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RĪGA STRADIŅŠ UNIVERSITY

Sandra Rozenštoka

The Impact of Exercise Consultation on Athlete Health and Exercise Tolerance

Summary of the Doctoral Thesis for obtaining a doctoral degree "Doctor of Science (*Ph.D.*)"

Sector – Clinical Medicine
Sub-Sector – Internal medicine

Riga, 2022

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Sandra Rozenštoka

ORCID 0000-0003-1957-3493

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The Doctoral Thesis was developed at the "Sports Laboratory", Ltd. – FIMS Collaborating Centre of Sports Medicine, Latvia

Supervisor of the Doctoral Thesis:

Dr. med., Professor **Andrejs Ērglis**
University of Latvia

Official Reviewers:

Dr. med., Professor **Aivars Lejnieks**
Rīga Stradiņš University, Latvia

Dr. med., Professor **Iveta Mintāle**
University of Latvia

Ph.D., Exercise biochemistry, Professor of Sport and Exercise Science **Yannis Pitsiladis**, School of Sport and Health Sciences, University of Brighton, Eastbourne, United Kingdom

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Secretary of the Promotion Council:

Dr. med., Professor **Ilze Konrāde**

Table of Contents

Abbreviations used in the Thesis

BF	breathing frequency
BMI	body mass index
bpm	beats per minute
DBP	diastolic blood pressure
ECG	electrocardiogram
HI	chronotropic index
HR	heart rate
HR170	heart rate 170 bpm
kg	kilogram
l	litre
max	maximum
MET	metabolic equivalent
min	minute
ml	millilitre
n	number of participants
p	probability
Pp	pulse pressure
qCO_2	carbon dioxide quotient
qO_2	oxygen quotient
Qt	ardiac output
rel VO_2	relative volume of oxygen
RER	respiratory exchange rate
RI	Robinson index
SBP	systolic blood pressure
SV	stroke volume
SVES	supraventricular extrasystole

TPR	total peripheral resistance
VCO_2	volume of carbon dioxide
VE	expired volume
VES	ventricular extrasystole
VO_2	volume of oxygen
W	watt
WHO	World Health Organization

Introduction

As people's life expectancy increases, maintaining the population’s health and quality of life throughout their lifetimes becomes important in Latvia and worldwide. It is also emphasized in the European Union's guidelines on physical activity (Andersen et al., 2008). However, in society, there is a tendency for people to become less physically active when they reach adulthood. This is probably due to mainly general recommendations for physical activity, without an individually explained necessity and ways of practical implementation. The growth in numbers of physically active individuals would significantly decrease the number of cardiovascular diseases as well as metabolic diseases, oncologic and other diseases. In order to implement this goal, a more considerable state support to the sports medicine field is required. Sports medicine is characterized by a multidisciplinary approach to the promotion of the physical activity of inhabitants. A sports physician who is knowledgeable about the effects of physical activity and sports on an individual’s organism, taking into account the health status, medical history and exercise tolerance, educates the public and advises male and female individuals of various ages by advocating for physical activity as a way of improving their health and quality of life, prevention from chronic diseases caused by physical inactivity and recommends a suitable physical activity to athletes, para athletes, children and adults, people with obesity, elderly people and individuals with various diseases (Andersen et al., 2008; Ionescu et al., 2021; Cabinet of Ministers of the Republic of Latvia [CM LR], 2009). The duration of physical activity was set in the WHO Guidelines on Physical Activity and Sedentary Behaviour issued by the World Health Organization (WHO) in November 2020, which also includes an important notification: physical exercise yields extra health benefits in adult organism and health, if the duration of physical exercise is prolonged to 300 minutes per week and a child's 60 minutes of daily physical exercise is supplemented with organized sports trainings up to 120 minutes per day several times per week (WHO, 2020).

Objectives of the Thesis

Sports is developing and becoming increasingly popular in Latvia and worldwide contributing to the growing numbers of sports events and competitions. The line between professional and amateur sports begins to blur. The number of sports competitions increases and so does the number of participants – individuals with various health status, training programmes and physical fitness levels. The training programme of these individuals is often irregular and/or inappropriate for their health status and exercise tolerance, yet the in-depth preventive medical screening, as determined by the Sports Law of the Republic of Latvia, are carried out irregularly or never. The significant difference between the functional parameters of professional athletes and physically inactive individuals as well as the absence of comprehensive studies in scientific literature, lead to the necessity to carry out research.

The aim of the Thesis

To prospectively assess the exercise tolerance, its relevance to health condition and overall physical fitness of physically active individuals – athletes; to evaluate the impact of sports physician's exercise consultation on athlete health and exercise tolerance and create physical working capacity index and heart functional index assessment scales, depending on age, sex and training programmes.

Tasks of the Thesis

To achieve the Aim of the Thesis, the following tasks were set out:

1. To divide the physically active individuals – athletes, into research groups according to specific demographic and other indicators: age, gender, training programme, and assess their influence on exercise tolerance.
2. To assess the athletes' subjective and objective health status, functional condition and physical working capacity.
3. To evaluate the impact of sports physician's exercise consultation and prophylactic medical measures on athletes' health and exercise tolerance.
4. To assess the aerobic and anaerobic capacity of the athletes, recovery and their effect on exercise tolerance before and after a sports physician's recommendations.
5. To compare the functional parameters, physical working capacity index and heart functional index of the physically active individuals who participated in the competition, to the data available in the scientific and professional literature, and create evaluation scales depending on age, gender and training programme.

Hypotheses of the Thesis

Exercise tolerance of the majority of the physically active people – athletes – is not adequate for their health status and/or overall physical fitness levels.

WHO's general physical exercise guidelines could not be suitable for the inhabitants of a specific region or are insufficient for individuals and their sports trainers to choose an adequate training programme without consulting with a sports physician.

Novelty of the Thesis

The first large-scale study in Latvia and Europe, with the cardiopulmonary exercise testing in order to scientifically justify and evaluate the impact of exercise tolerance and training programme on the amateur athlete's health status, physical working capacity and to assess the influence of the sports physician's exercise consultation on it.

Practical application of the Thesis

In the study the significance of a sports physician's exercise consultation for physically active people – athletes of various ages – was objectively assessed; its importance in the planning of the individually suitable physical load and the increasing of exercise tolerance was evaluated. In the study, depending on age, gender and training programme, physical working capacity index and heart functional index scales for physically active individuals – athletes – were created. These scales can be employed in sports medicine and other branches of medicine.

Personal contribution

The Author of the Thesis has analysed the scientific literature and professional publishing, developed the study design and confirmed it in the Riga Stradins University Research Ethics Committee, as well as carried out 2900 cardiopulmonary exercise tests that were included in the study. Every athlete was advised twice by the Author – certified sports physician and specialist in electrocardiography (ECG) and exercise testing, their test results were explained, an exercise consultation was done, and the necessary changes in the training programme were suggested. After the acquisition of the results, a database was created, the acquired data were analysed and developed physical working capacity index and heart functional index scales which are practically applicable in sports medicine and other medicine fields. The Author has also written Thesis, publications and the Thesis Paper. The list of references consists of 170 sources. The volume of the Thesis covers 246 pages, including 9 chapters, 22 tables, 25 figures and 4 appendices. The Thesis is supported by 4 indexed publications.

1. Literature Review

1.1. Sports Medicine

Sports medicine is a multidisciplinary, scientific and practical healthcare field. It covers health protection, diagnostics of health status, functional condition, physical working capacity, exercise tolerance, morphofunctional features related to physical activity and physical inactivity, treatment, rehabilitation, prevention of various diseases, injuries or overload and recommendations for optimal physical exercise of professional, amateur and paediatric athletes, as well as the general public. (European Federation of Sports Medicine Association [EFSMA], 2018; Ionescu et al., 2021).

The Latvian Sports Medicine Association represents the sports medicine field in Latvia, uniting all sports physicians. Internationally sports medicine field is represented by the European Federation of Sports Medicine Associations (EFSMA) and the Internationale Federation of Sports Medicine (FIMS). The goals of the Sports Medicine field are:

- to promote full medical supervision and healthcare of elite athletes and to improve their results in sports,
- to prevent the health risks and death risk connected with physical exercise for athletes and the general public,
- to raise the awareness in specialists and society of the effects of physical activity on the human body, including cases of various diseases and injuries and about the proper training process, athlete and sports nutrition,
- to ensure the principle of fair play in sport (FIMS, 2018).

1.2. Physical Activity, Physical Exercise and Sports

Physical activity is defined in the current European Union Physical Activity Guidelines, 2008, and in the WHO Fact Sheet – Physical Activity, 2018, which states that physical activity is muscle-powered body movements that increase energy consumption compared to rest and also promote social and psychological benefits (Andersen et al., 2008; WHO, 2018). It includes all the individual's daily physical activity: leisure, work, housework and sports physical activity.

Sport, as a type of physical activity, is defined in the Sports Law of the Republic of Latvia as all types of individual or organized activities for maintaining and improving physical and mental health, as well as for success in sports competitions (Sports Law, 2002). Physical exercise is the process and effect of a certain amount of exercise on the human body and can be organized or practiced individually (WHO, 2018). When conducting research in Sports Medicine and also working in clinical practice, it is important to define whether an individual is a physically active person who engages in physical activity and sports to maintain or improve health and fitness, or an athlete – a physically active person who exercises with regular/irregular training programme; with/without membership in a sports organization; with/without the cooperation of a sports coach in the training process; low, medium and high intensity physical exercise with the aim to achieve a higher sports score in sports competitions. The Sports Law of the Republic of Latvia defines an athlete as a person who engages in sports and participates in sports competitions – an official event to determine the best athletes or sports teams (Sports Law, 2002). Sports training is a process of acquiring, maintaining and improving skills and abilities in sport (Sports Law, 2002).

Sports are divided according to the influence of physical exercise on the human body. Such a classification of sports was developed in 1994 by scientists Jere H. Mitchell, William L. Haskell and Peter B. Raven. They analysed the degree of activation of the sympathetic nervous system, energetic metabolism in the muscles involved in exercise, an increase in cardiac output (Qt), peripheral circulatory resistance and cardiovascular risk (Mitchell et al., 1994). As shown in Table 1.1, sports were divided into 9 groups, according to the type of physical exercise: dynamic or static, and according to the intensity of physical exercise: high, medium or low intensity. In 2005, the Classification of Sports, with new sports additions, was accepted by the European Society of Cardiology (Pelliccia et al., 2005).

Table 1.1

The Classification of Sports (Mitchell et al., 1994; Pelliccia et al., 2005)

Type and intensity of physical exercise	**High dynamic exercise**	**Moderate dynamic exercise**	**Low dynamic exercise**
High static exercise	Boxing Canoeing Cycling Decathlon Kayaking Rowing Speed skating Triathlon	Body building Downhill skiing Snowboard Wrestling	Athletics: throwing Bobsledding Luge Rock climbing Water skiing Weight lifting Windsurfing
Moderate static exercise	Basketball Biathlon Cross country skiing: skating Field and Ice hockey Handball Rugby Running: middle dist. Soccer Swimming	American football Athletics: • Jumping • Sprinting Figure skating Lacrosse Surfing Synchronized swimming	Archery Auto racing Diving Equestrian Gymnastics Judo Karate Motorcycling Sailing

Table 1.1 continued

Type and intensity of physical exercise	High dynamic exercise	Moderate dynamic exercise	Low dynamic exercise
Low static exercise	Badminton Cross country skiing: classic Orienteering Race walking Running: long dist. Squash Tennis: single	Baseball Fencing Softball Table tennis Tennis: doubles Volleyballs	Billiards Bowling Cricket Curling Golf Riflery

Latvia follows the WHO Global Recommendations on Physical Exercise for Health and encourages adults to exercise 75 to 150 minutes a week, and children 60 minutes a day (WHO, 2010). In the Latvian Public Health Guidelines for 2014–2020 it is mentioned that 90.0 % of the Latvian population does not follow the WHO recommendations (MH LR, 2014). A 2017/2018 study on Latvian students' health habits showed that also 78.8 % of boys and 84.6 % of girls did not get enough physical activity (Pudule et al., 2020). The 2016 health survey in Latvia showed another interesting result – self-assessment of the physical capacity of the population: 88.5 % of the Latvian population or 91.3 % of men and 86.1 % of women rated their physical capacity as very good to average (Grinberga et al., 2017). These data show the inability of people to objectively assess their physical health and fitness, thus maintaining high health and life-threatening risks during stress and high-intensity physical exercise.

In each country, popular or amateur sports have an important role, as they promote the participation of people of different ages and social groups in physical exercise, maintain people's physical and psychological health, and provide primary and secondary prevention of various diseases. In Latvia and around the world, the number of amateur sports events and the number of people participating in them are growing every year, for example, 16,358 runners participated in various distances of the Riga Marathon in 2011, but in 2018 – 35,020 participants from 60 countries participated. (Nords Event Communication, 2019). The most physically active adult population is aged 25–40. They take part in popular sports competitions, at the same time, unlike professional athletes, many of them do not devote enough time to training, nor do they check their health and exercise tolerance. This poses risks to overload, acute cardiac events, sports injuries and sudden death in sports. After the age of 40, the number of people engaged in physical exercise decreases significantly.

1.3. The Effects of Physical Exercise on Human Body

Optimal, regular and prolonged physical exercise causes well-known permanent physiological, adaptive and morphological changes in the body, develops physical working capacity and physical abilities in sports and decreases risk of illness and injury (Auliks, 1985; Bremanis, 1991; Ionescu et al., 2021; Carpan, 1988; Wasserman et al., 2005). Participation in sports competitions significantly increases the risk for athletes. All individuals who train in sports and participate in sports competitions have 2.8 times higher relative sudden death risk in sport compared to individuals who train but do not participate in sports competitions (Ferreire et al., 2010). The risk is related to an individual's subjective and objective health status, functional condition, physical exercise factors and exercise planning. Improper, irregular or excessive exercise can cause physical overload, increase the risk of exercise-related illness, injury and sudden death in sport.

The only direct source of energy for muscle contraction is the energy from the hydrolysis reaction of the macroergic compound adenosine triphosphate or ATP. Continuous and efficient ATP resorption must be ensured during muscle work. There are three ATP resynthesis reactions in the body: creatine kinase reaction, anaerobic glycolysis and oxidative phosphorylation (Bremanis, 1991).

1.4. The Evaluation of Functional Condition and Individualization in Sports

In Europe, 70 % of the countries decree preparticipation screening as obligatory for athletes. Preparticipation screening is similar to an in-depth preventive medical screening in Latvia, and includes:

- complaints, medical, family and sports history, training programme, physical examination, objective examination including 12-lead ECG, blood and urine tests;
- anthropometry, somatoscopy, assessment of physical development, posture, determination of movement quality and control;
- examination of physical working capacity, exercise tolerance and physical abilities, assessment of psychological condition and neuromuscular function, electromyography, cardiopulmonary exercise testing functional condition, aerobic and anaerobic thresholds, adaptation to physical exercise and training programme, echocardiography and spirometry (Ionescu et al., 2021; CM LR, 2016).

A person's ability to make physical activity is limited by the functional systems of the body, aerobic capacity, anaerobic capacity and the availability of energy resources. Repeated testing gives the possibility to assess changes in aerobic and anaerobic capacity, exercise tolerance, adequacy of the training programme, impact on health and an increased risk of overload or health events.

Physical working capacity is based on an individual's physical abilities. It depends on body composition, morphological and functional status of the organ systems, aerobic and anaerobic capacity, energy production efficiency, muscle strength, endurance, speed and neuromuscular coordination. The Physical working capacity index describes the individual's maximum relative exercise capacity and is measured in W/kg (watts/kilogram). Currently, the only methodology available for estimating the physical working capacity index in the male and female populations, was published in 1969 and 1988 by the Russian sports medicine researcher V. Karpman (Карпман, 1969; Карпман, 1988).

The heart functional index describes the relative workload or physical working capacity at HR170 (Zukovskis, 1991). It is also referred to as PWC170. When the heart rate (HR) exceeds 170 ×/min, the linear relationship decreases. The ability of physically active individuals and athletes to perform regular and intense training programmes is ensured by adequate neural, physiological and morphological adaptation of the body. It depends on an individual’s health, the training programme and the kind of sport (Bompa and Haff, 2009). If the training programme is not appropriate, it may increase health risks, including overload and cardiovascular risk (Skalik, 2015). Exercise tolerance is assessed by determining an individual's age, gender, physical exercise, physical working capacity index, heart functional index, maximum HR (Rozenstoka and Erglis, 2020), Robinson index (RI), functional parameters of the respiratory system, complaints, and whether ischemic changes in ECG are registered during the exercise (Mintale and Erglis, 2008).

An individual's adaptation to physical exercise is determined by the response of the body's functional systems, the maximum HR achieved during exercise, comparing whether the individual is able to reach the theoretical maximum HR (determined by the Astrand formula: 220 – age, years) (Dobre et al., 2013), the recovery process after physical exercise: good recovery – full recovery of functional parameters in six minutes after exercise; satisfactory recovery – partial recovery of functional parameters in six minutes after exercise, extended recovery – prolonged recovery of functional parameters in six minutes after exercise.

Physical activity and physical exercise must be individually appropriate for each individual, both a professional athlete and a physically active person. According to data from the European Society of Cardiology study, regular preparticipation screening, including diagnostic methods during exercise, reduces the risk of sudden cardiac death by 89% (Borjesson et al., 2019). An appropriate and guided development of the training programme is characterized by its individual suitability for health status, physical working capacity and exercise tolerance with the determined regularity, frequency and duration of training. The necessary changes or additions to the training programme are explained by a sports physician to each individual, taking into account the individual's age, type of sport, time spent on physical exercise and the purpose of physical exercise. Regular assessment of the impact of physical exercise is important in individualization of the training programme.

2. Organization of the Study

2.1. Structure, Volume and Methods of the Study

A longitudinal prospective study was performed at a certified medical centre “Sports Laboratory” – FIMS collaborating centre of sports medicine. This study involved 1,600 self-perceived as healthy individuals aged 12 to 70 years (1,050 males, 550 females) who regularly engaged in high intensity dynamic and medium-high intensity static exercise (Mitchell et al., 1994) and participated in sports competitions (Sports Law, 2002). All of the individuals in the study were convinced that they did not have a cardiovascular, respiratory or other disease, and that they were healthy. In the research data basis were registered individuals who took part in both testings. In the study groups and the database were recorded individuals who participated at both testings and if the athlete did not participate in the second testing, none of the participant's results were included in the study. The design of the study is shown in Figure 2.1.

Participants were divided into study groups by gender and age, although there are significant individual differences up to 19 years of age (De Lamater and Friedrich, 2002): 12–15 years age group – early puberty; 16–19 years age group – late puberty; 20–29 years age group – early adult stage or onset of physiological maturity of the organism; the next age groups were divided into 10 years to 70 years of age, when the individual maintains a sufficiently high level of endurance through regular physical exercise (Zidens et al., 2008). According to the training duration per week, individuals were divided into groups of more than 300 or less than 300 exercise minutes per week according to the 2020 WHO guidelines on physical activity and sedentary lifestyle (WHO, 2020). Participants were included in the study groups according to following criteria and study groups as shown in Table 2.1 were numbered encrypted:

- gender: F – female or M – male;

- age group: 12–15 years, 16–19 years, 20–29 years, 30–39 years, 40–49 years, 50–59 years and 60–69 years;
- duration of training per week: < or less than 300 exercise minutes per week or ≥ or more than 300 exercise minutes per week;
- appointment time: 1 – first appointment or 2 – second appointment.

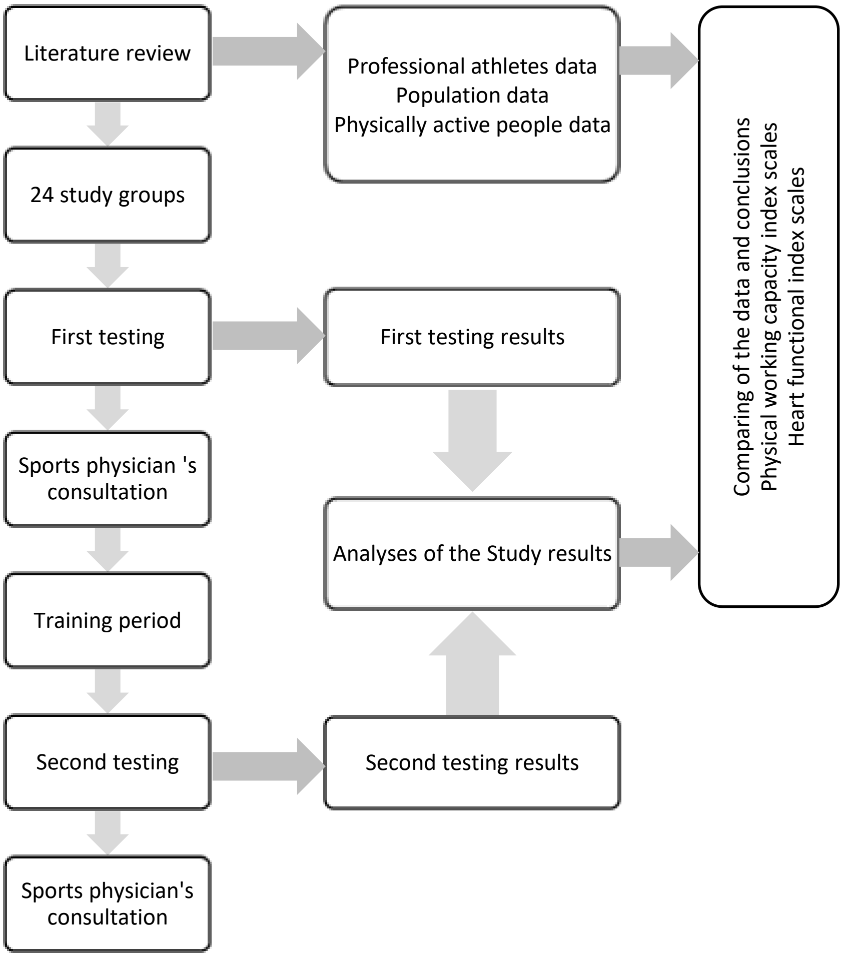

Figure 2.1 **The design of the study**

In the older study groups, it was not possible to ensure the participation of healthy individuals who train regularly and participate in sports competitions.

Before each appointment, participants were introduced to the study process, objectives, data protection, confidentiality, preparation and received answers to all questions and signed consent to participate in the study. The health status of each athlete was assessed at the consultation with a sports physician: absolute and relative contraindications for the cardiopulmonary exercise testing were excluded by questioning about complaints and athlete's medical card (State Agency of Medicine, 2020). The subject was considered healthy, if he / she had no complaints or symptoms of any disease, normal skin colour, normal heart rate, arterial blood pressure, respiratory rate, and resting ECG. The participant was warned to immediately inform the sports physician of any complaints that occurred during the testing. The maximum workload of the cardiopulmonary exercise testing poses high risk to human health and life, especially if the individual has not been previously tested, therefore all participants were tested in the office by the author of the Thesis – a certified sports physician and specialist in ECG and exercise testing methods and a nurse; the office was equipped with emergency care equipment and medicines.

Table 2.1

Numbering of study groups and number of participants

Gender	**Female athletes**				**Male athletes**			
Training programme	**< 300 exercise minutes per week**		**≥ 300 exercise minutes per week**		**< 300 exercise minutes per week**		**≥ 300 exercise minutes per week**	
Appoint-ment time	**First**	**Second**	**First**	**Second**	**First**	**Second**	**First**	**Second**
12–15 years	F12–15 < 1 n–50	F12–15 < 2 n–50	F12–15 ≥ 1 n–50	F12–15 ≥ 2 n–50	M12–15 < 1 n–50	M 12–15 < 2 n–50	M 12–15 ≥ 1 n–100	M 12–15 ≥ 2 n–50
16–19 years	F16–19 < 1 n–50	F16–19 < 2 n–50	F16–19 ≥ 1 n–50	F16–19 ≥ 2 n–50	M 16–19 < 1 n–50	M 16–19 < 2 n–50	M 16–19 ≥ 1 n–100	M 16–19 ≥ 2 n–100
20–29 years	F20–29 < 1 n–50	F20–29 < 2 n–50	F20–29 ≥ 1 n–50	F20–29 ≥ 2 n–50	M 20–29 < 1 n–100	M 20–29 < 2 n–100	M 20–29 ≥ 1 n–100	M 20–29 ≥ 2 n–100
30–39 years	F30–39 < 1 n–50	F30–39 < 2 n–50	F30–39 ≥ 1 n–50	F30–39 ≥ 2 n–50	M 30–39 < 1 n–100	M 30–39 < 2 n–100	M 30–39 ≥ 1 n–100	M 30–39 ≥ 2 n–100
40–49 years	F40–49 < 1 n–50	F40–49 < 2 n–50	F40–49 ≥ 1 n–50	–	M 40–49 < 1 n–100	M 40–49 < 2 n–50	M 40–49 ≥ 1 n–100	M 40–49 ≥ 2 n–100
50–59 years	F50–59 < 1 n–50	–	–	–	M 50–59 < 1 n–50	M 50–59 < 2 n–50	M 50–59 ≥ 1 n–50	–
60–69 years	–	–	–	–	M 60–69 < 1 n–50	–	–	–

After testing, each individual received the sports physician's consultation with the assessment of the results and recommendations for an individually suitable training programme and preventive measures. The second appointment was performed approximately 5–9 months after the initial consultation but still during the athlete's active training period or sports season. After the second testing, the sports physician evaluated the results, including the change in dynamics compared to the first testing, and made recommendations for further improvement in health and exercise. The study was approved by the RSU Research Ethics Committee, Decision No E – 9 (2).

The following methods were used in the study: literature review, anthropometric method (body weight, height, BMI), the estimation of sports history (sports as adolescent age, the age at which the individual started playing the current sport), current training programme (an existing membership in a sports organisation, the cooperation with a sports coach, the regularity, frequency and duration of training or exercise minutes per week), complaints that were and were not related to physical activity, habits, including smoking, repeated cardiopulmonary exercise testing and statistical analysis of the data were performed. The following predictive parameters were calculated for each study participant: maximum HR (×/min), maximum work-rate (W), absolute VO_2 max (ml/min) and metabolic equivalent (MET).

Cardiopulmonary exercise testing as a standardized qualitative and quantitative method was performed on a Master Screen CPX cardiopulmonary exercise testing system with a simultaneous 12-lead ECG, manual arterial blood pressure monitoring for higher measurement accuracy, breathing gas and respiratory volumes analysis. It is a scientifically based, objective and non-invasive assessment method. The exercise testing protocol was developed on the basis of the existing exercise testing method by creating an original protocol in consultation with the scientists of the Latvian Institute of Cardiology and the supervisor of the study, Professor Andrejs Erglis. The test included 4 phases: the rest phase – 1 minute; the warm-up phase – 1 minute with a power of 50 watts (W) with cycling speed or cadence 60 rate per minute; the load phase – physical exercise of various durations with a gradually increasing power of 15 W/min up to the maximum work-rate; the recovery phase – 6 minutes, of which the first 2 minutes are active recovery and 4 minutes – passive recovery. Parameters were determined at specific time points during the testing: rest, aerobic threshold, anaerobic threshold, at HR170, maximum work rate, and the sixth minute of the recovery phase.

The following functional parameters were determined and assessed for the evaluation of the functionality of the cardiovascular system: heart rate (HR; ×/min); systolic and diastolic arterial blood pressure (SBP, DBP; mmHg); pulse pressure (Pp; mmHg); stroke volume (SV; ml); cardiac output (Qt; l/min); total vascular resistance (TPR); Robinson Index (RI) and Chronotropic Index (HI). The cardiopulmonary exercise testing was also used for diagnosing coronary heart disease. The ECG was determined and analysed during the rest, exercise and recovery: HR; heart conduction system; rhythm and arrhythmias – supraventricular and ventricular extrasystoles (SVES; VES); nonspecific or ischemic changes in ECG.

For the evaluation of the respiratory system, the qualitative respiratory parameter – respiratory rhythm and the following quantitative parameters were determined and analysed: breathing frequency (BF; ×/min); expired volume (VE; l/min); inhale volume (l); exhale volume (l); volume of breathing air in 1 breathing cycle (l); absolute oxygen uptake (VO_2; ml/min); relative oxygen uptake (rel VO_2; ml/min/kg); metabolic equivalent (MET); absolute volume of carbon dioxide (VCO_2; ml/min); oxygen quotient (qO_2); carbon dioxide quotient (qCO_2); oxygen pulse (VO_2/HR; ml/min/rpm) and respiratory exchange rate (VCO_2/VO_2, RER).

The exercise phase was terminated according to the following criteria: fatigue in the leg muscles with difficulty cycling for a certain cadence; the predicted maximum HR has been reached; increasing shortness of breath; general fatigue; maximum arterial systolic blood pressure of 250 mmHg has been reached; chest pain; ECG changes that limit continued exercise: frequent ventricular extrasystoles or ischemic changes in ECG; other general symptoms: hypoxaemia, sudden paleness, confusion or dizziness. After the cardiopulmonary exercise testing each athlete was consulted by the sports physician and provided with the explanation of the results and recommendations for further training.

As it is written in the literature, the cardiopulmonary load testing is a relatively safe method, if it is performed by a trained, experienced and certified medical specialist, following the methodology, evaluating successive changes in two monitors, following the individual's complaints and stopping the testing when it is necessary (Myers et al., 2014). During the cardiopulmonary exercise testing complications are rare, usually they are associated with the underlying disease 0–14 cases per 100,000 tests, while the risk of sudden death is lower by 0–5 cases per 100,000 tests (Myers et al., 2014).

All statistical analyses were performed using International Business Machines Corporation Statistical Package for the Social Sciences software, version 22.0 (IBM SPSS, Corp., Armonk, NY). Categorical variables were described as frequencies and percentages. Normally distributed continuous variables were described as means and standard deviations (SD) using frequency and percentages or as medians and ranges in the case of not-normal distribution. Comparisons between 2 groups of participants accordingly to gender, training programme and appointment time were performed with the Student t-test for independent groups or with the Mann–Whitney test, according to the distribution of variables. Categorical variables were compared between groups with Pearson chi-square or Fisher exact test. Significance was considered as $p < 0.05$.

3. Results

3.1. First Appointment

At the first appointment, all the participants were tested without receiving a sports physician's exercise consultation and taking preventive measures. It provides an opportunity to collect and assess the health and functional data of physically active people – athletes of different age and gender.

3.1.1. Anthropometric Measurements

For athletes aged 12–15 years and 16–19 years, regardless of the training programme, the BMI was determined within the norm according to the percentile scales. For female athletes in the adult age groups, BMI was also within the normal range, except in the F50–59 < 1 group – elevated 25.48 ± 3.78 kg/m^2. In male athletes M20–29 < 1, M20–29 ≥ 1 and M30–39 < 1 groups, the BMI was within the normal range, but in the other groups it was increased – overweight.

3.1.2. Training Programme

Assessing the current training programme, both gender athletes with the training programme of < 300 exercise minutes per week in all age groups had to start exercising statistically significantly later, exercising for a shorter time without interruption and less regularly compared to athletes with the training programme ≥ 300 exercise minutes per week ($p < 0.05$). Athletes of both genders in the youngest age groups: 12–15 years and 16–19 years, trained statistically more often in a sports organization and under the guidance of a sports coach than adults ($p < 0.001$). In the age groups of 20–29 years, 30–39 years and 40–49 years, male athletes with the training programme ≥ 300 exercise minutes per week were statistically significantly more likely to exercise regularly in a sports organization and under the guidance of a sports coach than male athletes with the training programme of < 300 exercise minutes per week ($p < 0.05$). 81.3–85.6 % of all female athletes and 90.0–91.3 % of all male athletes had a sports history in adolescence. Athletes of both genders in all age groups had a statistically significant difference in training duration ($p < 0.001$) (Table 3.1).

Table 3.1

Duration of training per week for athletes undergoing different training programmes on the first appointment

Group < 300 exercise minutes per week	Duration of training per week, min	Group ≥ 300 exercise minutes per week	Duration of training per week, min	p compares the influence of training programme
F12–15 < 1	245 [210; 285]	F12–15 ≥ 1	567 [420; 1020]	< *0.001**
F16–19 < 1	270 [230; 285]	F16–19 ≥ 1	720 [540; 1110]	< *0.001**
F20–29 < 1	154 [98; 185]	F20–29 ≥ 1	360 [360; 458]	< *0.001**
F30–39 < 1	150 [60; 180]	F30–39 ≥ 1	360 [326; 376]	< *0.001**
F40–49 < 1	120 [60; 180]	F40–49 ≥ 1	320 [300; 400]	< *0.001**
F50–59 < 1	172 ± 79	–	–	–
M12–15 < 1	240 [180; 270]	M12–15 ≥ 1	450 [360; 600]	< *0.001**
M16–19 < 1	270 [165; 270]	M16–19 ≥ 1	630 [450; 900]	< *0.001**
M20–29 < 1	240 [124; 293]	M20–29 ≥ 1	540 [370; 743]	< *0.001**
M30–39 < 1	155 [120; 210]	M30–39 ≥ 1	383 [360; 600]	< *0,001**
M40–49 < 1	180 [100; 200]	M40–49 ≥ 1	360 [300; 480]	< *0.001**
M50–59 < 1	180 [88; 229]	M50–59 ≥ 1	360 [338; 484]	< *0.001**
M60–69 < 1	185 ± 28	–	–	–

* $p < 0.05$ was considered statistically significant.

3.1.3. Subjective Health Status

In female athlete groups, the most common complaints were about the musculoskeletal system and its function, except for F20–29 < 1 – excessively increased pulse and fatigue, decreased endurance and prolonged recovery; F30–39 ≥ 1 – fatigue, reduced endurance and prolonged recovery and F40–49 ≥ 1 – increased pulse. In male athlete groups, regardless of the training programme, the most common complaints were about the musculoskeletal system and its function, except for M50–59 < 1 – fatigue, reduced endurance and prolonged recovery. No statistically significant difference was found between the study groups ($p > 0.05$). Some participants smoked: 5.5 % of all females and 6.5 % of all male participants.

3.1.4. Physical Working Capacity

Athletes performed the maximum absolute work-rate according to their body's physical working capacity. Comparing the maximum absolute work-rate with the predicted maximum absolute work-rate, statistically significant gender differences were observed (Figure 3.1). Female athletes in all age groups, regardless of the training programme, exceeded the predicted maximum absolute work-rate ($p < 0.05$). Male athletes in M12–15 < 1, M12–15 ≥ 1, M16–19 < 1 and M20–29 < 1 groups did not reach ($p < 0.05$); in M16–19 ≥ 1, M20–29 ≥ 1, M30–39 < 1, M40–49 < 1, M50–59 < 1 groups reached ($p > 0.05$); in M30–39 ≥ 1, M40–49 ≥ 1, M50–59 ≥ 1 and M60–69 < 1 groups statistically significantly exceeded the predicted maximum work-rate ($p < 0.05$). Female athletes in the F20–29 ≥ 1, F30–39 ≥ 1 and F40–49 ≥ 1 groups and male athletes in all age groups with training programme ≥ 300 exercise minutes per week showed statistically significantly higher aerobic capacity, anaerobic capacity, relative work-rate at HR170 and reached the maximum work-rate compared to athletes in the respective age group with training programme < 300 exercise minutes per week ($p < 0.018$).

Athletes of both genders undergoing training programme of more than 300 exercise minutes per week had a significantly higher heart functional index by 0.55–0.57 W/kg, higher physical working capacity index by 0.67–0.69 W/kg compared to athletes following training programme of less than 300 exercise minutes per week.

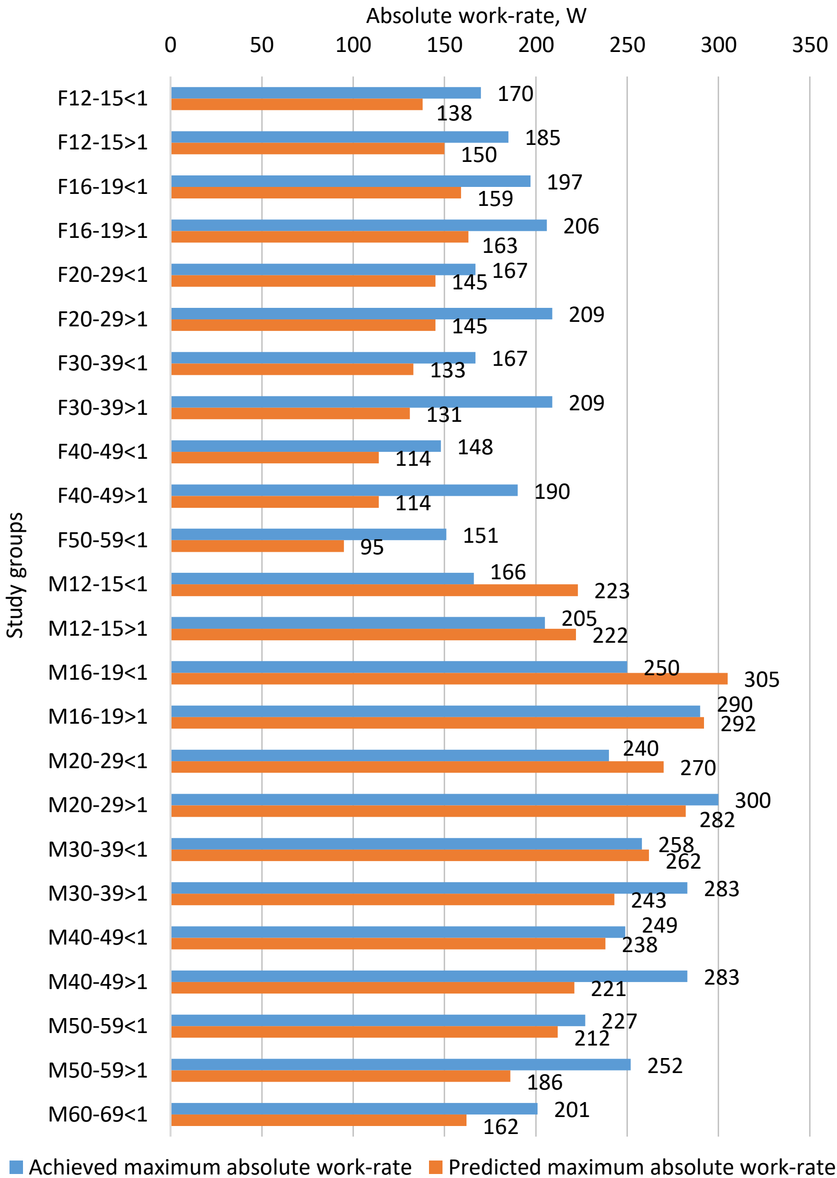

Figure 3.1 **Predicted and achieved maximum absolute work-rate for athletes undergoing different training programmes**

3.1.5. Functional Parameters of the Cardiovascular and Respiratory Systems

A statistically significant difference in results was observed in athletes of both genders undergoing training programme ≥ 300 exercise minutes per week compared to athletes who followed training programme < 300 exercise minutes per week at specific time points during the testing in the following parameters ($p < 0.05$): higher SV, Qt, Pp and lower DBP; F20–29 ≥ 1, M20–29 ≥ 1 higher SBP; M20–29 ≥ 1 higher RI; F40–49 ≥ 1 higher HI. No statistically significant difference in the results depending on the training programme was observed for female athletes aged.

At rest SBP and DBP were recorded to be normal in all study groups, except male athlete groups M50–59 < 1, M50–59 ≥ 1 and M60–69 < 1 where prehypertension was observed. During exercise, a normal normotonic reaction was observed in all 24 study groups. However, analysing each individual's blood pressure reaction to exercise, the hypertensive reaction to exercise was identified in each group of both gender athletes in post-puberty and adult athletes: 12 women and 96 men undergoing training programme < 300 exercise minutes per week and 5 women and 107 men undergoing training programme ≥ 300 exercise minutes per week. In male athletes, hypertensive reactions to exercise were significantly more common than in female athletes, and the incidence increased with age. During exercise, SV increased, reaching its highest level at the aerobic threshold. A statistically significant difference, dependence of the training programme and gender was observed, except in age groups of 12–15-year-old athletes. The highest Qt was reached at the maximum work-rate, with a statistically significant dependence on the training programme. In all groups of adults, RI and HI were within normal range. Analysing the qualitative data, RI was below middle and the risk of coronary heart disease was higher in 9 adult athletes, but reduced HI was detected of 118 individuals.

In the analysis of respiratory rhythm, more frequent non-rhythmic and forced respiration, regardless of gender, was detected in adolescents. At maximal work-rate, the highest VE was exhibited by female athletes in the F16–19 ≥ 1 group – 80.56 ± 18.16 l/min, and by male athletes in the M20–29 ≥ 1 group – 121.38 ± 18.22 l/min. A statistically significant difference in respiratory functional parameters was observed in athletes of both gender undergoing training programme ≥ 300 exercise minutes per week compared to athletes following training programme < 300 exercise minutes per week ($p < 0.05$): higher VE, VO_2 max, rel VO_2, VCO_2 and oxygen pulse; additionally, F20–29 ≥ 1 lower qO_2 and qCO_2; M16–19 ≥ 1, M20–29 ≥ 1 and M50–59 ≥ 1 higher ITV, ETV and VB; F40–49 ≥ 1, M20–29 ≥ 1 and M50–59 ≥ 1 higher BF. There was no statistically significant difference in respiratory performance ($p > 0.05$) in female athletes aged 16-19 years, depending on the training programme. The highest oxygen uptake was determined for athletes aged 16–19 years: females in groups F16–19 < 1 2345 ± 422 ml/min and F16–19 ≥ 1 2473 ± 489 ml/min, and males in groups M16–19 < 1 3318 ± 549 ml/min and M16–19 ≥ 1 3663 ± 582 ml/min. There were statistically significant gender differences – male athletes showed a higher maximum oxygen uptake ($p < 0.05$), except at 12–15 years of age. MET achieved during exercise was also statistically significantly dependent on the training programme. Athletes undergoing training programme ≥ 300 exercise minutes per week reached a higher MET ($p \leq 0.001$). Comparing the maximum and predicted MET, female athletes in all groups except F40–49 ≥ 2 and F50–59 < 2 did not achieve the predicted MET, as did male athletes who followed training programme < 300 exercise minutes per week, except in group M60–69 < 2. Male athletes in group M12–15 < 2 undergoing training programme ≥ 300 exercise minutes per week did not reach, but in the other groups slightly exceeded the predicted MET.

3.1.6. Reasons of the Termination for Cardiopulmonary Exercise Testing

The most common reason for the termination of cardiopulmonary exercise testing in female athlete group F12–15 < 1 was achieving the predicted maximum HR. In adult female athlete groups, regardless of the training programme, the most frequent reason was the shortness of breath. In male athletes aged 12–15, 16–19, 20–29 and 30–39 years, regardless of the training programme, the most frequent reason was lower limb muscle fatigue with difficulties in further pedalling in definite cadence, 40–49 years old – the shortness of breath, 50–59 years age – reaching of the predicted maximum HR. No statistically significant difference in the frequency of the reasons for the cardiopulmonary exercise testing was observed ($p > 0.05$).

3.1.7. Electrocardiography

During resting, exercise and recovery, the ECG recorded sinus rhythm in all individuals, regardless of gender, age, and chosen training programme, except for 1.0–2.0 % of athletes of both genders in the 30–39 and 40–49-years age groups with ectopic atrial rhythm. 28.3 % (n–453) of athletes had cardiac conduction changes: 10.7 % (n–59) of female athletes and 20.0 % (n–221) of male athletes had incomplete blocks of the His bundle right branch.

Non-specific ST-segment T-wave changes were observed relatively more often in females at rest than in males at rest, especially in the older study groups. During the exercise its frequency decreased (Figure 3.2). None of the participants in the study had complaints which would indicate ischemia in the heart muscle, however the cardiopulmonary exercise testing revealed cases of ischemic ECG changes during the exercise: ST-segment 1 mm depression of 0.06–0.08 milliseconds from the J-spot . As the age of the athletes increased, ischemic ECG changes during exercise were more common. All the athletes with diagnosed ischemic ECG changes were sent for additional cardiological and blood biochemical analyses and an individualized exercise programme with restrictive measures was planned.

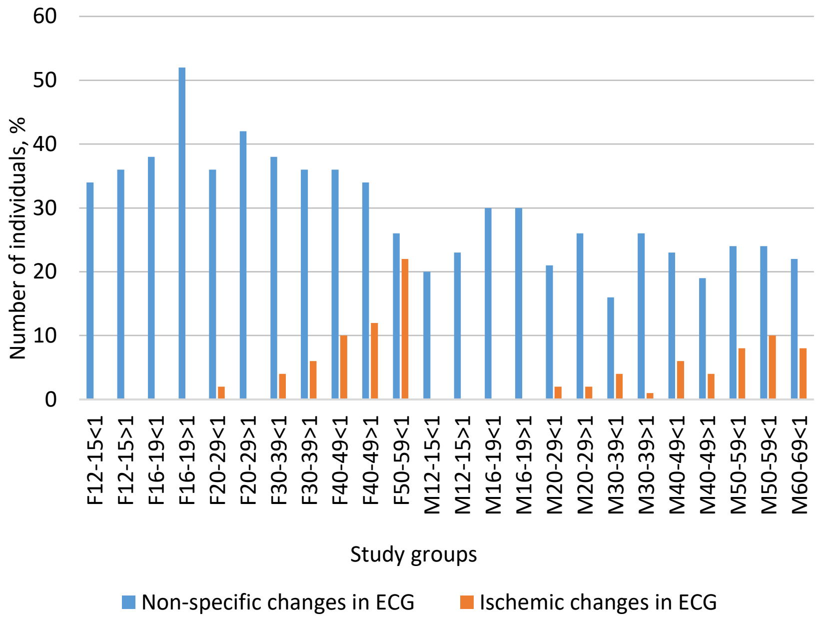

Figure 3.2 **Non-specific and ischemic ECG changes during exercise in athletes undergoing different training programmes**

3.1.8. Evaluation of the First Appointment Testing Results

All the testing results were important in assessing the health status of athletes and the need for further supervision by a sports physician. As the age increased, athletes were more often in need of a regular sports physician's supervision (Figure 3.3). Good functional status was statistically significantly more common in athletes undergoing training programme ≥ 300 exercise minutes per week ($p < 0.05$). Athletes were divided into clinical functional groups: Group 1–2.1 % (n–33); Group 2–67.6 % (n–1081); Group 3–30.4 %

(n–486) of all the athletes, without statistically significant dependence on the training programme ($p > 0.05$). 20.0 % (n–320) of all the athletes had adapted to exercise, 52.5 % (n–840) of the athletes demonstrated reduced adaptation and 27.5 % (n–440) of the athletes had not adapted to physical activity.

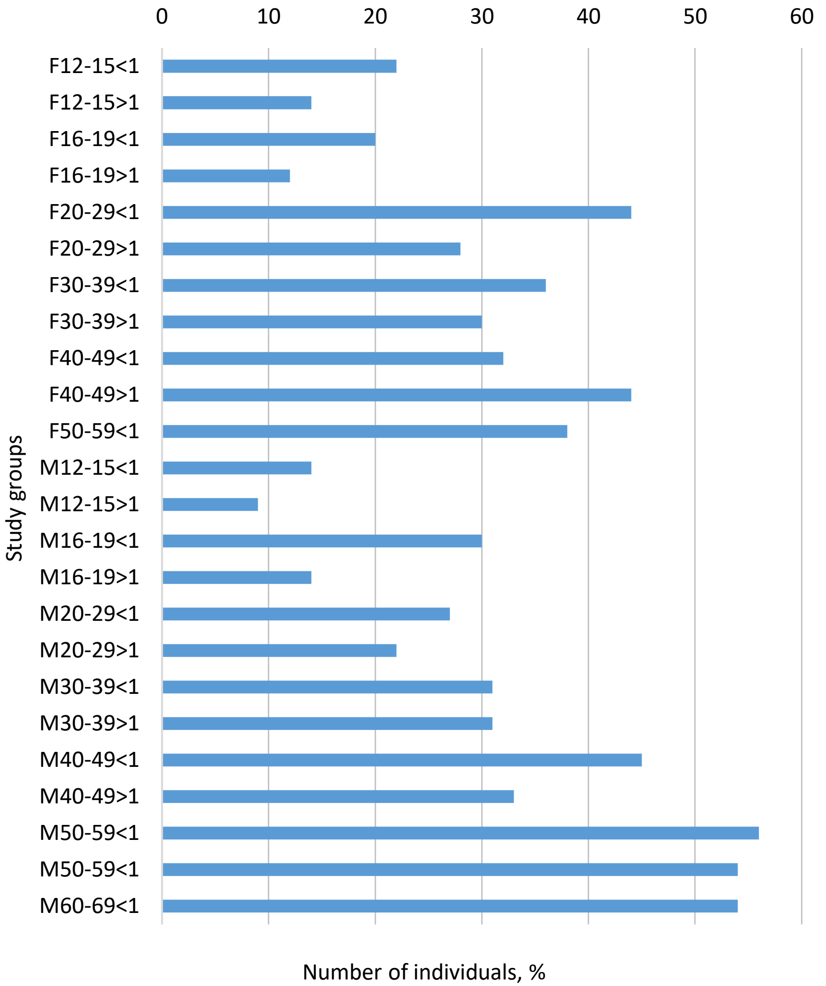

Figure 3.3 **Percentage of Athletes Under Regular Sports Physician's Supervision**

During the first appointment all the participants received a sports physician’s consultation in which the individual's health status, functional condition, physical working capacity and exercise tolerance were analysed and recommendations for maintaining and improving health and adjusting their training programme were provided, as well as individualized exercise planning, treatment and supplement prescription was done if necessary.

3.2. Second Appointment

In 5–9 months, during the second appointment, participants were retested according to an identical protocol. This made it possible to assess the impact of a sports physician's consultation and individualized physical exercise on the participants' health status, functioning of the body's systems, exercise tolerance and physical working capacity.

3.2.1. Anthropometric Measurements

During the second testing, no statistically significant changes in BMI were found in female athletes ($p > 0.05$), but in male athletes, BMI was found to be statistically significantly lower and was in norm in the M30–39 < 2, M40–49 < 2, and M50–59 < 2 groups ($p < 0.045$).

3.2.2. Training Programme

No statistically significant difference in the organization of the training process was observed in adolescents of both gender athletes ($p > 0.05$). The female athletes F20–29 ≥ 2 ($p = 0.008$) and male athletes M20–29 ≥ 2 statistically significantly more often performed training in a sports organisation or / and with coach guidance ($p = 0.027$).

3.2.3. Subjective Health Status

Complaints were statistically significantly less frequent in female athletes: F12–15 ≥ 2 by 28.0 % (n–14) ($p = 0.005$), F30–39 < 2 by 22.0 % (n–11) ($p = 0.028$); in male athletes: M50–59 < 2 by 34.0 % (n–17) cases ($p = 0.001$). The number of physically active people who smoked decreased: 2.0 % of all female athletes and 3.4 % of all male athletes.

3.2.4. Physical Working Capacity

After a sports physician's consultation, following an individually appropriate training programme, athletes showed statistically significantly higher aerobic capacity in groups: F16–19 ≥ 2 and F20–29 ≥ 2; higher aerobic and anaerobic capacity in groups: F20–29 < 2 and F40–49 < 2 and M12–15 ≥ 2, M16–19 < 2, M20–29 < 2, M20–29 ≥ 2, M30–39 < 2, M40–49 < 2, M50–59 < 2; depended on the gender and training programme in groups: F20–29 < 2, F30–39 < 2, F40–49 < 2, M12–15 < 2, M20–29 < 2, M30–39 < 2, M40–49 < 2, M50–59 < 2 and F16–19 ≥ 2, F20–29 ≥ 2, M12–15 ≥ 2, M20–29 ≥ 2 and M30–39 ≥ 2 ($p < 0.05$). A substantial difference was observed comparing the achieved maximum absolute work-rate with the predicted maximum absolute work-rate (Figure 3.4).

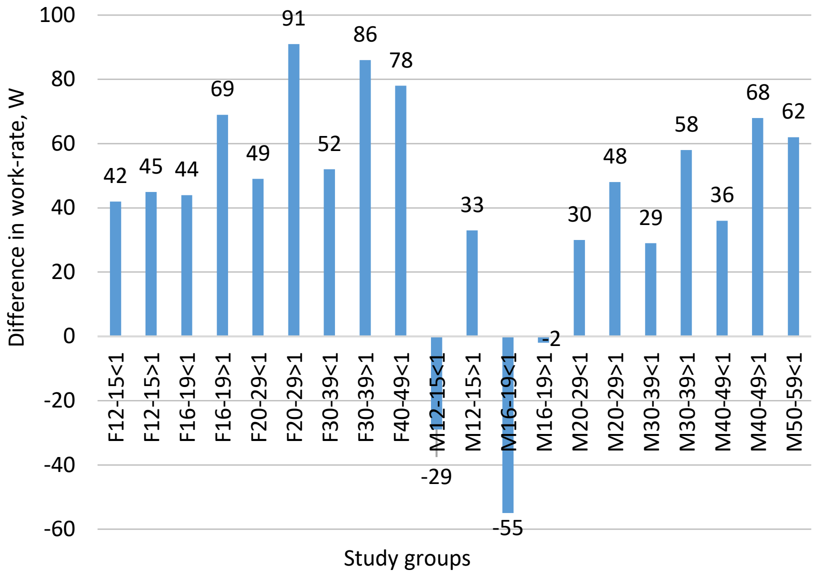

Figure 3.4 **The difference between the achieved and predicted absolute maximum work-rate in athletes undergoing different training programmes during the second appointment**

At the second appointment, athletes showed a statistically significantly higher physical working capacity index ($p < 0.05$) depending on the training programme, the same as the heart functional index. Athletes aged 20–29 years showed the highest physical working capacity index: females in group F20–29 ≥ 2 3.57 ± 0.74 W/kg and males in group M20–29 ≥ 2 4.28 ± 0.93 W/kg.

3.2.5. Functional Parameters of the Cardiovascular and Respiratory Systems

Following the sports physician's exercise recommendations, the athletes statistically significantly increased the functional parameters of the cardiovascular system: lower HR and higher systolic volume ($p < 0.05$). An increase in Qt was also observed in all study groups at specific time points during the testing. During exercise, a normal normotonic reaction was observed in all 24 study groups but individual cases with a hypertensive reaction were less reported: F20–29 ≥ 2 only 1 in female athletes and 137 in male athletes or 32.51 % less frequently. The reduced HI was observed significantly infrequently – in 64 individuals. Statistically significantly lower total vascular resistance was detected ($p < 0.05$).

VE, VO_2, rel VO_2, VCO_2 and oxygen pulse was statistically significantly increased in all study groups at specific time points of the exercise testing ($p < 0.05$). The highest VO_2 max was observed in athletes aged 16–19 years: female group F16–19 ≥ 2 2879 ± 455 ml/min or by 406 ml/min or 9.53 % more than during the first testing ($p < 0.001$); male group M16–19 ≥ 2 4049 ± 527 ml/min or 386 ml/min or 14.10 % more than during the first testing ($p < 0.001$). All female athlete groups significantly exceeded the predicted VO_2 max by 10.5–33.9 %, but male athletes in M12–15 < 2 – did not reach the predicted VO_2 max by 21.1 %, M16–19 < 2 group did not reach VO_2 max by 3.4 %, M12–15 ≥ 2; M16–19 ≥ 2 reached it, but in the adult athlete groups the predicted VO_2 max was exceeded by 6.7–32.1 %. The maximum number of METs achieved depended on age, gender, and training programme. At the maximum work-rate, athletes of both genders statistically significantly increased the number of METs and reached parameters listed in the Table 3.2 ($p < 0.05$). The maximum MET achieved at the maximum work-rate was compared with the predicted values: female athletes, except F40–49 < 2, F12–15 ≥ 2, F16–19 ≥ 2, did not reach the predicted maximum MET (as in the first testing). Male athletes in all groups, regardless of the training programme, exceeded the predicted maximum MET.

Table 3.2

Maximum metabolic equivalent in athletes undergoing different training programmes

Groups < 300 exercise minutes per week	Maximum reached MET	Groups ≥ 300 exercise minutes per week	Maximum reached MET	p compares the influence of training programme
F12–15 < 2	10.74 ± 1.53	F12–15 ≥ 2	11.27 ± 1.54	*0.378*
F16–19 < 2	10.09 ± 1.63	F16–19 ≥ 2	11.33 ± 1.65	*0.001**
F20–29 < 2	10.18 ± 1.61	F20–29 ≥ 2	11.85 ± 1.86	< *0.001**
F30–39 < 2	9.51 ± 1.93	F30–39 ≥ 2	11.37 ± 1.90	< *0.001**
F40–49 < 2	9.80 ± 2.12	–	–	–
M12–15 < 2	12.21 ± 2.23	M12–15 ≥ 2	13.90 ± 1.99	< *0.001**
M16–19 < 2	13.14 ± 2.38	M16–19 ≥ 2	14.33 ± 2.24	< *0.001**
M20–29 < 2	12.58 ± 2.21	M20–29 ≥ 2	14.15 ± 2.41	< *0.001**
M30–39 < 2	12.23 ± 2.09	M30–39 ≥ 2	12.64 ± 2.09	*0.468*
M40–49 < 2	11.17 ± 1.93	M40–49 ≥ 2	12.26 ± 2.17	*0.021**
M50–59 < 2	11.22 ± 1.92	–	–	–

* $p < 0{,}05$ statistically significant difference.

In both genders, the oxygen pulse was statistically significantly dependent on the training programme ($p < 0.05$).

3.2.6. Reasons of the Termination for Cardiopulmonary Exercise Testing

The most common reason for the termination of cardiopulmonary exercise testing in female athletes changed from other reasons to lower limb muscle fatigue, the same as it was in male athletes in the older groups.

3.2.7. Electrocardiography

The study did not find a statistically significant difference in the analysis of heart rhythm and cardiac conduction changes depending on the training programme. In the F20–29 ≥ 2 group there were statistically significantly less athletes – by 24.0 % (n–12) – with nonspecific ECG changes at rest ($p = 0.013$).

3.2.8. Evaluation of the Second Appointment Testing Results

At the second appointment, the health status of athletes was statistically significantly more often assessed as healthy for athletes undergoing training programme < 300 exercise minutes per week ($p < 0.05$). The functional condition and recovery were depended on the training programme ($p < 0.05$). In the first clinical functional group were 4.2 % (n–55), in the second clinical functional group were 78.5 % (n–1021), in the third clinical functional group were 17.2 % (n–224) of all athletes. A statistically significantly better recovery was observed in athletes undergoing training programme < 300 exercise minutes per week: F16–19 < 2, F20–29 < 2, F30–39 < 2, F40–49 < 2 ($p \leq 0.009$) and M30–39 < 2 ($p \leq 0.025$); athletes undergoing training programme ≥ 300 exercise minutes per week: F20–29 ≥ 2, F30–39 ≥ 2 ($p \leq 0.013$) and M12–15 ≥ 2 groups ($p = 0.021$). Athletes were statistically significantly adapted to physical exercise more often in female groups F12–15 ≥ 2, F16–19 < 2, F20–29 < 2, F20–29 ≥ 2, F30–39 < 2, F30–39 ≥ 2, F40–49 < 1 ($p \leq 0.046$) and in male group M30–39 < 2 ($p = 0.002$).

4. Discussion

In the study, involving the largest group of physically active people – athletes who consider themselves healthy and participate in sports competitions, exercise tolerance and its characteristics and the relevance of exercise tolerance to health status were studied. In order to analyse the obtained results, the discussion part of the Thesis was divided as follows: training programme, physical working capacity, cardiovascular system, respiratory system, reasons for termination of the cardiopulmonary exercise testing, recovery, adaptation to physical exercise and the planning of individually suitable training programme.

Training programme

It is crucial for athletes who participate in sports competitions in all sports levels to follow a training programme suitable for their individual health status, functional condition and physical working capacity. It is characteristic of popular or amateur sports that individuals who initially perform physical activity with the aim of improving their health and increasing their physical working capacity, after a while increase the frequency, duration and intensity of training and start participating in sports competitions. Within the meaning of the Sports Law, these individuals become athletes (Sports Law, 2002). If the training programme chosen by amateur sports athletes does not give the desired result, it may increase health risk, including cardiovascular events, and overload (Skalik, 2015). In the study, it was observed that having received recommendations after sports physician’s exercise consultation an athlete trained more regularly, achieving longer exercise time per week and an increased exercise tolerance.

Physical working capacity

Athletes' physical working capacity was also affected by their training programme and gender, but was not affected by age (Beaumont et al., 2018). Following an individually suitable training programme, athletes undergoing training programme < 300 exercise minutes per week in the long term demonstrated a statistically significant increase in physical working capacity. Regular training programmes provided better cardiovascular and respiratory function, and reduced the risk of cardiovascular disease and sudden death in athletes (Corrado et al., 2006).

Comparing the physical working capacity index determined at the second appointment with the assessment of V. Karpman's physical working capacity for adults available in the scientific literature, a significant difference was observed: female athletes undergoing training programme < 300 exercise minutes per week exceeded the high level by 20.9–30.9 %, female athletes undergoing training programme ≥ 300 exercise minutes per week – by 37.0–55.2 % (Карпман, 1969; Карпман, 1988). Male athletes showed similar results. The increase in fitness and physical working capacity was ensured by statistically significantly improved aerobic and anaerobic capacity, better functional capacity of the cardiovascular system and respiratory system. The significant difference in the data for female athletes created a scientific and practical need to develop more objective scales for the evaluation of the physical working capacity index, taking into account the training programme and in the future possibly include this information in the predicted parameter scales of a diagnostic equipment. The highest physical working capacity index was achieved by athletes of both genders aged 20-29 years undergoing training programme ≥ 300 exercise minutes per week. Comparing them with data from professional athletes of a similar age, a significant difference was observed. Female athletes showed a 54.5–76.7 % and male athletes showed a 47.8–79.1 % lower physical working capacity index (Areta, 2020; Fornasiero et al., 2018; McArdle, Katch FI and Katch VL, 2010).

Cardiovascular System

A sports physician must be able to identify individuals with inappropriately high heart rate, low physical working capacity and fitness or poor body functionality. The heart rate at specific time points during the cardiopulmonary exercise testing was dependent on the individual's health status, functional condition of the body, training programme and the physical working capacity. Regular exercise with included individually appropriate endurance exercises, such as cycling, running or cross-country skiing provided prevention of arterial hypertension (Pescatello et al., 2004) or normalized increased blood pressure. This was evidenced by the data of the study: after an individually suitable training programme, the number of individuals with a hypertensive response to exercise decreased significantly or by 38.1% (n–85). Individuals were informed that physical exercise is an important factor in the treatment of arterial hypertension (Maron, Pelliccia, 2006; Pelliccia et al., 2005). The European Society of Cardiology has included in its recommendations the ethical, medical and legal responsibility of a physician to inform an athlete at any sports level about the effects of exercise on the body, increased acute cardiovascular risk and the choice of appropriate treatment, including individually suitable exercise for the delay of cardiovascular disease (Pelliccia et al., 2005).

In athletes of different ages, stroke volume depended on gender, body composition, heart size, sympathetic stimulation of the heart, its contractility, sports history, and other factors (Csecs et al., 2020; Wheatley et al., 2014). During the second testing a significant increase in stroke volume at specific time points during the testing was observed, which resulted in a lower heart rate at the respective work-rate. During exercise, stroke volume was statistically significantly dependent on the chosen training programme and exercise duration (Rozenstoka and Erglis, 2020). During exercise, the highest stroke volume was shown by female athletes aged 16–19 years following training programme of ≥ 300 exercise minutes per week: 105 ± 17 ml. However, it was significantly lower than the 125 ml stroke volume in professional female athletes mentioned in the literature (Ferguson et al., 2001). Male athletes aged 20–29 years undergoing training programme ≥ 300 exercise minutes per week showed the highest stroke volume 140 ± 13 ml, which was significantly lower than that reported in the literature for male professional athletes 160–180 ml at a heart rate 120–150 bpm or higher than stroke volume in untrained male population 100 ml (Degens et al., 2019; McArdle, Katch FI and Katch VL, 2010). This difference in results creates an objective need for an in-depth assessment of the functional performance of physically active people.

Cardiac output as a parameter for assessing cardiac function is important for diagnosing heart disease, prescribing treatment, preventing it (Vignati and Cattadori, 2017; Vignati et al., 2017) and planning physical activity with necessary limitations. It significantly affects an individual's anaerobic capacity, physical working capacity and fitness and allows a more accurate determination of the individual's functional condition or diagnoses the disease (Vignati and Cattadori, 2017). The data of the study showed that the cardiac output depends on the age, gender, physical working capacity and training programme of the athletes. Following sports physician’s exercise consultation recommendations, female athletes increased their maximum cardiac output by 1.5–2.8 l/min and male athletes – by 1.6–3.8 l/min, regardless of the training programme.

Intensive load of training and participation in sports competitions can increase the relative risk of sudden cardiac death by 2.8 times compared to untrained individuals (Corrado et al., 2006). Therefore, during the cardiopulmonary exercise testing ECG analyses made possible to diagnose heart disease, changes in heart rhythm, or conditions that increase the risk of acute cardiac events or sudden death in sport (Sharma, Merghani and Mont, 2015). Characteristic changes in an athlete's ECG are influenced by age, gender, race, and the sports exercise (Sharma, Merghani, and Mont, 2015). In athletes of both genders, the most frequent changes of the heart conduction system reported in ECG were incomplete block of the His bundle right branch with a normal-length QRS complex. It is diagnosed in 3.0–4.6 % of the population and 9.0–24.0 % more often in the athlete population, which is in-line with the frequency of this finding among the study participants. For most individuals, this was the only finding in ECG and did not indicate structural damage to the heart (Bussink et al., 2013; Le et al., 2010; Malhotra et al., 2015).

Accelerated heart rate and increased stroke volume during exercise were associated with shorter cardiac diastolic time (Bodegard et al., 2005; Wasserman et al., 2005). At rest, non-specific changes in the ST segment – T wave, regardless of the training programme, were detected more often in females – in 37.3–38.0 % of cases, less often in males – in 22.7–23.7 % of cases. Preventative measures such as adequate daily regime, good sleep, healthy and balanced diet with omega – 3 fatty acids, vitamins and minerals, adequate hydration, other measures and adherence to an individually suitable training programme reduced the incidence by 4.3 %. Coronary heart disease is the most common cause of exercise-related sudden death in individuals over the age of 35, therefore diagnosis of ischemic changes during maximum exercise was very important (Singh and Baggish, 2018). According to the scientific literature, the ischemic changes on the ECG are recorded in 4.4 % of the adult athlete population (Ng, 2006). In this study, 3.6 % or 30 adult females and 3.0 % or 31 adult males without typical complaints, had the ischemic changes in ECG during the exercise: ST-segment 1 mm depression of 0.06–0.08 milliseconds from the J-spot. In both testings individuals did not meet the exercise termination criterion when ST-segment 2–3 mm depression of 0.06–0.08 milliseconds from the J-spot was observed (Bodegard et al., 2005). In the second testing less individuals with the ischemic changes in ECG during the exercise: ST-segment 1 mm depression of 0.06–0.08 milliseconds from the J-spot, could be explained with better cardiovascular adaptation to the physical exercise, economical use of resources, decreased demand and the sensitivity of testing method. When an individual was diagnosed with ischemic ECG changes, an in-depth blood biochemical parameter measuring and additional cardiac examination were prescribed, and an individual exercise with significant limitations was prescribed by a sports physician.

Respiratory System

The functioning of the athlete's respiratory system at rest and during exercise is affected by various factors: health status, stress durability, physical exercise, intensification of the body functions, including the respiratory system and others (Rozenstoka et al., 2016; Rozenstoka and Erglis, 2020; Smoliga et al., 2016; Wasserman et al., 2005). During the first testing, 24.0 % (n–384) of all individuals mentioned shortness of breath as a reason for exercise termination, the reason was statistically significantly more often mentioned by females. In all of these cases, it was important to find the cause. A significant proportion of individuals had an irregular breathing rhythm: 53.6–54.0 % of females and 49.3–52.6 % of males, more frequently in the 12–15 and 16–19-years age groups. This reflected a problem that children are not taught proper breathing techniques during various physical activities during sports lessons and also during organized training by sports education institutions.

Expired volume was influenced by the chosen training programme, age, gender, physical working capacity and other factors. During the second testing, athletes statistically significantly increased their expired volume during the maximum work-rate. Athletes undergoing training programme ≥ 300 exercise minutes per week reached the highest expired volume: females in the 16–19 age group – 90.18 ± 17.26 l/min and males in the 20–29 age group – 131.15 ± 18.17 l/min. It was 27.2–28.5 % less than that reached by professional athletes and 27.3–34.6 % more than expired volume at maximum work-rate in the population (Jordan et al., 2009; Rozenstoka et al., 2016).

An important parameter in sports medicine is the oxygen uptake determined during exercise (Fletcher et al., 2013; Mayolas et al., 2017). The study confirmed that the maximum oxygen uptake and the volume of carbon dioxide were dependent on gender, age and the chosen training programme. In different age, gender and training programme groups, athletes statistically significantly exceeded the predicted maximum oxygen uptake by 6.7–34.2 % ($p < 0.001$). The data detected the discrepancy between the predicted maximum oxygen uptake at significantly lower absolute work-rate. This requires further research into the calculation of theoretical values, taking into account the influencing factors. It has been reported in the literature that individuals show higher relative oxygen uptake between the ages of 15 and 30, which was also confirmed in the study (Fletcher et al., 2013). However, the study was able to clarify that the highest relative oxygen uptake was shown by athletes undergoing training programme ≥ 300 exercise minutes per week: females aged 20–29 years 41.49 ± 6.50 ml/kg/min and males aged 16–19 50.14 ± 7.84 ml/kg/min.

Metabolic equivalent is an important prognostic parameter in medicine for assessing the body's cardiorespiratory health, function and physical performance (Fletcher et al., 2013). The size of metabolic equivalent during exercise could theoretically be used for exercise planning, however, this isolated single-parameter method was found to have significant shortcomings in overestimating or underestimating an individual's fitness and physical working capacity, including individuals with coronary heart disease and other diseases (Franklin et al., 2018). Thus, in order to compile recommendations for such a complex issue as an individually suitable physical exercise and to plan the training programme, all the obtained parameters and their interrelationships must be analysed. A statistically significant increase in the size of metabolic equivalent was observed in all groups of athletes after following the sports physician's exercise consultation. This indicated a lower risk of cardiac events (Franklin et al., 2018). The Latvian Society of Cardiology guidelines "Physical exercise tests, methodology, 2008" are used in exercise testing where the norm size of metabolic equivalent for population is mentioned (Mintale and Erglis, 2008). In this study was shown that the maximum size of metabolic equivalent reached by female athletes did not reach the predicted size in either the first or second testing. Female athletes who did not reach the predicted size of metabolic equivalent achieved and exceeded other predicted parameters. Such a different interpretation of the results could lead to difficulties in evaluating and interpreting the results in the sports physician's practice. The highest size of metabolic equivalent reached by male athletes, regardless of the training programme, exceeded the predicted size of metabolic equivalent. It created a need to re-evaluate the guidelines of methodological materials used in cardiology and sports medicine.

Reasons for termination of cardiopulmonary exercise testing

High intensity continuous physical exercise causes physiological fatigue in the body, which manifests itself in the individual's desire to stop exercise for central and peripheral reasons (Carriker, 2017). The reason for termination of the cardiopulmonary exercise testing, as one of the important factors of the exercise testing, showed the weakest possible functioning of the body's functional systems, lack of system cooperation or symptoms of a disease. During the first testing, the most common reason for exercise termination in a relatively large number of subjects, especially females, was shortness of breath. After a sports physician’s consultation about a suitable training programme and the athlete's technical training in proper breathing techniques during exercise, the functioning of the respiratory system and the cardiovascular system improved, and the athlete's ability to work increased. For most athletes, the most common reason for termination of the cardiopulmonary exercise testing was leg muscle fatigue.

Recovery

Recovery is an important part of the exercise and training process. In the first appointment, good and adequate recovery after the maximum work-rate was only 20.8 % of all athletes, in the second appointment the number of athletes with adequate recovery increased. Prolonged recovery was facilitated by individual inadequate and over-intensive training programmes, rapid growth in adolescence, daily stress, too short time to sleep and other factors.

Adaptation to physical activity

It is determined by the Sports Law of the Republic of Latvia and is generally accepted in professional sports that a healthy or practically healthy and trained athlete should schedule an appointment with a sports physician at least once a year for an in-depth preventive medical screening. Physically active people – athletes often do not undergo preventive medical screenings for various reasons, although their health and functional condition can be very different, possibly even associated with an increased risk to health. Individuals who considered themselves to be healthy were also included in this study, however, during an examination of individuals at the first appointment, it was found that as male athletes got older, they were more often recommended to see a sports physician regularly; their individual training programme needed to be reviewed more frequently: 50–59 and 60–69-years age groups even in 54–56 % of cases.

After the sports physician’s exercise consultation, the need for regular monitoring with a sports physician was observed statistically less often.

Adaptation of an athlete's body to physical exercise is one of the most important assessments in sports medicine. It describes the athlete's body response to the chosen sport, physical activity, training programme and the influence on the health status and the effectiveness of the functionality of body systems (Bompa and Haff, 2009; Dickhuth et al., 2012; Rozenstoka, Lace and Jubele, 2010; Rozenstoka and Erglis, 2020). Only 20.7 % of athletes were adapted to physical exercise at the first appointment and 31.2 % of athletes in the second appointment. The results confirmed that athletes who followed the recommendations provided at the exercise consultation with sports physician, did regular, longer and individually adapted exercise under the guidance of a sports coach, had higher exercise tolerance, better adaptation and faster recovery after exercise. This pointed to the usefulness of an individually suitable exercise and the value of the sports physician’s exercise consultation. Accordingly, each athlete and physically active individual must undergo an in-depth preventive medical screening, including a cardiopulmonary exercise testing, as required by the Sports Law of the Republic of Latvia, the Preparticipation medical evaluation for elite athletes: the European Federation of Sports Medicine Associations recommendations on standardized preparticipation evaluation form in European countries 2021 and recommendations of many international sports federations (Ionescu et al., 2021; Sports Law, 2002).

Individual training planning

A training programme with long enough and intense physical exercise can affect the way of existing heart disease and the risk of sudden cardiac death in sport (James et al., 2013; La Gerche, Heidbuchel, 2014; Mont et al., 2017). The sports physician should recommend physical activity that is adequate and appropriate to the individual's health, but should avoid the potential risks that physical exercise may pose. The sports physician provides an exercise consultation with guidelines for the training programme on the regularity, frequency and duration of exercise, successive changes in exercise and rest regime, the proportions of training parts, and specific tasks in the preparation cycle for a sports competition. When compiling the training plan, it is recommended to follow four parts of the training: a warm-up, the basic part of the training, a cool-down and a separate stretching part. Often, with individually suitable physical exercise, a significant therapeutic effect is achieved for an individual in the case of various diseases and rehabilitation after an injury, ensuring a faster return to sports.

Conclusions

Analysing the data obtained in the Thesis, it was concluded:

1. Athletes of both genders undergoing training programme more than 300 exercise minutes per week had significantly higher exercise tolerance, cardiac chronotropic and inotropic capacity, respiratory function, physical performance, 0.67–0.69 W/kg higher physical working capacity index and 0.55–0.57 W/kg higher heart functional index compared to athletes undergoing training programme less than 300 exercise minutes per week, but with advancing age, physically active individuals reduced training regularity and training duration as well as participation in a sports organization or did not seek the guidance of a sports coach.
2. For most physically active individuals – athletes, the training programme was adequate to their health status, but inadequate to the level of physical working capacity, which indicated that the general physical activity recommendations, while beneficial, may not be sufficient for an individual to choose an adequate training programme at each sport level to improve health and functional condition, to increase physical working capacity, to succeed in sports competitions and to reduce the risks of acute health events.
3. An exercise consultation with a sports physician improved an individual's health status, adaptation to physical exercise (more in females) and exercise tolerance: better physical working capacity (by 0.32–0.46 W/kg), greater stroke volume (by 4–21 ml) and cardiac output (1.6 to 3.6 l/min), expired volume (8.8 l/min), oxygen uptake (4.0 ml/kg/min) and volume of carbon dioxide during exercise, higher size of metabolic equivalent (by 1.14 MET) and

oxygen pulse (by 0.7–3.1 ml/min/bpm), as well as faster recovery after exercise.

4. Higher aerobic capacity, anaerobic capacity and faster recovery which significantly affected exercise tolerance and performance benefits, were observed in amateur athletes undergoing training programme more than 300 exercise minutes per week depending on gender, age and training programme.
5. Functional parameters of physically active people – athletes, physical working capacity index and heart functional index did not correspond to the data available in the professional literature and in order to ensure a full and clear interpretation and evaluation of the results it was necessary to establishing age-, gender- and training specific physical working capacity index and heart functional index evaluation scales for general use, as well as re-evaluate the guidelines of methodological materials used in the future.

Practical Recommendations

Athletes at all sports levels should be monitored regularly for in-depth preventive medical screenings, including cardiopulmonary exercise testing, especially if the duration of training exceeds 300 minutes per week. It is determined by the Sports Law of the Republic of Latvia, European Society of Cardiology and European Federation of Sports Medicine Associations recommendations. The in-depth preventive medical screening should include methods that ensure a full assessment of health and the functional condition of human body systems, adaptation to physical exercise and exercise tolerance. In order to provide an athlete with an individually suitable training programme, to reduce the risk of cardiac event and sudden death in sports, the athlete himself and the sports specialist must regularly cooperate with a sports physician. The sports physician will provide an exercise consultation and recommendations for the physical exercise suitable for an individual's health and physical working capacity: training programme: regularity, frequency and duration, training parts, specific tasks of the respective training cycle and recovery.

The author of the study developed physical working capacity index evaluation scales (Table 4.1 and Table 4.3) and heart functional index evaluation scales (Table 4.2 and Table 4.4), depending on age, gender and training programme. In practical work, these scales will be used by sports physicians and other specialists who are certified and use the cardiopulmonary exercise testing method and ECG and exercise testing methods. In the practice of sports physicians these scales will also be useful in exercise consultation for patients and physically active individuals – athletes of different gender, age, health status and physical working capacity undergoing different training programmes with or without participation in sports competitions to improve health and exercise tolerance and help achieve the goal in sports.

Table 4.1

Physical Working Capacity Index Scale for Physically Active Female, W/kg

Age groups	< 300 exercise minutes per week			≥ 300 exercise minutes per week		
	Low level	**Middle level**	**High level**	**Low level**	**Middle level**	**High level**
12–15 years	2.27–2.65	2.66–3.12	3.13–4.07	2.31–2.88	2.89–3.33	3.34–4.10
16–19 years	2.14–2.66	2.67–3.09	3.10–3.73	2.39–3.00	3.01–3.47	3.48–3.92
20–29 years	2.01–2.67	2.68–3.16	3.17–3.97	2.59–2.26	3.27–3.61	3.62–5.01
30–39 years	2.01–2.61	2.62–2.87	2.88–3.69	2.49–3.12	3.13–3.71	3.72–4.70
40–49 years	1.56–1.96	1.97–2.32	2.33–3.18	2.01–2.52	2.53–2.88	2.89–4.00
50–59 years	1.37–1.85	1.86–2.33	2.34–3.16	–	–	–

Table 4.2

Heart Functional Index Scale for Physically active Female, W/kg

Age groups	< 300 exercise minutes per week			≥ 300 exercise minutes per week		
	Low level	**Middle level**	**High level**	**Low level**	**Middle level**	**High level**
12–15 years	1.57–1.99	2.00–2.44	2.45–3.07	1.86–2.43	2.44–2.72	2.73–3.24
16–19 years	1.50–2.17	2.18–2.55	2.56–3.00	1.84–2.29	2.30–2.73	2.74–3.33
20–29 years	1.56–2.21	2.22–2.52	2.53–3.26	2.09– 2.74	2.75–3.13	3.14–4.21
30–39 years	1.81–2.37	2.38–2.59	2.59–3.16	2.28–2.57	2.58–3.21	3.22–4.20
40–49 years	1.50–1.85	1.86–2.29	2.30–3.18	1.89–2.24	2.25–2.64	2.65–3.62
50–59 years	1.28–1.85	1.86–2.14	2.15–2.48	–	–	–

Table 4.3

Physical Working Capacity Index Scale for Physically Active Male, W/kg

Age groups	< 300 exercise minutes per week			≥ 300 exercise minutes per week		
	Low level	**Middle level**	**High level**	**Low level**	**Middle level**	**High level**
12–15 years	2.38–2.93	2.94–3.44	3.45–4.34	3.30–3.54	3.55–3.97	3.98–5.52
16–19 years	2.53–3.09	3.10–3.59	3.60–4.91	2.58–3.29	3.30–4.04	4.05–5.31
20–29 years	2.63–3.33	3.34–3.72	3.73–5.22	3.01–3.67	3.68–4.63	4.64–5.90
30–39 years	2.54–3.24	3.25–3.68	3.69–4.85	2.75–3.39	3.40–3.80	3.81–4.87
40–49 years	2.3 –3.02	3.03–3.38	3.39–4.02	2.29–3.08	3.09–3.63	3.64–4.78
50–59 years	1.85–2.21	2.22–2.75	2.76–3.20	1.95–2.89	2.90–3.36	3.37–4.54
60–69 years	1.55–1.97	1.98–2.56	2.57–3.36	–	–	–

Table 4.4

Heart Functional Index Scale for Physically active Male, W/kg

Age groups	< 300 exercise minutes per week			≥ 300 exercise minutes per week		
	Low level	**Middle level**	**High level**	**Low level**	**Middle level**	**High level**
12–15 years	1.80–2.39	2.40–2.88	2.89–3.85	2.39–2.77	2.78–3.21	3.22–4.05
16–19 years	1.84–2.42	2.43–2.93	2.94–4.04	2.10–2.76	2.77–3.31	3.32–4.19
20–29 years	2.00–2.67	2.68–3.06	3.07–4.18	2.29–3.03	3.04–3.79	3.80–4.81
30–39 years	2.11–2.73	2.74–3.12	3.13–4.12	2.10–2.88	2.89–3.24	3.25–3.85
40–49 years	1.96–2.66	2.67–3.09	3.10–3.74	2.05–2.90	2.91–3.34	3.35–4.23
50–59 years	1.75–2.21	2.22–2.75	2.76–3.16	1.95–2.81	2.82–3.25	3.26–4.54
60–69 years	1.55–1.97	1.98–2.56	2.57–2.95	–	–	–

Publications on the Topic of the Thesis

Scientific publications included in international database SCOPUS

1. Ionescu, A. M., Pitsiladis, Y. P., Rozenstoka, S., Bigard, X., Lollgen, H., Bachl, N., Debruyne, A., Pigozzi, F., Casasco, M., Jegier, A., Smaranda, A. M., Caramoci, A., Papadopoulou, T. 2021. Preparticipation medical evaluation for elite athletes: EFSMA recommendations on standardised preparticipation evaluation form in European countries. *BMJ Open Sport & Exercise Medicine*, 7(4),e001178. doi:10.1136/bmjsem-2021-001178.

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Appendix 1

Permission of Rīga Stradiņš University Research Ethics Committee, Decision No E-9 (2)

Veidlapa Nr E-9 (2)

RSU ĒTIKAS KOMITEJAS LĒMUMS

Rīga, Dzirciema iela 16, LV-1007
Tel.67409137

Komitejas sastāvs	Kvalifikācija	Nodarbošanās
1. Asoc. prof. Olafs Brūvers	Dr.theo.	teologs
2. Profesore Vija Sīle	Dr.phil.	filozofs
3. Docente Santa Purviņa	Dr.med.	farmakologs
4. Asoc. prof. Voldemārs Arnis	Dr.biol.	rehabilitologs
5. Profesore Regīna Kleina	Dr.med.	patanatoms
6. Asoc. prof. Guntars Pupelis	Dr.med.	ķirurgs
7. Asoc. prof. Viesturs Liguts	Dr.med.	toksikologs

Pieteikuma iesniedzējs: Sandra Rozenštoka
RSU Doktorantūras nodaļa

Pētījuma nosaukums: Fiziskās slodzes tolerances atbilstība veselības stāvoklim un vispārējās fiziskās sagatavotības līmenim sportistiem profesionāļiem un amatieriem.

Iesniegšanas datums: 03.10.2011.

Pētījuma protokols:

(X) Pētījuma veids: Minētā pētījuma mērķis tiek sasniegts izvērtējot organisma funkcionālās spējas raksturojošo rādītāju izmaiņas atkarībā no treniņu režīma sportistiem profesionāļiem un amatieriem, iegūto datu apstrādi un analīzi, kā arī izsakot secinājumus un priekšlikumus. Personas datu aizsardzība un konfidencialitāte nodrošināta

(X) Pētījuma populācija: brīvprātīgi indivīdi - sportisti

(X) Informācija par pētījumu:

(X) Piekrišana dalībai pētījumā:

Citi dokumenti:

Lēmums: piekrist biomedicīniskajam pētījumam

Komitejas priekšsēdētājs Olafs Brūvers Tituls: Dr.miss., asoc.prof.

Paraksts ______

Ētikas komitejas sēdes datums: 06.10.2011.