple, polymorphic, and multifocal) were noted in 6.6% of the participants or 49% of the total number of registered extrasystoles.

In this study extrasystoles were registered at 10% of the participants. A total of 3.6% of the tested extrasystoles were registered during the recovery. Of the total number of recorded extrasystoles 73% had a pathological character (multifocal and polymorphic). R / T phenomena were detected in 0.8% of the participants. Asystole was registered in the case of 0.33% of the participants. (Legend: Fig 2.)

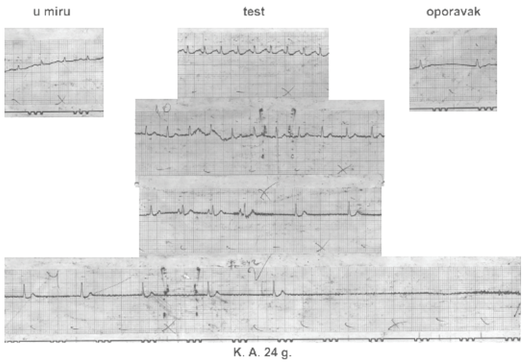

Fig. 2. Asystole during the apnea phase

The results of the survey are generally similar to those of these authors. The occurrence of pathological extrasystoles gives a good evalution, with big certainty, of the functional state of the cardiovascular system of the participants tested with Flack's test.

Changes of the ST segment and T wave. Schlomka and Lammert (1) considered the change in the T wave height during the Valsalva maneuver an important sign in assessing the ability of the heart muscle. During the apnea, the healthy heart is characterized by low T waves with a reduced R / S ratio, while the reverse features are characteristic of a weak heart.

Much later Južnič (4) used the change in ECG records to evaluate participants by means of Flack's test. He concluded that a preponderance of the vagal or sympathetic nerve plays a key role in altering the length of the ECG complex, that a high T wave is characteristic of vagal dominance, and lowered ST segment is a sign of myocardial ischemia.

Kelečević et al. (7) found non-specific T wave changes in 12% of their 111 participants.

Barnini et al. (7) registered a changed ST segment in 90% of the tested participants and evaluated it in accordance with the clinical significance of this phenomenon.

In the study, a changed ST segment was registered at 3.8%. A sloping ST segment of 1 mm or more, lasting longer than 0.08%, is certainly a sign of myocardial ischemia.

The appearance of inverted T waves without a pathologically altered ST segment could be described as the nonspecific disturbance of repolarization. Normally it may occur among healthy subjects and young people during hyperventilation, but the final judgment can be made only in the context of the overall morphological changes of electrocardiographic recording.

(Legend: Figures 3-11).

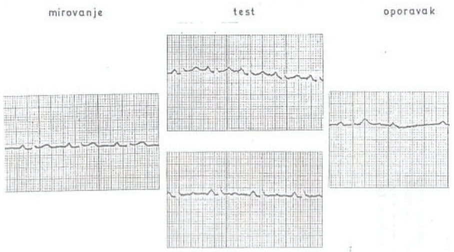

Fig. 3. Exceeded PQ segment during the rest phase, normalization during the period of the apnea, second degree of AV block during the recovery phase

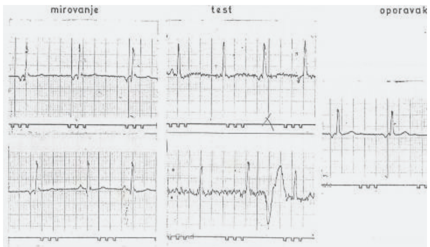

Fig. 4. Nodal rhytm during all the phases of Flack's test

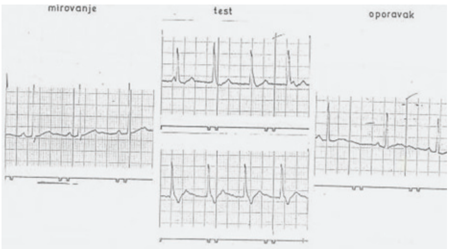

Fig. 5. Nodal rhytm during apnea. Extrasystole before abruption of the apnea phase

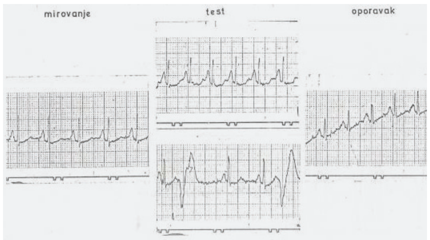

Fig. 6. P wave is above 3 mm during the rest phase, during apnea and during the recovery phase. Extrasystoles before abruption of the apnea (R/T phenomenon)

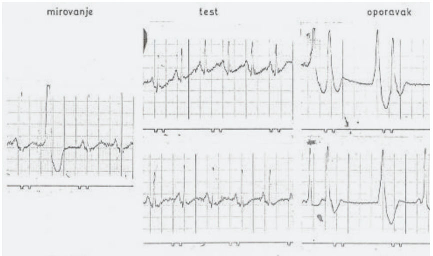

Fig. 7. Ventricular extrasystoles during the rest phase. Supraventricular and ventricular extrasystoles in a salvo form during recovery phase

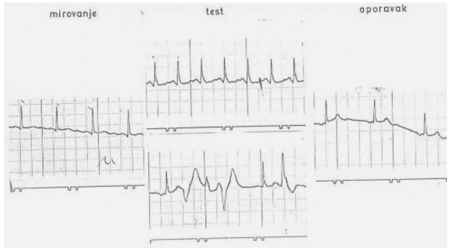

Fig. 8. Supraventricular and multifocal extrasystoles before abruption of the apnea (R/T phenomenon). Nodal rhytm before abruption of the apnea and during the recovery phase

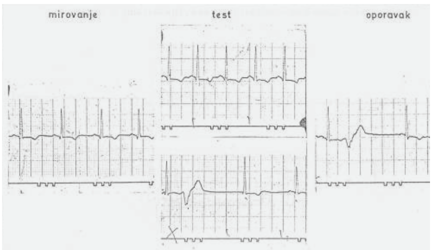

Fig. 9. Bradycardia and extrasystole before the abruption of the apnea and extrasystole during the recovery phase. Reverse T wave during the rest phase and during Flack's test

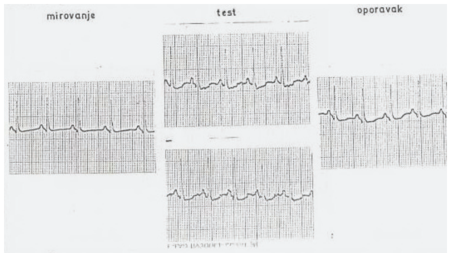

Fig. 10. Depressed ST segment 1mm during Flack's test and during the recovery phase

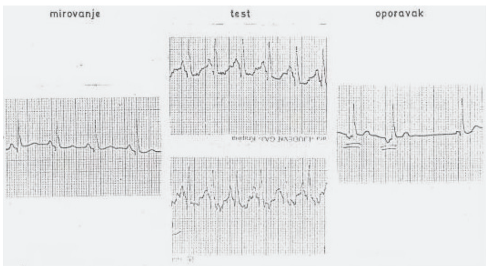

Fig. 11. Depressed ST segment more than 1mm during the test. High P wave (above 3mm). Nodal rhytmin recovery phase

CONCLUSION

Like most other researchers who monitored ECG recordings during Flack's test, a high percentage of morphological changes were recorded during the test and during the recovery phase.

If significant changes to the P waves, with negativisation, missing or "walking" P waves, persist during the breath hold or in recovery phase, it indicates that the subjects is unprepared for greater physical effort with a potential tendency to syncope. Candidates with persistent pre-excitation syndrome, the appearance of atrioventricular block that is not normalized during the breath hold when dominated by sympathetic stimulation, should be examined further. Subjects with an extended QRS above the permissible limits, multifocal and polymorphic exstrasystoles at any stage of the test, as well as the depression of the T wave and ST segment above 1 mm shall be declared incapable for diving activities.

Because of the high fidelity that Flack's test provides by interpreting the state of the cardiovascular system, and the simplicity of its use, it can easily be used for the evaluation of the cardiovascular system of other participants with increased physical exertion.

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FLAKOV TEST U SELEKCIJI RONILACA

Ana Perišić, Slađana Antonijević, Sandra Tepić, Miodrag Živković

Flakov test spada u grupu EKG stres testova. Namenjen je za procenu funkcionalnog prilagođavanja kardiovaskularnog sistema na intezivni stres izazvan istovremenim delovanjem nadpritiska u plućima (40mmHg) i voljnim prekidom disanja trajanja od 1 minuta. Ispitanici su bili muškarci starosne dobi od 18 do 22 godine, ukupno je testirano 627 ispitanika. Tokom Flackovog testa kontinuirano je sniman EKG kroz sve faze testa (u miru, tokom nadpritiska u plućima i oporavku). Pribor potreban za izvođenje testa je: EKG aparat, U-cev graduisana milimetarskom podelom ispunjena živom do oznake "O" sa produženim gumenim crevom koje se završava piskom za usta, gumena štipaljka za nos i štoperica. Ukupno je kod 46.5 % ispitanika nađen izmenjen EKG zapis (3,4% u fazi mirovanja, 42,4% u fazi nadpritiska i 11% u fazi oporavka). Promene P talasa u 26,2%, QRS kompleksa u 15,2%, T talasa u 7% i ST segmenta u 3,8%. Fenomen R/T registrovan je u 0,8%, a asistolija u 0,33%. Značaj Flakovog testa jeste u tome da otkrije skrivene fiziološke ili patološke abnormalnosti kod zdravih i mladih ljudi koji imaju nameru da se sportski ili profesionalno bave ronjenjem.

Ključne reči: *Flakov test, ronioci, EKG.*