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ORIGINAL SCIENTIFIC ARTICLE

INTEGRATION OF INFORMATION SYSTEMS IN THE CONTROL OF HEART RATE IN THE PROCESS OF PHYSICAL EDUCATION

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Abstract

The study objective. Substantiation and implementation of the heart rate monitoring tool, developed on the basis of information systems for the rapid registration of cardiac rhythm during exercise.

Material and Methods. The study was implemented at the theoretical and empirical level. The basis of the study is the use of a set of theoretical methods: scientific analysis and synthesis, comparison, systematization, induction and deduction, generalization. The following methods of empirical research were used: description, empirical comparison, technical modeling, sphygmographic method of registration of pulsograms.

Results. According to the results of the search activity, a device designed to monitor heart rate in real time was presented. To implement the new electronic method and heart rate monitor of the functional state of the cardiovascular system, an optical block that eliminates the subjective determination of control results associated with the probability of errors was created. The use of an optical unit provides a fast dynamic picture of heart rate measurement, since the unit uses an optical sensor. Spectral characteristics of blood, which change under the influence of physical activity, were used for heart rate registration. Positive characteristics that ensure the quality of real-time HR monitoring procedures using the developed device in addition to high technical parameters are: high level of sensitivity, wide dynamic range, harmonized frequency response, linearity of conversion, note also non-invasiveness, security in application, low energy consumption signal, and transformations that do not affect or distort the control results.

Conclusions. The use of information systems in heart rate control ensures the accuracy of the measurement information and the correspondence between the degree of scientific reliability and practical value of the obtained results.

Keywords: physical education, monitoring, heart rate, device, sensor, control.

Introduction

Problem statement. The effectiveness of physical education is correlated with scientifically sound management of the functional potential of the organism. The effectiveness of the latter is provided by the availability of high-quality operational information about the impact of physical activity on the body (Anikieiev, 2015). On the basis of knowledge about the regularities of the functioning of physiological systems, the expediency of influence of the means of physical culture on the body is determined. Thus, exercise control is exercised during the training (Schmidt & Lee, 2013).

The criterion for the adequacy of physical activity, the basis of their regulation and planning in the process of physical education is to determine the physiological reactions of the cardiovascular system. Such monitoring of heart rate (HR) is realized, which is an important indicator of the functional activity of the cardiovascular system and the state of the circulatory system as a whole (Zanevskyy & Zanevska, 2019). This takes into account the increase in heart rate directly during exercise or the nature of recovery of this indicator after their completion. In the pulse signal of the radial artery are reflected and the processes of higher levels of regulation, and many hemodynamic indicators of the cardiovascular system, including intravascular pressure, arterial wall voltage, wave processes in the arterial system, movement of blood masses and more (Dinesh, Sforzo, & Swensen, 2007). All these pro-

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cesses, to varying degrees, affect the shape of the pulse wave and its rhythmic structure (Fedorov, 2008).

Therefore, current information on the control of HR dynamics during training is necessary in terms of indicating the intensity of the impact of physical activity on the body. Such control involves: control, assessment of the state of the organism, accumulation of statistics, their analysis, determination of dynamics and trends (Ozemek, Whaley, Holmes Finch, & Kaminsky, 2017). First of all, it is of paramount importance for the specialists of physical culture for solving the issues of admission to training sessions (Laurson, Brown, Dennis, & Cullen, 2008), since the HR is available for rapid control of the heart when determining the body's response to physical activity, in the study of physical performance, emotional stress, etc (Ivashchenko, 2020; Oliver & Stembridge, 2011).

Given that the results of HR monitoring are the basic basis for planning the mode of exercise and the strategy of further physical education in the practice of physical education, it is very important to choose the right method for measuring HR (Arena, Myers, & Kaminsky, 2016; Jrgensen, Andersen, Froberg, Maeder, von Huth Smith, & Aadahl, 2009). Currently, several methods are used to determine the HR in the course of training: manual, mechanical, electrical and optical. The most widely used are palpation, photoplethysmography, sphygmography, rheography, electrocardiography (Thomas, Nelson, & Silverman, 2015; Reiman & Manske, 2009; Fainsilberg, 2007). However, the technical difficulties that accompany the use of these methods make it impossible to control the HR directly while performing physical work (Nichols, Davis, McCord, Schmidt, & Slezak, 2013). In some cases, HR cannot be measured at all (during interval training, etc.).

Therefore, despite the wide range of HR control tools in the current practice of physical education, the problem of objective and reliable real-time monitoring of such control has not been solved to date. Given the importance of having information about the cardiovascular system's response to physical activity, the issue of HR control is very important.

Analysis of recent research and publications. The problem of ensuring the reliability of control in physical education has been studied at different times (Alfrey & Gard, 2014; Osipov et al., 2020; Koryahin, Blavt, & Ponomaryov, 2019). Nowadays, the possibilities of introduction of innovations in the control of physical education are being given increased attention in the works of specialists of the industry. Trends in the use of new controls in physical education to improve its effectiveness are discussed in the works (Gasser & Hoppeler, 2015; Vasconcelos, Damorim, Santos, Lima, Santos, Lima, & Damasceno, 2020).

Many authors have addressed the problem of development of information systems of HR monitoring and diagnostics of the cardiovascular system (Cooper, Watras, O'Brien, Luke, Dobratz, Earthman, & Schoeller, 2009; Faulkner, Greey, & Hunsicker, 2013; Yankovenko, 2010). In the scientific researches the methods of electrocardiography and types of pulsometry (sphygmography, plethysmography), which are the most common methods of diagnostics of the condition of the cardiovascular system, and through it – and other organs and systems of the organism, are considered (Dinesh, Sforzo, & Swensen, 2007; Fainsilberg, 2007; Warburton, Nicol, & Bredin, 2006). It is determined that the disadvantage of modern HR systems is the complexity and the high cost, the sensors in such systems are purely analog, which causes a decrease in the accuracy of recording the primary signal.

The range of devices with optical HR measurement technology is quite common in publications (Fedorov, 2018; Hotra, Mahlovanyy, Mykytyuk, Ivakh, & Politanskyi, 2019). It is on the basis of optical sensors that smartphones, bracelets-trackers, watches have been developed, and all the major companies are expanding the line of HR monitors with models with optical sensors (Vasconcelos, Damorim, Santos, Lima, Santos, Lima, & Damasceno, 2020). However, the development of information systems today allows to implement the processing of the pulse signal by many available methods using a wide range of technical means. Methods for digital processing of pulsations are aimed at computer filtering and selection of useful signal (slate approximation, fourier analysis, various types of wavelet transform) and to determine changes of diagnostic parameters (American College of Sports Medicine, 2013). At the heart of these methods – HR control is carried out according to the normative HR, that is, compare the parameters of the received HR with the diagnostic HR characteristics that were established earlier. According to contour analysis, pulse curves reflect only the general form of blood pressure fluctuations, and do not provide qualitative and quantitative characteristics of the cardiovascular system. Such techniques are quite complicated both in understanding and in calculations, since they require the early processing of pulse signals from vessels, complex decomposition into spectra, speed of mathematical calculations and programs. The high reliability of the methods in this case is achieved by an individual approach to each individual spectrum, which makes it impossible to automate such a procedure.

We note the recent progress in the use of electronic methods in measuring devices, systems and devices. Moreover, the mutual impact of electronics and measurement tools today and the prospects for this impact on future advances in physical education are evident. It is convincing to look (Fedorov, 2008; Reiman & Manske, 2009; Sartor, Bonato, Papini, Bosio, Mohammed, & Bonomi, et al., 2016) at the need to find ways to modernize and identify the means of HR control. According (Yankovenko, 2010; Oliver, & Stembridge, 2011), it is important to choose the right measurement method, to create sensors with the appropriate specifications, to perform the full range of information processing measures.

Purpose of the research is substantiation and implementation of the HR monitoring tool, developed on the basis of information systems for the rapid registration of cardiac rhythm during exercise.

Materials and methods

Organization of research

The study was implemented at the theoretical and empirical level.

The basis of the study is the use of a set of theoretical methods: scientific analysis of synthesis, comparison – as ways of knowing the objective reality, to determine the state of solution of the selected scientific problem, which allowed to study the existing methods of HR monitoring, heart rate currently used in practice and concretization existing methods of analysis of pulsograms; systematization – to justify the feasibility of using computerized HR monitoring systems; induction and deduction for collecting theoretical and factual material for revealing the peculiarities of HR detection tech-

niques, its generalization for determining the possibilities of using sensors in HR monitoring devices and systems that allow to quantify the functioning of the cardiovascular system.

Among the methods of empirical research were used: description of the proposed method of optical pulsometry and a formal (abstract) description of the signal of movement of the artery wall in view of the availability of information in it; empirical comparison of HR the recording techniques to identify their disadvantages that reduce the practical value of their use; technical modeling was used to create the device to be studied: the use of technical means gave the simulation an experimental character; experimental use of the sphygmographic method of registration of pulsograms and the developed technique of optical pulsometry for the purpose of obtaining empirical data, their visualization in digital and graphical forms for giving objective conclusions.

The experimental study was aimed at eliminating a number of problematic factors and ensuring promptness, objectivity of control procedures, etc. using information systems. This involved the synthesis of new sensors, including nanosensors, with improved technical performance to create a state-of-the-art device for efficient HR measurement in real time.

Results

To realize the purpose of the study, first of all, the assumption was made regarding the shortcomings of sphygmographic HR recording devices, which are now most used in the practice of physical education. There is confidence that they have significant limitations and do not fully meet the needs of control. This is due to low research efficiency and limited signal recording channels. In addition, modern sphygmographic recording systems use sensitive solid-state pressure sensors with an elastic membrane, piezoelectric and pneumatic sensors, the application of which is a significant drawback of the significant influence of vibrations of mechanical origin. There is a likelihood of measurement errors dependent on changes in ambient temperatures. It has been found that the HR determination by a sphygmograph is characterized by low efficiency and limited signal recording channels, which makes it impossible to obtain the pre-existing control results.

To implement the new electronic method and HR monitor of the functional state of the cardiovascular system a created optical block that eliminates the subjective determination of control results associated with the probability of errors.

The use of an optical unit provides a fast dynamic picture of HR measurement, since the unit uses an optical sensor (Malaric, 2011). The feasibility of containing an optical sensor is justified by the simplicity of the structure, the low cost, the acceptable accuracy of operation, the absence of influence on the organism of the subject of monitoring. The optical sensor used is based on an optocoupler that combines a radiation source and an electronic photoconverter. The choice of radiation source parameters is determined by the optical characteristics of the blood, including the absorption coefficient. Spectral characteristics of blood, which change under the influence of physical activity, were used for HR registration. Figure 1 presents the spectral characteristic that reflects the absorption value of venous and arterial blood.

The above dependence has characteristic spectral areas with pronounced peak values of the absorption coefficient.

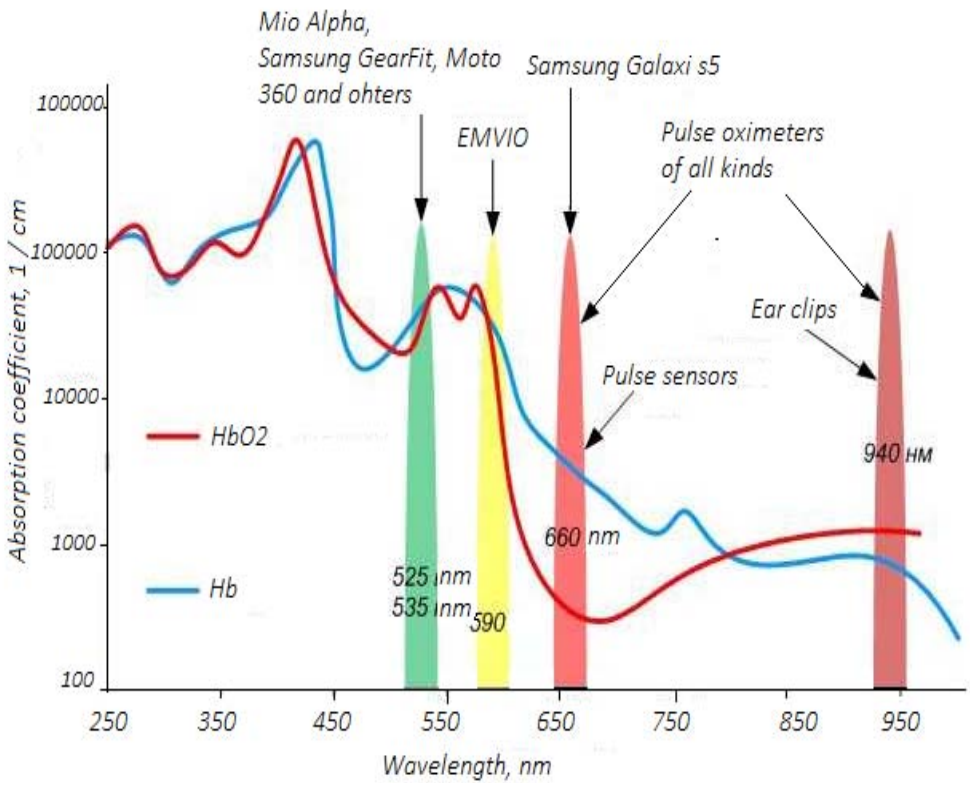

Fig. 1. Spectral characteristics of blood

These spectral ranges are used to record the HR. The arrows show the spectral ranges used by some manufacturers for the production of HR monitoring devices.

Human skin contains many thin capillaries filled with blood. At a time when the heart is contracting, the blood pressure rises, it enters the blood vessels more actively, which means that it absorbs more light. The sensor records this and determines the HR by calculating the number of such bursts per minute.

The vast majority of optical HR monitors, as can be seen from Fig. 1, use a certain, defined range within which irradiation and registration of the reflected signal are carried out. This approach is easy to implement, however, it has the drawbacks associated with errors that can occur in the absence of good contact between the sensor and the body. The latter is almost impossible to provide during the course.

Another disadvantage of optical HR monitors is the dependence on the body's response to the cold. Any decrease in blood flow (for example, in cold weather) may interfere with the operation of the optical HR sensor. As the body cools, the blood flow in the capillaries decreases, the device becomes much more difficult to capture the contraction of the heart. Therefore, if you belong to the category of people who, in cool weather (even with physical activity), their hands lighten quickly and become cold, the optical heart rate monitor may distort the data obtained during autumn jogging.

Finally, the third drawback of the optical type heart rate monitor is the possible errors at high HR. If under high load the pulse exceeds 150-170 beats – the blood flow velocity becomes too high. Moments of diastolic pressure (lower when the heart relaxes) last a minimum of time and are almost not reflected in capillary blood flow. As a result, the sensor is not able to recognize these moments, resulting in a malfunction of the device (Fedorov, 2008).

To increase the sensitivity of the optical sensor, the optical unit is designed to receive data on the blood spectrum and changes in it under the influence of physical activity, which allows for multi-parameter analysis of the spectral characteristics of blood. The unit uses the VLMU1610-365-135 (Vishay Semiconductors), VLMTG1400 and VSMS3700 LEDs. At a time when the heart is contracting, the blood pressure rises, it enters the blood vessels more actively, which means that it absorbs more light. LEDs record this, and by calculating the number of such bursts per minute, determine the HR.

In order to confirm the effectiveness of the created device, the study of the absorption coefficient of blood in the ultraviolet and infrared spectral range. Since human blood has a red color (that is, it best reflects the optical radiation corresponding to red), for better accuracy it is necessary to use another shade, which is well absorbed by it. This is green, located on the spectral circle opposite to red, which means that it is well absorbed by the blood (Fig. 2).

Based on the obtained results, the HR curves using the spectral analysis realize the qualitative and quantitative characteristics of the state of the cardiovascular system and the HR response to physical activity in real time. The high accuracy of spectral analysis methods is achieved by an individual approach to each individual spectrum of each subject.

Using the developed device, a method of monitoring the functional state of the cardiovascular system, namely HR monitoring, is proposed, at physical activity. The method is to place an optical block with an optical sensor and LEDs

Fig. 2. Color circle by Johannes Iten

on the body of the subject (wrist). The opic sensor with the help of an optocoupler records the intensity of the signals that are formed during movement of the artery wall, which arise under the influence of a wave of blood pressure at each contraction of the heart. Information signals are output to a synchronous detector and fed to the microcontroller. The microcontroller is required to control the optical unit and to measure the signal. Measured by the microcontroller signal, wireless infrared communication devices are provided to the electronic computing device, where the results obtained perform a multi-parameter analysis of the spectral characteristics of the blood, which is judged on changes in HR and functional state of the cardiovascular system in the process of physical training. Displays monitoring results on LCDs using developed software in numerical and graphical form.

To ensure the wireless communication of multiple optical units and to transmit information to the electronic computing device, they use a developed 16-channel multichannel radio modem. Its use provides the recording of the results of HR monitoring of several persons at a time (Fig. 3). Built-in function of viewing both channels and individually. It is possible to specify the magnitude of both the amplitude and time axes.

The operation of the device and the processes of HR registration, accumulation and reading of measurement results are remotely via the Bluetooth interface between the personal computer and the measuring device. For this purpose specially developed software is used. Synchronization of measurement processes is accomplished by real time counter.

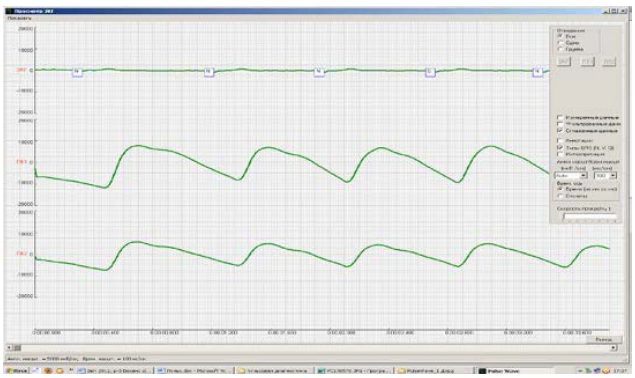

Fig. 3. Example of recording the heart rate of several persons at a time

The measurement results of the device obtained through the Bluetooth interface are stored as a text file.

It implements the functions of recording, saving with subsequent loading and visualization of the recording. There is a choice of recording duration and a convenient overview of the result. Presentation of control results and continuous observations in the form of electronic protocol, allows to significantly expand and enlarge the range of views, facilitate search and interpretation of the obtained results over a long time, preserve information and conveniently view the dynamics of the results of a particular subject.

Control procedure information requires processing and analysis using quantitative methods that are used to process large data sets. Therefore, we envisage the use of a modern information complex of electronic computers in the structure of the device, which will allow to obtain not only quantitative values of individual parameters, which, when applied to the study of the cardiovascular system, allows to solve a wide range of diagnostic problems.

Summarizing the above, and taking into account the fact that in assessing the possibilities of the proposed method of HR registration, we consider several considerations, among which the most important are the following:

- high accuracy of the obtained results for the assessment of the condition of the monitoring subject;
- simplicity of implementation of all methodical techniques for preparation of the monitoring subject by this method;
- simplicity and availability of technical means for carrying out research;
- availability of calculation algorithms according to registration data and simplicity of biomedical interpretation of results;
- the possibility of combining this method with others.

Positive characteristics that ensure the quality of real-time HR monitoring procedures using the developed device in addition to high technical parameters – high level of sensitivity, wide dynamic range, harmonized frequency response, linearity of conversion, note also non-invasiveness, security in application, low energy consumption signal and transformations that do not affect or distort the control results.

The HR registration method of the proposed method combines all the benefits of optical methods of registration. By providing a high level of information, studies of one monitoring entity based on the analysis of heart rate records over a long time are possible. This, in turn, allows the individual components of the pulse curves to be monitored and digitized or quantified, and by analogy with the rhythmic approach to the dynamics of cardiac activity (Yankovenko, 2010), it is possible to determine the effect of nervous and humoral regulation on the contractile activity of the vascular system.

Discussion

The results of our study are consistent with a number of scientific studies (Schmidt & Lee, 2013; Sartor et al., 2016; Ozemek et al., 2017) on the need to ensure the effectiveness of the control of functional systems in the process of physical training, which is the basis for regulating the rationality of pedagogical effects to ensure the effectiveness of physical education.

We support scientific approaches to ways to optimize controls in physical education using information systems (Koryahin, Blavt, Vanivska, & Stadnyk, 2020; Vasconcelos, Damorim, Santos, Lima, Santos, Lima, & Damasceno, 2020). Our research is consistent with reports (Aadahl & Jorgensen, 2003; Koryahin & Blavt, 2018) that the automation of the process of obtaining and processing control information contributes to improving the speed of receipt, reliability and objectivity of information and its analysis in real time and significantly reducing the time lost on the implementation of control.

The results of the study complement the data on the control of the condition of the cardiovascular system in the process of physical education (Faulkner et al., 2013; Nichols et al., 2013).

Scientific ideas on real-time HR monitoring with the use of modern information systems have been further developed as an opportunity to significantly increase control efficiency.

Our study is consistent with a number of scientific findings that the transition to a fundamentally new system of quality assurance testing in physical education involves the use of innovative tools of control and diagnostics to ensure the reliability of results (Jrgensen et al., 2009; Oliver & Stembridge, 2011).

Conclusions

At the present stage, the need for modernization of control procedures as an opportunity to improve the efficiency of physical education has been actualized. According to the results of the search activity, a device designed to monitor HR in real time is presented. The efficiency of the created device in the process of heart rate control was experimentally proved with the use of spectral analysis, which realizes the qualitative and quantitative characteristics of the condition of the cardiovascular system and the response of HR to physical activity in real time.

Using the developed device, a method of monitoring the functional state of the cardiovascular system, namely the control of HR during physical activity, is proposed. The use of information systems in HR control ensures the accuracy of the measurement information and the correspondence between the degree of scientific reliability and practical value of the obtained results. Equipping the process of HR control with modern means, including the field of nanotechnology, will undoubtedly contribute to ensuring a high level of control and, consequently, high efficiency of physical education.

Conflict of interest

The authors state no conflict of interest.

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ІНТЕГРАЦІЯ ІНФОРМАЦІЙНИХ СИСТЕМ У КОНТРОЛІ ЧАСТОТИ СЕРЦЕВИХ СКОРОЧЕНЬ В ПРОЦЕСІ ФІЗИЧНОГО ВИХОВАННЯ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 3 рис., 31 джерело.

Мета дослідження – обґрунтування та реалізація засобу контролю частоти серцевих скорочень, розробленого на основі інформаційних систем для здійснення оперативної реєстрації серцевого ритму при фізичному навантаженні.

Матеріал та методи. Дослідження виконано на теоретичному та емпіричному рівнях. Основою дослідження є використання комплексу теоретичних методів: наукового аналізу, синтезу, порівняння, систематизації, індукції та дедукції, узагальнення. Серед методів емпіричного дослідження використовувалися: опис, емпіричне порівняння, технічне моделювання, сфігмографічний метод реєстрації пульсограми.

Результати. За результатами пошукової діяльності представлено пристрій, призначений для контролю частоти серцевих скорочень у режимі реального часу. Основою пристрою є створений оптичний блок на основі оптичного датчика. Використання оптичного блоку забезпечує реєстрацію динамічного вимірювання частоти серцевих скорочень, який побудовано так, щоб отримувати дані спектру крові та зміни у ньому. Для реєстрації серцевого ритму використано багатопараметричний аналіз спектральних характеристик крові, які змінюються під впливом фізичних навантажень. На основі такого аналізу отримують якісні та кількісні характеристики стану серцево-судинної системи та інформацію про реакцію серцевого ритму на фізичні навантаження в режимі реального часу. До позитивних характеристик, які забезпечують якість контролю частоти серцевих скорочень в режимі реального часу з використанням розробленого пристрою, крім високих технічних параметрів (високий рівень чутливості, широкий динамічний діапазон, гармонізована частотна характеристика, лінійність перетворення), відзначено й неінвазивність, безпечність у застосуванні, низьку енергетику отримання інформаційного сигналу та перетворення, які не впливають та не спотворюють результати контролю.

Висновки. Застосування інформаційних систем у контролі частоти серцевих скорочень забезпечує точність подання вимірювальної інформації та відповідність між ступенем наукової достовірності й практичної цінності отриманих результатів.

Ключові слова: фізичне виховання, частота серцевих скорочень, пульсограма, пристрій, датчик, контроль.

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ORIGINAL SCIENTIFIC ARTICLE

SECULAR TRENDS IN ANTHROPOMETRIC CHARACTERISTICS AND HEALTH-RELATED PHYSICAL FITNESS IN MACEDONIAN CHILDREN: THE MAKFIT STUDIES

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Abstract

The purpose of the present study was to analyze the secular trends in anthropometric characteristics and health-related physical fitness (i.e., flexibility, muscular strength and speed/agility) in Macedonian children between 2012 and 2019.

Materials and methods. We analyzed the secular trends in anthropometric characteristics and health-related physical fitness in Macedonian children between 2012 and 2019. Two representative population studies were conducted 7 years apart in children (6-10 years) from Skopje (Macedonia). Both studies used the same anthropometric measures and tests to assess physical fitness: height, weight, body mass index, body fat percentage, muscle mass percentage, sit and reach, handgrip strength, standing long jump, 30 sec sit ups, and 4 × 10 m shuttle run.

Result. The boys and girls measured in 2019 had significantly better performance in the sit and reach (Cohen's d ~0.4 and ~0.5, respectively), 30 sec sit ups (Cohen's d ~0.3 and ~0.2, respectively), and 4 × 10 m shuttle run (Cohen's d ~0.7 and ~0.8, respectively) tests compared to those measured in 2012-2013. Levels of the standing long jump were significantly lower in 2019 in boys and girls (Cohen's d ~0.6 for both).

Conclusions. Based on the results of the study, it can be concluded that Macedonian children measured in 2019 have higher levels of flexibility, abdominal muscle strength and coordination, speed and agility, but lower levels of explosive force of the lower limbs than their counterparts measured. 7 years ago, no statistically significant differences were found in anthropometric measures and measures of body weight.

Keywords: fitness, muscular strength, youth, physical activity.

Introduction

Physical fitness is a powerful marker of childhood health and adolescence (Myers et al., 2002; Andersen et al., 2006). Even in children and adolescents, physical fitness is inversely related to critical physiological factors for occurrence of chronic diseases, including high blood pressure (Sallis et al., 1998; Ruiz et al., 2006), obesity (Ruiz et al., 2006), hyperinsulinemia (Gutin et al., 2004), increased abdominal adiposity (Brunet et al., 2006), atherogenic lipid profile (Mesa et al., 2006) insulin resistance, inflammatory markers (Gulati et al., 2003), and other metabolic risk factors (Brage et al., 2004; Ruiz et al., 2007).

Several meta-analyzes have shown a decrease in cardiorespiratory fitness in recent years and a stabilization of muscle strength (Macfarlane & Tomkinson, 2007; Tomkinson & Olds, 2007a; Tomkinson, 2007; Olds et al., 2006; Tomkinson & Olds, 2007b; Tomkinson et al., 2007). Available original reports around the world show different trends depending on the geographic region. To our knowledge, there is no information available regarding the secular trends in physical fitness in Macedonian children. Developing appropriate public health strategies requires regular analysis of the evolution of fitness, especially among young people.

The purpose of the present study was to analyze the secular trends in anthropometric characteristics and health-related physical fitness (i.e., flexibility, muscular strength and speed/agility) in Macedonian children between 2012 and 2019.

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Materials and methods

Sample of respondents

In this study we considered data from two separate cross-sectional studies, both representative from the city of Skopje (Macedonia). The research was conducted in seventeen primary schools in the City of Skopje situated in different municipalities. Five classes were randomly selected from each school. Both the first and second measurements were conducted in the same schools. In 2012 the survey was conducted on a sample of 2269 respondents out of which 1110 boys and 1159 girls with an average age of 8.58 ± 1.34 years. In 2019 the survey was conducted on a sample of 2028 respondents of which 1018 boys and 1010 girls with an average age of 8,58 ± 1,33 years.

The study included students for whom their parents had given consent to take part in the research, who were psychically and physically healthy and who regularly attended the classes of physical and health education. Both studies were performed following the ethical guidelines of the Declaration of Helsinki 1961 (revision of Edinburgh 2000). Measurements were realized in March, April and May 2012 and 2019, in standard school conditions at regular classes of physical and health education. The measurement was realized by experts from the area of kinesiology and medicine, previously trained to perform functional tests and to take anthropometric measures.

Anthropometric measures and body composition

Measuring of the anthropometric measurements was realized at the recommendations given by IBP-International Biology Program (Lohman et al., 1988). For estimation of the morphologic characteristics the following anthropometric measures have been applied: body height in standing position (cm), body weight (kg), as well as the body mass index (BMI).

Components of the body composition have been determined by the method of bioelectrical impedance (measuring of the electric conductivity – Bioelectrical Impedance Analysis – BIA). The measuring was realized by a Body Composition Monitor, model "OMRON – BF511", by means of which we have measured the body weight, fat tissue percent and muscular mass percent. Prior to commencing the measurement, we entered the parameters of gender, years and body height of the respondent in the Body Composition Monitor. In order to provide better precision of the results obtained from the estimation of the body composition, prior to each measuring, we ensured that the preconditions recommended by ACSM (2005) and Heyward (2006) had been fulfilled.

Evaluation of Physical Fitness

Prior to starting the study, the researchers involved in the project undertook training sessions in order to guarantee the standardization, validation, and reliability of the measurements. Five tests, forming part of the EUROFIT battery, validated and standardized by the European Council, were applied in the following order:

Sit and Reach test. With the subject seated on the floor and using a standardized support, the maximum distance reached with the tip of the fingers by forward flexion of the trunk is measured. Test indicative of amplitude of movement or flexibility.

Hand Grip test. With the use of a digital Takei TKK 5101 dynamometer (range, 1-100 kg), the maximum grip strength was measured for both hands.

Standing broad jump test. The maximum horizontal distance attained, with feet together, was measured. This test evaluates lower limb explosive-strength.

Sit-ups 30 sec. Maximum number of sit ups achieved in 30 seconds. This test measures the endurance of the abdominal muscles

Shuttle run: 4 × 10 meters. This test provides an integral evaluation of the speed of movement, agility and coordination. The subject does four shuttle runs as fast as possible between 2 lines, 10 meters apart. At each end the subject places or picks up an object (a sponge) beside the line on the floor.

Definition of weight status

Three weight status groups were established in this study: underweight/normal weight, overweight and obesity. Participants were categorized according to the international gender and age-specific BMI (kg/m^2) cut-off points (Cole et al., 2000, 2007). These points have been particularly established for children and adolescents aged from 2-18 years, separately for males and females and for 0.5 year age groups. These cutoff values are based on percentiles passing at age 18 through BMI 18.5 kg/m^2 for underweight, 25 kg/m^2 for overweight and 30 kg/m^2 for obesity (Cole et al., 2000, 2007).

Statistical analysis

The data are presented as frequencies (percentage) for categorical variables and mean (SD) for continuous variables. Gender differences for each measurement point were assessed by one-way analysis of variance (ANOVA). Categorical data (weight status) were analyzed using the χ^2 – test. Mean differences of the secular trends in health-related physical fitness performances (i.e., height, weight body mass index, body fat percentage, muscle mass percentage, sit and reach, handgrip strength, standing long jump, 30 sec sit ups and 4 × 10 m shuttle run) between measurement points were analyzed by one-way analysis of covariance (ANCOVA) for boys and girls separately. The measurement point was entered as fixed factor, each fitness test was entered as dependent variable in separate models, and age were entered as covariates. We calculated the effect size statistics as Cohen's d (standardized mean differences) and 95% confidence interval. Values of Cohen's d ~0.2, ~0.5 and ~0.8 are considered small, medium and large effects, respectively. All the analyses were performed using the Statistical Package for Social Sciences software (SPSS, v. 22.0 for Windows; SPSS Inc., Chicago, IL, USA), and values of $p < 0.05$ were considered statistically significant.

Results

The characteristics of the study population by measurement point (2012 and 2019) and gender are shown in Table 1. The table shows that boys in 2012 and 2019 are heavier, have higher body mass index, higher percentage of fat tissue and higher muscle mass, and show better results in all physical assessment tests related to health, except in the deep-seated bend test in which girls show better results.

Table 2 shows the mean of physical fitness tests by gender in both measurement points after controlling for age. The

Table 1. The characteristics of the study population by measurement point (2012 and 2019) and gender

Indicator	Years 2012					Years 2019				
	Boys		Girls		p	Boys		Girls		p
	Mean	SD	Mean	SD		Mean	SD	Mean	SD	
Height (cm)	134.04	9.92	132.72	9.94	0.002	133.09	9.83	132.39	10.22	0.118
Weight (kg)	34.65	10.44	32.72	9.80	0.000	33.98	10.63	32.41	9.54	0.001
Body mass index (kg/m^2)	19.00	3.62	18.29	3.49	0.000	19.04	4.16	18.35	3.33	0.000
Body fat (%)	24.09	7.56	22.54	8.41	0.000	23.99	8.16	22.80	8.23	0.002
Muscle mass (%)	30.44	3.51	29.82	2.64	0.000	30.32	3.27	29.83	2.72	0.000
Sit and reach (cm)	12.58	5.63	14.49	5.84	0.000	14.74	6.06	17.68	6.46	0.000
Handgrip strength (kg)	14.15	3.91	12.32	3.52	0.000	13.77	4.82	12.51	4.57	0.000
Standing long jump (cm)	122.93	22.98	110.35	19.91	0.000	101.98	42.41	89.65	39.69	0.000
30 sec sit ups (n)	11.95	5.65	10.24	5.79	0.000	13.49	5.60	11.20	5.76	0.000
4 × 10 m shuttle run (s)[a]	16.17	1.80	17.28	1.71	0.000	14.97	2.13	15.79	2.01	0.000

Table 2. Performance in physical fitness tests by measurement point and gender

	Fitness tests	Years 2012			Years 2019			p	Cohen's d	95% CI
		n	Mean	SD	n	Mean	SD			
Boys	Height (cm)	1110	133.59	9.92	1018	133.61	9.84	0.944	0.00	-0.585 to 0.604
	Weight (kg)	1110	34.31	10.44	1018	34.38	10.63	0.850	-0.01	-0.621 to 0.647
	Body mass index (kg/m^2)	1108	18.96	3.62	1009	19.11	4.16	0.363	-0.04	-0.255 to 0.226
	Body fat (%)	1108	24.08	7.56	1009	24.06	8.14	0.954	0.00	-0.449 to 0.521
	Muscle mass (%)	1108	30.35	3.51	1009	30.43	3.27	0.482	-0.02	-0.234 to 0.183
	Sit and reach (cm)	1084	12.64	5.63	1013	14.67	6.05	0.000	-0.35	-0.682 to 0.030
	Handgrip strength (kg)	1105	14.03	3.91	1017	14.23	11.72	0.581	-0.02	-0.254 to 0.697
	Standing long jump (cm)	1095	122.23	22.98	1013	102.71	42.48	0.000	0.58	-0.783 to 3.194
	30 sec sit ups (n)	1112	11.81	5.66	1021	13.58	5.65	0.000	-0.31	-0.646 to 0.033
	4 × 10 m shuttle run (s)[a]	1095	16.23	1.80	1012	14.88	2.23	0.000	0.67	-0.564 to 0.808
Girls	Height (cm)	1159	132.53	9.94	1010	132.67	10.20	0.626	-0.01	-0.587 to 0.618
	Weight (kg)	1159	32.58	9.80	1010	32.62	9.53	0.921	0.00	-0.568 to 0.586
	Body mass index (kg/m^2)	1154	18.28	3.49	1000	18.37	3.33	0.560	-0.03	-0.228 to 0.188
	Body fat (%)	1154	22.53	8.41	1000	22.85	8.22	0.389	-0.04	-0.527 to 0.489
	Muscle mass (%)	1154	29.80	2.64	1000	29.85	2.72	0.618	-0.02	-0.172 to 0.156
	Sit and reach (cm)	1152	14.51	5.84	1001	17.64	6.46	0.000	-0.51	-0.847 to 0.109
	Handgrip strength (kg)	1155	12.26	3.52	1004	12.60	4.57	0.018	-0.08	-0.288 to 0.198
	Standing long jump (cm)	1153	110.08	19.91	1004	89.79	39.82	0.000	0.66	-0.490 to 3.122
	30 sec sit ups (n)	1158	10.19	5.79	1003	11.23	5.78	0.000	-0.18	-0.513 to 0.178
	4 × 10 m shuttle run (s)[a]	1140	17.30	1.71	1001	15.77	2.07	0.000	0.81	-0.712 to 0.940

Values are adjusted means ± standard deviation. *p* values from one-way analysis of covariance after controlling for age.
[a] In this test, lower scores (time in s) indicate better performance.

boys and girls measured in 2019 had significantly better performance in the sit and reach (Cohen's d ~0.4 and ~0.5, respectively), 30 sec sit ups (Cohen's d ~0.3 and ~0.2, respectively), and 4 × 10 m shuttle run (Cohen's d ~0.7 and ~0.8, respectively) tests compared to those measured in 2012-2013. Levels of the standing long jump were significantly lower in 2019 in boys and girls (Cohen's d ~0.6 for both). Statistical differences between the two sexes were not found in the anthropometric measures of height, weight and body mass index and in the measurements for assesment of body composition, body fat percentage and muscle mass percentage. We repeated all the analyses after further controlling for fat mass, fat free mass and the results did not materially change (data not shown).

Table 3, 4 shows the change in the percentage of boys and girls in this study who were classified as normal, overweight and obese between 2012 and 2019. The analisys of table 3 and the overview of χ^2 test indicate that there are no statistically significant differences in boys and girls in nutrition levels between 2012 and 2019.

Discussion

The results of this study showed that Macedonian children in 2019 have higher levels of flexibility, abdominal muscles strength, coordination, speed and agility, and lower levels of explosive force on the lower limb than their counterparts

Table 3. The proportion of boys classified as normal, overweight or obese using the Cole et al cut-offs

BMI classification	Years 2012		Years 2019		
	n	%	n	%	
Normal weight*	627	56.60%	597	59.20%	
Overweight	281	25.40%	226	22.40%	
Obese	200	18.10%	186	18.40%	ns

*Difference between measurement point (Chi-Square Tests); ns, non-significant.

Table 4. The proportion of girls classified as normal, overweight or obese using the Cole et al cut-offs

BMI classification	Years 2012		Years 2019		
	n	%	n	%	
Normal weight*	701	60.70%	604	60.40%	
Overweight	272	23.60%	256	25.60%	
Obese	181	15.70%	140	14.00%	ns

*Difference between measurement point (Chi-Square Tests); ns, non-significant.

7 years ago. The percentage of overweight and obese children classified on the basis of the BMI criterion in 2012 was 41%, while in 2019 it was 40%. Similar results for overweight and obesity have been obtained in several international studies (Jehn et al., 2006; Ortega et al., 2007; Al-Nakeeb et al., 2007; Ostojic et al., 2011). Over 20% of the respondents in both 2012 and 2019 have a body fat percentage greater than 30%. Such a high percentage of body fat is associated with an increased risk of acute and chronic diseases especially osteoarthritis, hypertension, diabetes mellitus and cardiovascular disease, which can lead to poorer quality of life and increased financial burden of the individual, the family and the society, as well as shorten life expectancy (Williams et al., 1992; Dugan, 2008).

Several meta-analyzes describe global changes in components of physical fitness related to health (Tomkinson & Olds, 2007; Tomkinson, 2007). Studies covering 27 countries and five geographic regions have shown a decrease in cardio-respiratory fitness from late 1970 to 2003, (Tomkinson & Olds, 2007) whereas performance at power and speed tests remained fairly stable from 1980s. (Tomkinson, 2007). Other meta-analyzes performed on large samples yielded similar results (Macfarlane & Tomkinson, 2007), but they were mainly focused on exploring cardio-respiratory fitness (Olds et al., 2006; Tomkinson & Olds, 2007; Tomkinson et al., 2007). Macfarlane and Tomkinson (2007) analyzed the secular changes in strength, speed and cardiovascular fitness tests in 23.5 million Asian children aged 6 to 19 years between 1917 and 2003 and found a steady decline in cardio-respiratory fitness over the last 10-15 years, and a global stabilization in power and speed. Tomkinson and Olds (2007) analyzed 46 studies and identified changes in cardio-respiratory fitness in 161,419 Australian children aged 6 to 17 years from 1961 to 2002 and found a marked decline in the youngest children and boys until about 1990 that appears to be slowing. Tomkinson et al. (2007) analyzed aerobic performance data of over 22 million Koreans (6-18 years) between 1968 and 2000 and found a significant decrease in the years after 1984.

The rich history of pediatric fitness testing all around the world shows many original reports about secular trends in adolescent health-related physical fitness in peer-reviewed scientific journals, especially focused on cardiorespiratory fitness. Analyzes of other health-related components such as muscle strength, speed, or agility show uneven trends across geographic regions (Matton et al., 2007; Albon et al., 2010; Jurimae, et al., 2007; Tomkinson et al., 2003). Matton et al. (2007) conducted a representative sample of Flemish adolescents aged 12 to 18 between 1969 and 2005 and found a decrease in bent arm hang and 10 × 5 m shuttle run results in girls, and an improvement in the results of the boys in 10 × 5 m shuttle run. Albon et al. (2010) analysed changes in New Zealand children between 1991 and 2003 and did not find significant differences in the 4 × 9 m shuttle run and the standing long jump tests. Jürimäe et al. (2007) analysed secular trends of Estonian and Lithuanian children and adolescents in 1992 and 2002. Lithuania's respondents reported a decrease in test scores bent arm hang, standing long jump and 20 m shuttle run, whereas in the Estonian respondents only a decrease in the results of the bent arm hang tests was found. Test results in 10 × 5m shuttle run in Lithuanians and standing long jump, 10 × 5 m and 20 m shuttle run tests in Estonians remained unchanged. Tomkinson et al. (2003) investigated the fitness trends of 18,631 South Australian students (12-15 years) between 1995 and 2000 and found a statistically significant decrease in the 20 m shuttle run and 40 m sprint test results, but found no statistically significant changes in the vertical jump tests. Moliner-Urdiales et al. (2010) researched the secular trends in health-related physical fitness in Spanish adolescents between 2001-2002 and 2006-2007. Both studies used the same tests to assess physical fitness: the handgrip strength, bent arm hang, standing broad jump, 4 × 10 m shuttle run and 20 m shuttle run tests. The results indicate that levels of both speed/agility and cardiorespiratory fitness were higher in 2006-2007 than in 2001-2002, whereas muscular strength components were lower in 2006-2007.

Although there is consistency in the secular trends identified in other studies conducted on the population of children and adolescents, our results do not fully coincide with the above studies. The increase in flexibility, strength of abdominal muscles, coordination, speed and agility while the decrease in lower body muscularity, discard theories related to the increases of fat mass over the reported changes in physical fitness components. And the results of this study disprove this theory, namely that anthropometric measures and body composition measures (fat percentage and muscle mass) did not detect statistically significant differences between the two sexes in 2012 and 2019. According to the model established by Tomkinson (Tomkinson & Olds, 2007; Tomkinson, 2007) we agree in that the reported secular trends in physical fitness are caused by a network of social, behavioral, physical, psychosocial and physiological factors.

Despite the lack of information on secular trends in other populations in recent years, which confirms our findings, the results obtained in this study can be attributed to various factors. The popularity of the more holistic approach to physical activity and exercise over the last decade has seen an increase in activities that have an emphasis on core strength, stability and flexibility (Chang, 2000). These exercises find their way into the physical education curriculum (Kloubec & Banks, 2004) and may affect children in this study. Other factors such as a change in the ergonomics of the schools' seats cannot be discounted, and further research is required to uncover the causes of this positive trend.

The major strength of the present study is the use of identical protocols, sampling methods and sampling frames in two representative cohorts of children from Skopje (Macedonia), as well as the application of valid, reliable and objective fitness tests to assess health-related fitness, and the recent measurement data (2019). It is important to consider when interpreting the findings from the present study that only two dataset including children from Skopje (Macedonia), were used over a 7 years period.

Conclusions

Based on the results of the study it can be concluded that the Macedonian children measured in 2012-2019 have higher levels of flexibility, abdominal muscle strength and coordination, speed and agility, and lower levels of explosive force on the lower limb than their counterparts measured 7 years ago. In order to guarantee healthy levels of physical fitness, Macedonian public health programs should promote physical activity among chidren, especially focussed on muscular strength which was seen to decrease and measures for decrease in obeasety among this group of the population. Schools may play a key role, and parents also have a great responsibility to encourage and support active living of their off spring.

Conflict of interest

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article

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ВІКОВІ ТЕНДЕНЦІЇ В АНТРОПОМЕТРИЧНИХ ХАРАКТЕРИСТИКАХ ТА ФІЗИЧНІЙ ПІДГОТОВЛЕНОСТІ У МАКЕДОНСЬКИХ ДІТЕЙ: ДОСЛІДЖЕННЯ МАКФІТА

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 4 табл., 34 джерела.

Мета дослідження – проаналізувати вікові тенденції в антропометричних характеристиках та фізичній підготовленості у македонських дітей між 2012 та 2019 роками.

Матеріали та методи. Проаналізовані вікові тенденції в антропометричних характеристиках та фізичній підготовленості, пов'язаній зі здоров'ям, у македонських дітей між 2012 та 2019 рр. Проведено два репрезентативні дослідження популяції з різницею у 7 років у дітей (6-10 років) із Скоп'є (Македонія). В обох дослідженнях використовували однакові антропометричні вимірювання та тести для оцінки фізичної підготовленості: зріст, маса тіла, індекс маси тіла, відсоток жиру в тілі, відсоток м'язової маси, нахил тулуба з положення сидячи, сила кисті, стрибки у довжину з місця, 30-секундні присідання та човниковий біг 4 × 10 м.

Результати. Хлопчики та дівчатка, дані 2019 року, мали значно кращі показники в тестах нахил тулуба з положення сидячи (d ~0.4 і ~0.5 Коена відповідно), 30-секундні присідання (d ~0.3 і ~0.2 Коена відповідно) і човниковий біг 4 × 10 м (тести Коена d ~0,7 та ~0,8 відповідно) порівняно з результатами тестування 2012-2013 рр. У стрибках у довжину з місця результати були значно нижчими у 2019 році у хлопчиків та дівчаток (d Коена ~0,6 для обох груп).

Висновки. Македонські діти у 2019 році, мають вищий рівень гнучкості, сили та координації, швидкості та спритності, але нижчий рівень вибухової сили нижніх кінцівок, ніж їхні однолітки 7 років потому. Статистично значущих відмінностей в антропометричних вимірах та показниках маси тіла не виявлено.

Ключові слова: фітнес, м'язова сила, діти, фізична активність.

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ORIGINAL SCIENTIFIC ARTICLE

PHYSIOLOGICAL AND COMPETITIVE CHARACTERISTICS OF PROFESSIONAL FEMALE FUTSAL PLAYERS

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Abstract

The study purpose was to examine the anaerobic and aerobic performance and also determine the influence of the anaerobic performance on specific movements during a match-play.

Materials and methods. A total of 12 Indonesian professional female players from Bandung district female futsal club were recruited and enrolled to participate in this study. They were required to complete one familiarization and two experimental sessions. During the first session (laboratory test), all players performed a treadmill test to ascertain their maximum rate of oxygen consumption (VO_2 max) and a running-based anaerobic sprint test (RAST) to measure their anaerobic performance. For the second session (on-court test), the participants played a simulated match on the court. A training team of 5 experts carried out an investigation regarding each player's competitive performance per match. Furthermore, the blood lactate concentration and Rate of Perceived Exertion (RPE) were assessed in the pre- and post-test for both sessions, which were separated by a week to enable the players to recover.

Results. The results showed that there was no significant difference between the mean power (MP) and fatigue index (FI) ($p = 0.425$, $p = 0.938$, respectively) for anaerobic performance using Analysis of Variance (ANOVA), although, the MP and FI of team C was lower compared to A and B. Furthermore, the total number of failed passes and shot off target of team C was larger compared to B and A (for failed passes = 30 vs 20 vs 25, for shot off target 14 vs 13 vs 8).

Conclusions. The results obtained indicate that there are strong associations between anaerobic capacity and explosive movements (shooting, tackling, heading and passing) among female futsal players.

Keywords: anaerobic performance, sprint test, shooting, team sports, technique, VO_2 max.

Introduction

As a country consisting of 268,074,600 inhabitants, Indonesia is one of the countries that have improved in futsal enthusiasm (Chandra, 2013). According to the world's trend, its popularity increases each year and is played by millions of either gender worldwide (Beato, Coratella, Schena, & Hulton, 2017). The match is played between two teams, with each consisting of one goalkeeper and four outfield players (winger, defender and pivot) (Ayala, Sainz de Baranda, De Ste Croix, & Santonja, 2011). Furthermore, it is played for two periods of 20 minutes and mainly indoor, with pitch dimensions of 25-42 m long and 1525 m wide (Farhani et al., 2019). Interestingly, the game usually lasts 70-80% longer than the scheduled 40 minutes, due to possibilities given by the rules such as stoppages for injuries, medical attention, time-outs from both teams etc. (CF et al., 2011).

Many studies are enthusiastic to investigate the physiological characteristic of futsal due to its increasing popularity (Barbero-Alvarez, Soto, Barbero-Alvarez, & Granda-Vera, 2008; Barbero-Alvarez et al., 2015; Naser, Ali, & Macadam, 2017). For example, Barbero-Álvarez et al. (2015) explained that it is an intermittent high-intensity strenuous sport which requires physical, technical and tactical exigencies on the players. In addition, previous studies observed that 85-90% of heart rate (HRmax) and 75% of VO_2 max are the average intensity characteristics needed during a match-play (Naser et al., 2017). Another study also observed that sprinting performance is a decisive factor, which is needed in intermittent high-intensity characteristics sports such as futsal (Barbero-Alvarez et al., 2008; Naser et al., 2017). This argument was arisen due to the fact that players spend 5 and 12% of the game time sprinting and performing high-intensity running (Sales et al., 2018).

During a futsal match, anaerobic processes play the biggest role in supplying energy, especially in the explo-

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sive movements such as ball kicking, tackling, heading and sprinting (Corrêa et al., 2016). Meanwhile, the aerobic system predominantly provides the energy needed for continuous alternation of high intensity during the match-play (Castagna, D'Ottavio, Vera, & Álvarez, 2009). Therefore, the game requires a high aerobic fitness along with well-developed anaerobic pathways (Astagna, 2010; Corrêa et al., 2016). Although, previous studies successfully revealed the its physiological characteristics, scientific knowledge regarding the physiological characteristics of female futsal players is rather limited. Furthermore, studies investigating the influence of anaerobic processes on the performance of players during match-play are scarce.

This study was carried out with interest in a few previous studies which observed the physiological characteristics of female futsal players (Beato et al., 2017; Lago-Fuentes et al., 2018; Ramos-Campo, Rubio-Arias, Carrasco-Poyatos, & Alcaraz, 2016). For example, Beato et al. (2017) reported that there was a decrease in performance in the second half compared to the first. Specifically, it was explained that there was a significant decrease in the total distance covered between the first and the second half. Although, these studies showed great discoveries for the decreased performance caused by low aerobic fitness among female futsal players, measurement of other performance analysis like shooting, tackling, heading and passing were lacking. Consequently, the effects of anaerobic processes on the performance of players during match-play remain unclear.

The study purpose was to examine the anaerobic and aerobic performance of Indonesian professional female futsal players and secondly, to determine the influence of the anaerobic process on specific movements such as shooting, tackling, heading and passing in the match-play. It was hypothesized that a low anaerobic performance among players would significantly decrease their performance in shooting, tackling, heading and passing. Furthermore, the discoveries of this study may be added to the scientific study that supports the use of physiological characteristics as a formula to determine training regimens used by coaches, sports scientists and female futsal players.

Materials and methods

Study participants

Twelve Indonesian professional female players from Bandung district female futsal club were recruited and enrolled to participate in this study. This was on the basis of the following criteria: they should have at least 5 years of experience in the game, involved in training of at least 8-10 sessions per week for approximately 60 minutes duration per session, participated in national and international female futsal tournaments. Participants on any anti-inflammatory or anti-oxidant drugs within 2 months prior to the initial testing or during the experimental period and had a history of musculoskeletal injury 3 months prior to the study began, were not included. Subsequently, the participants were classified based on their level of achievement. The Bandung district female futsal club has reached the runner up position in the National District Female Futsal Championship (PORDA West Java 2018). Therefore, they were classified as professional players. The study was carried out from 2-30 January 2019, which was two weeks after the PORDA West Java 2018 Championship and two months prior to West Java District Female National League 2019. All members of the committee were required to provide an explanation of the procedure, the risks that would later be faced and an informed consent. In addition, this study was approved by the ethics committee of the POLTEKKES Bandung and all procedures were in accordance with the Declaration of Helsinki. The anthropometric characteristics of the subjects are shown in Table 1.

Table 1. Anthropometric characteristics of three teams

Variables	Team A x ± SD	Team B x ± SD	Team C x ± SD
Age (years)	19.2 ± 0.50	18.7 ± 0.50	19.2 ± 0.96
Body mass (kg)	52.63 ± 1.86	55.83 ± 3.44	54.90 ± 3.70
Height (cm)	156.3 ± 4.35	158.8 ± 2.63	159.3 ± 6.60
BMI (kg/m2)	21.57 ± 0.91	21.13 ± 0.74	21.64 ± 0.53

BMI – body mass index, SD – standard deviation

Study organization

This was an observational study which required all participants to complete one familiarization session and two experimental sessions. During the first session (laboratory test), all players performed a treadmill test for VO_2 max and the running-based anaerobic sprint test (RAST) for measuring anaerobic performance. Both tests were separated by an interval of at least 3 days for recovery. For the second session (on-court test), the participants played a simulated match on court, according to the current rules of Fédération Internationale de Football Association (FIFA) (https://www.fifa.com/mensyoutholympic/news/the-rules-of-futsal-explained). Furthermore, the blood lactate concentration and RPE were assessed in the pre and post-test in both sessions which was separated by a week for recovery. Participants were allowed and encouraged to drink enough mineral water ad libitum in other to remain hydrated after the last task in each session. In this study, the players considered for analysis were those at the defender (n = 3), left-winger (n = 3), right-winger (n = 3) and pivot (n = 3) positions, excluding goalkeepers (n = 3). The research design is illustrated in Figure 1.

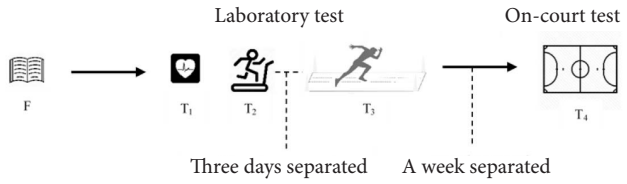

Fig. 1. The research designs: F = familiarization session, T_1 = Anthropometry assessments, T_2 = VO_2 max test, T_3 = RAST test, T_4 = Match exhibition

Laboratory

A week after a familiarization session, laboratory assessments were carried out on participants. Before the commencement of the test, they were instructed to take a light dinner (before 9:00 p.m.) a day before and not to eat food or drink caffeine beverages on the test day. For the first laborato-

ry measurements, anthropometric characteristics were measured using the Omron HBF-375 Karada Scan Body Composition Scale, which assess the percentage of body weight and fat of all participants. The stadiometer with 0.1cm readability (Seca 214 Portable Stadiometer, Cardinal Health, Ohio, USA) was used to measure body height. Furthermore, Body mass index was calculated as the ratio of body mass (kilograms), to the square of body height (metres).

After the anthropometric measurements, a 100μL sample of fingertip capillary blood was obtained from each player to measure for lactate, using the Lactate Pro analyzer (Arkray, Shiga, Japan). An hour prior to VO_2 max testing, all participants completed the Electro Cardio Graph (ECG) to monitor their cardiac normalities. After receiving health declaration based on ECG assessments, they continued with the VO_2 max assessments. Prior to VO_2 max test, they were required to perform warm-ups (6 min jog at 6.8 $km \cdot h^{-1}$). The VO_2 max test began at approximately 10:00 a.m indoors with a temperature range between 23-25 °C and relative humidity 65-75%. A treadmill cardio pulmonary exercise test Quark CPET T170, was used to measure th VO_2 max of each participant, with a velocity dependent ramp test (INCS) incremental protocols, at constant inclination (0°) and increasing speed (0.5 $km \cdot h^{-1}$ every 30 s from the initial 12.0 $km \cdot h^{-1}$). VO_2 max is defined as the plateau attained from by the relationship between VO_2 and running speed therefore, participants were verbally encouraged until volitional exhaustion. The heart rate (HR) was continuously monitored with a test employing a Polar V800 GPS during the VO_2 max test. At the end of the last task, the lactate was measured immediately after the VO_2 max test, followed by the determination of the rate of perceived exertion (RPE) using CR-10 scale as described by previous study (Arney et al., 2019).

Three days after the last tasks of VO_2 max test measurement, the RAST test was performed. The protocols and formula calculation of the RAST test were based on previous studies (Zagatto, WR, & CA, 2009). The RAST test was carried out by following a number of stages: (i) The participant was ready in a "standing start position" at one end of the 35 m sprint track (i.e. cone A) (ii) The second test administrator performed a countdown to the start of the test (iii) On the "GO" signal, the participant performed a sprint with maximal effort to the end of the 35 m track (i.e. cone B) (iv) Upon crossing the 35 m line, the second test administrator (standing on the end line) screamed "CLEAR". Subsequently, the first test administrator began the 10 secs recovery period countdown using a stopwatch (Seiko Stopwatch S23601P) (v) During the recovery period, the participant was getting ready to perform another 35 m sprint back to the start position (vi) All participants repeated this procedure for six sprints (five 10 sec recovery periods). (vii) To minimize any problems after the last task of the RAST test, they were to rest, either by sitting or standing. The running time of the sprints was recorded using a beam photocell system (Microgate, Bolzano, Italy). In addition, pre and post-testing of blood lactate and RPE measurements in the RAST test were carried out in the same way as that of the VO_2 max test.

On-court test

A week after the last day of the RAST test, on-court test was carried out in the Saraga Futsal Arena Bandung. Three matches were played according to the current rules of FIFA which began at 5.00 p.m., with a warm weather (22-23 °C) and relative humidity (65-75%). To ensure that players were highly motivated, a one-off match exhibition was included and the opponent was the main rival of Bandung district female futsal club. Meanwhile, all matches were performed under the supervision, tactical and motivation of head coaches in order to keep running euphoria and performance of players high. For the match exhibition, 5 female players consisting of a goalkeeper (n = 1), left-winger (n = 1), right-winger (n = 1) and pivot (n = 1) were randomly picked and assigned to team A. Furthermore, with the same amount and composition, other players were assigned to team B and C, respectively (match design is displayed in Figure 2). Specifically, all teams played without the opportunity to carry out substitutions. The Polar V800 GPS was used to monitored Heart Rate (HR) intensity during the match.

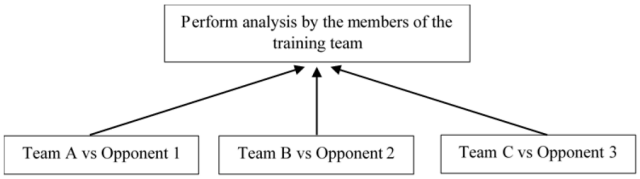

Fig. 2. The head to head futsal match designs

During futsal match exhibition, one video camera (Handycam Canon LEGRIA FS200) was mounted 5 m behind the baseline and 8 m above the ground at the same end of each court to film each match. Furthermore, the film from each match was used to assess the performance analysis. The video used technical assessment was developed by expert members of the training team (n = 5), with more 10 years of experience in futsal. The performance analysis of the match was carried out as follows: (i) successful passing, when a player in possession of the ball is able to send it to a teammate, (ii) failed passing, when a player is unable to make a reasonable attempt at playing a pass to a teammate, (iii) shot on target, a clear attempt to score that would have entered the net but was either saved by the goalkeeper or stopped by a player who is the last-man with the goalkeeper having no chance of preventing the goal (last line block), (iv) shot off target, any shot that goes over or wide off the goal area without making contact with another player, would have gone over or wide off the goal but was either saved by a goalkeeper or stopped by an outfield player, or directly hits the frame of the goal post (v) tackling, when a player not in possession of the ball engages with an opponent in possession of the ball and legally uses a foot to take the ball away, and (vi) heading, when a player uses the head to hit the ball in other for it to move in a certain direction.

Statistical analysis

The statistical analysis tests were performed with the SPSS software, V.21.0, while the normal distribution of the sample was checked by using the Shapiro-Wilk test. The repeated measurement and Post-hoc LSD were used to evaluate aerobic and anaerobic performance, HR and RPE in each group. Furthermore, the 95% confidence intervals and

change percentages were calculated. Statistical significance was accepted at the $p < 0.05$ level as indicated by the SPSS software, V.21.0.

Results

Table 2 shows the results for the aerobic and anaerobic performance during the INC_S and RAST tests, respectively. Table 3 depicts the results from the measurement of the lactate and RPE in the CWT and SJR groups. Table 4 displays the average characteristics for the different performance (shooting, tackling, heading and passing) in the three exhibition futsal matches. Additionally, Figure 3 shows the average heart rate during matches for the 3 teams.

Aerobic and anaerobic performance

Regarding aerobic capacity, there were no significant differences in the average VO_2 max obtained for the 3 teams ($p = 0.531$). Furthermore, for the anaerobic performance, Analysis of Variance (ANOVA) revealed no significant difference for the mean power (MP) and fatigue index (FI) ($p = 0.425$, $p = 0.938$, respectively) although, the MP and FI of team C was low compared to A and B.

Table 2. VO_2 max, MP and FI during the INCS and RAST tests in elite professional futsal players.

Group	VO_2 max ($ml \cdot kg^{-1} \cdot min^{-1}$)	MP (watts)	FI (watts/second)
Team A	40.08 ± 0.84	1813.25 ± 344.43	1.03 ± 1.02
Team B	40.73 ± 0.77	1970.25 ± 222.56	0.87 ± 0.84
Team C	40.33 ± 0.78	1720.50 ± 186.64	0.80 ± 0.98
p-value	0.531	0.425	0.938

MP – mean power, FI – fatigue index. The values are presented as mean ± SD.

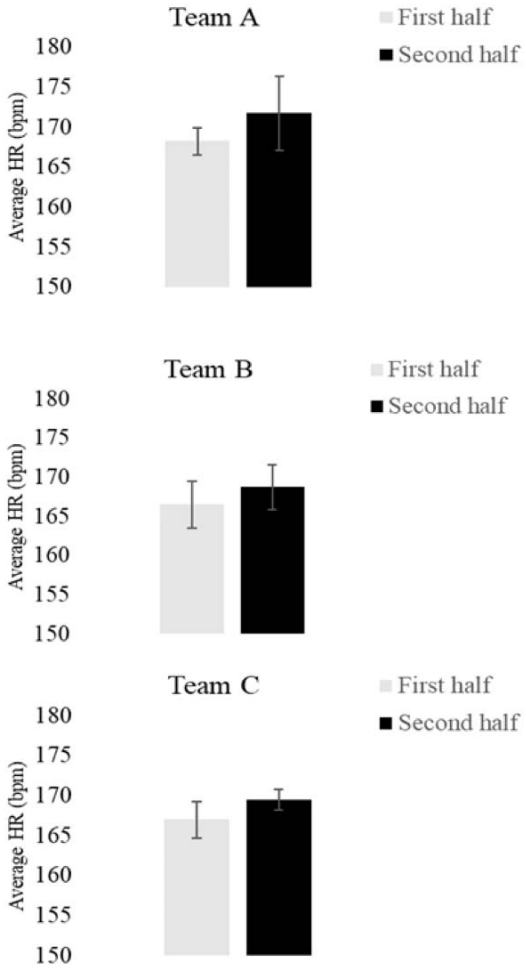

Fig. 3. Average HR of three group during futsal matches

Table 3. Difference changes in lactate measures in three groups

Group	Lactate-pre[1] (mmol/l)	Lactate-post[1] (mmol/l)	RPE[1]	Lactate-pre[2] (mmol/l)	Lactate-post[2] (mmol/l)	RPE[2]
Team A	1.73±0.33	11.58±0.62	9.75±0.50	1.93±0.92	8.23±0.63	8.50±0.58
Team B	1.38±0.59	12.25±0.70	9.00±0.82	1.70±0.44	8.23±0.88	8.00±0.82
Team C	2.00±0.89	11.95±0.91	9.72±0.50	1.58±0.74	7.70±0.88	8.50±1.29
p-value	0.422	0.476	0.201	0.792	0.587	0.698

[1]Lactate-pre – blood lactate response before INCS test, [1]Lactate-post – blood lactate response after INCS test, [1]RPE – rating of perceived exertion after INCS test, [2]Lactate-pre – blood lactate response before RAST test, [2]Lactate-post – blood lactate response after RAST test, [2]RPE – rating of perceived exertion after RAST test. The values are presented as mean ± SD.

Table 4. The distribution of the performance characteristics of three exhibition futsal matches

Team	Success Passing	Failed Passing	Shot on Target	Shot of Target	Tackling	Heading
A	160	25	15	8	1	3
B	181	20	18	13	2	2
C	154	30	12	14	1	3

Data as a mean total of the performance in each team

Blood lactate concentration and RPE

For the 3 teams, lactate concentration increased from pre to post-test in each session's test (INCS and RAST). Furthermore, ANOVA revealed no significant difference in lactate concentration at the pre-test for both sessions ($p = 0.422$, $p = 0.792$, respectively). It also revealed no significant difference in the lactate parameter post-test for both sessions ($p = 0.476$, $p = 0.587$, respectively). With reference to the RPE for all participants after the INCS and RAST tests, ANOVA revealed no significant difference among the 3 teams ($p = 0.201$ and $p = 0.698$, respectively).

On-court test

The team of analysts revealed that team C were less successful in passing and shot on target compared to B and A (for successful passes = 154 vs 181 vs 160, for shot on target = 12 vs 18 vs15). Conversationally, the total failed passes and shot off target of team C was frequent compared to B and A (for failed passes = 30 vs 20 vs 25, for shot off target 14 vs 13 vs 8). There was no significant difference in total of tackling and heading for each team during the matches.

Discussion

The purpose of the study was firstly, to examine the anaerobic and aerobic performance of Indonesian professional female futsal players and secondly, to determine the influence of the anaerobic performance on specific movements (shooting, tackling, heading and passing) in a match-play. To the best knowledge of the authors, this is the first study which assessed both anaerobic and aerobic performance on shooting, tackling, heading and passing. The main discoveries of this study were: (1) determination of the average anaerobic and aerobic performance of Indonesian professional female futsal athletes and (2) determination of the influence of MP and FI on shooting, tackling, heading and passing. These discoveries added to the scientific study that supports the use of physiological characteristics as a formula to determine training regimens used by coaches, sports scientists and female futsal players.

According to previous studies, VO_2 max is the maximal oxygen transport from the environment to the mitochondria which supports the oxidative production of ATP for carrying out physical work (Levine, 2008). Therefore, VO_2 max is a crucial physiological aspect which futsal players should improve on (Alvarez, D'Ottavio, Vera, & Castagna, 2009; Ayarra, Nakamura, Iturricastillo, Castillo, & Yanci, 2018; Naser et al., 2017). This study has been confirmed by Tomlin et al. (2002), which explained that VO_2 max is needed for inducing quicker recovery (e.g. improved Phosphocreatine (PCr) recovery) between high-intense efforts or even after exhaustion. In this study, the average VO_2 max of Indonesian professional female futsal players was 40.04 ± 0.04 $ml \cdot kg^{-1} \cdot min^{-1}$ (the average of the 3 teams). These values were considerably low compared to those in previous studies (Barbero-Alvarez et al., 2015; Datson et al., 2014; Haugen, Tonnessen, Hem, Leirstein, & Seiler, 2014; Krustrup, Mohr, Ellingsgaard, & Bangsbo, 2005). For example, Barbero-Alvarez et al. (2015) examined the VO_2 max of fourteen female futsal players from the Venezuelan National team, using the treadmill running test and obtained VO_2 max values of 45.3 ± 5.6 $ml \cdot kg^{-1} \cdot min^{-1}$. Responding to these differences in existing literatures, it was revealed that genetics and differences in level of training or competition may be considered as explanatory factors (Manzi, Iellamo, Impellizzeri, D'Ottavio, & Castagna, 2009; Perrier-Melo, Figueira, Guimarães, & Costa, 2018).

In this study, the RAST test was applied as a method to measure the anaerobic performance of participants. According to previous studies, it is a method that assesses the anaerobic power and capacity by measuring the peak power, MP and FI variables (Keir, Thériault, & Serresse, 2013; Zagatto et al., 2009). Specifically, Zagatto al. (2009), explained that the MP in the RAST test indicates a player's ability to maintain anaerobic performance over time (high score indicates a better ability), while FI variables indicates the rate at which power declines for a player i.e. the lower the FI value, the higher the ability to maintain anaerobic performance and vice versa. In this study, the average MP and FI value of team C was lower compared to A and B (see Table 2). Although, there were some difficulties in the discovery of supportive studies related to the anaerobic performance of futsal female players using RAST test. However, this study was able to show the importance of anaerobic capacity on performance. According to some previous studies, anaerobic actions are involved in the explosive movements in futsal (e.g. kicking, tackling, heading and sprinting) (Beato et al., 2017; Naser et al., 2017). Furthermore, an excellent anaerobic capacity is needed to improve the performance of these movements (Beato et al., 2017; Naser et al., 2017). In line with these studies, the results obtained in this study were strong associations between anaerobic capacity and explosive movements. This is evident from the fact that the average MP and FI values of team C were lower compared to the other teams. On careful analyzation, it was discovered that team C was less successful in making passes and shots on target (see Table 4). Furthermore, the results of this study clarified that excellent anaerobic capacity are needed to support explosive movement performance.

However, this study is not without limitations. Firstly, the physical, role-related and emotional functioning, including differences in the lifestyles of the participants could have an impact on the obtained results. Secondly, future studies should be concerned with the correlation statistical analysis (e.g. Pearson correlation coefficient) to measure the relationship between anaerobic capacity and explosive movements. More or less, this study is expected to assist coaches to improve the performance of players from the perspective of physiological characteristics of female futsal players.

Conclusions

The results of this study provided evidence and demonstrated strong associations between anaerobic capacity and explosive movements (shooting, tackling, heading, and passing) among female futsal players. Therefore, the high-intensity interval training method should preferably be used by coaches and players to improve anaerobic capacity.

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Conflict of interest

The authors state no conflict of interest.

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ФІЗІОЛОГІЧНІ ТА КОНКУРЕНТНІ ХАРАКТЕРИСТИКИ ПРОФЕСІЙНИХ ГРАВЦІВ ФУТЗАЛУ У ЖІНОК

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 3 рис., 4 табл., 26 джерел.

Метою дослідження було вивчити анаеробну та аеробну ефективність, а також визначити вплив анаеробної продуктивності на конкретні рухи під час матч-гри.

Матеріали та методи. Загалом було набрано 12 індонезійських професійних футболісток із жіночого футзального клубу району Бандунг, які взяли участь у дослідженні. Вони повинні були пройти одне ознайомлення та два експериментальних заняття. Під час першого заняття (лабораторне випробування) всі гравці провели тест на біговій доріжці, щоб визначити свою максимальну норму споживання кисню (VO_2 max) та анаеробний спринтерський тест на швидкості (RAST) для вимірювання анаеробних показників. На другому занятті (випробування на майданчику) учасники зіграли змодельований матч на корті. Тренерська група з 5 експертів провела дослідження щодо конкурентних результатів кожного гравця за матч. Крім того, концентрацію лактату в крові та швидкість сприйняття фізичних навантажень (RPE) оцінювали в попередньому та післятестовому проведенні обох сеансів, які були розділені тижнем, щоб гравці змогли відновитись.

Результати. Результати показали, що не було суттєвої різниці між середньою потужністю (MP) та індексом втоми (FI) ($p = 0{,}425$, $p = 0{,}938$, відповідно) для анаеробних показників з використанням дисперсійного аналізу (ANOVA), хоча, MP та FI команди С була нижчою порівняно з А та Б. Крім того, загальна кількість невдалих передач та попадання в ціль команди С була більшою порівняно з В та А (для невдалих пасів = 30 проти 20 проти 25, для відбиття цілі 14 проти 13 проти 8).

Висновки. Отримані результати показали, що існують сильні зв'язки між анаеробною здатністю та вибуховими рухами (простріли, боротьба, удар головою та передача) серед гравців жіночого футзалу.

Ключові слова: анаеробна ефективність, спринтерський тест, простріл, командні види спорту, техніка, VO_2 max.

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ORIGINAL SCIENTIFIC ARTICLE

IDENTIFICATION OF FACTORS DETERMINING WINNING IN MEN'S AND WOMEN'S BEACH VOLLEYBALL: A LOGISTICAL REGRESSION APPROACH

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Abstract

The purpose of this study was to find the factors responsible for winning in the men's and women's beach volleyball championship.

Materials and methods. The study sample consisted of a total of 212 matches for men and 214 matches for women of the 2017 & 2019 FIVB Men and Women Beach Volleyball World Championships held at Vienna & Hamburg from 28 July to 6 Aug 2017 and 28 June to 7 July 2019. The matches were played by 192 teams (both men and women combined) consisting of 384 numbers (both men and women combined) of players from different nations. The data were analyzed using Binary Logistic Regression (Forward: LR Method) with the result of the game as the dependent variable and predictor variables as covariates. β, standard error β, Wald's χ^2, odds ratio with 95% confidence interval were calculated. Model evaluation was conducted using the likelihood ratio test, Cox & Snell (R^2), and Nagelkerke (R^2) tests. The goodness of fit test for the models was conducted using the Hosmer & Lemeshow test.

Results. The analysis revealed seven factors related to winning in men's and women's competition. While in league rounds, six factors in men's and seven factors in women's competition were related to winning. Besides, in knockout rounds, four factors in men's and six factors in women's competition were related to winning.

Conclusion. The study shows that there is a significant association of important factors with respect to winning a match in an elite beach volleyball championship. The coaches and players can take note of the important factors responsible for winning in the elite beach volleyball championship, with different factors playing an important role in men's and women's competition during league and knockout rounds as well.

Keywords: notational analysis, chances, FIVB, prediction, world championship, skill.

Introduction

Beach volleyball has developed from a recreational activity to a professional sport over the last few decades. Since its inclusion in the Olympics in the 1996 Atlanta Summer Olympic Games, the game has shown tremendous growth in popularity all over the world. Beach volleyball is an intermittent sport played by teams of two players in a sand court and demanding powerful short rallies interspersed by pauses or less intense activities. Matches are characterized by repeated-jumps for attack-hit and block, rapid changes in moving direction, and a considerable number of explosive diving digs (Magalhães, Inácio, Oliveira, Ribeiro, & Ascensão, 2011).

The major skills which characterize the game of Beach volleyball are: serve, serve reception, set, attack, block, and dig (Hare & Sanderson, 1997; Homberg & Papageorgiou, 1995; Kiraly & Shewman, 1999; Stevenson & Obstfeld, 1989). Serve, attack and block give direct score points to the team, whereas serve reception, set, and dig allows for the next technical skills (Giatsis & Zahariadis, 2008). The game has two phases: side out and counterattack. The side out phase includes serve reception, setting, and dig & the counterattack phase includes block, dig, set, and attack (Costa, Afonso, Brant, & Mesquita, 2012).

Researchers have always been keen to analyze and evaluate technical and tactical aspects of the team's performances in various sports. The characteristics of the beach volleyball game have been previously studied (Hansen, 2002; Hömberg & Papageorgiou, 1995; Papageorgiou & Hömberg, 2004), but sports are in constant evolution and it is necessary to analyze them on a regular basis. In 2001, rules on court size and the scoring system changed, which led authors to research how this affected the game. Some studies investigated court size

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(Giatsis, Papadopoulou, Dimitrov, & Likesas, 2003; Hömberg & Papageorgiou, 1995; Kröger, 2006; Ronglan & Grydeland, 2006) and others focused on the scoring system (Giatsis, Zetou, & Tzetzis, 2005; Kröger, 2006; Ronglan & Grydeland, 2006). Furthermore, some studies analyzed technical and tactical aspects such as side out and counter-attack phases, receptions, and differences between winning and losing teams (Giatsis, Lopez Martinez, & García, 2015; Giatsis & Tzetzis, 2003; Michalopoulou, Papadimitriou, Lignos, Taxildaris, & Antoniou, 2005). A study conducted by Giatsis and Tzetzis (2003) postulates the different technical skills contribute to winning on different court dimensions (8x9m and 9x9m) in Hellenic Beach Volleyball finals. The results showed that winners have a better percentage in the attack in 8x8m, while they had better serve reception performance in the 9x9m court.

Traditionally, coaching intervention has been based on subjective observations of athletes, but such observations are not only unreliable but also inaccurate (Huges & Franks, 2010). To solve this issue, computer-aided analysis has been involved in sports performance analysis. The use of notational analysis (Castro, Souza, & Mesquita, 2011; Marcelino, Mesquita, & Sampaio, 2011) and computerized systems (Eom & Schutz, 1992a, 1992b) is the most common methodology in sports performance studies, which had improved the speed, accuracy, and efficiency of data analysis. Notational analysis is the process of recording, treatment, and diagnostics of events taking place in a competition (Drust, 2010). Several studies have been conducted on the notational analysis of technical and tactical aspects of volleyball (Ciuffarella et al., 2013) and beach volleyball (Jimenez-Olmedo, Penichet-Tomas, Saiz-Colomina, Martinez-Carbonell, & Jove-Tossi, 2012; Koch & Tilp, 2009b; Pérez-Turpin et al., 2019; Tilp, Koch, Stifter, & Ruppert, 2006). It has facilitated coaches in the analysis of movement patterns, strategy, and tactics of the individual player as well as the team's performance.

Although numerous studies have been published related to Beach volleyball (Giatsis & Zahariadis, 2008; Koch & Tilp, 2009a; Papadopoulou, Giatsis, Billis, Giannako, & Bakirtzoglou, 2020; Seweryniak, Mroczek, & Łukasik, 2013), only a few have been published regarding the factors responsible for winning and losing in Beach volleyball for men and women (Gabrio, 2021; Giatsis & Tzetzis, 2003; Medeiros, Marcelino, Mesquita, & Palao, 2017). As the game of beach volleyball is showing an exponential competitive growth pattern, technical skills that are key for success in this game are need to be researched and focused on so that the teams and coaches can prepare themselves accordingly. Therefore, *the purpose of this study was* to identify the factors which determine winning in a beach volleyball game for men as well as women using a logistical regression approach.

Materials and methods

To identify the factors which determine the winning of a beach volleyball game the matches played during the FIVB Beach Volleyball Men and Women World Championships of 2017 and 2019 were considered in this study. The study variables selected for analyses were the break point, service error, service point, reception error, attack error, attack blocked, attack point, attack point percent, block, and opponent error (Table 1).

Table 1. Description of selected skills for the analysis

Factors	Description
Break point	A point scored when the team is in possession of service
Service error	If the server hits or fails to go over the net, the serve goes out-of-bounds or the server called a foot or time violation
Service point	If the server gets a direct point from the service
Reception error	A player passes the ball, but it cannot be kept in play
Attack Error	When an attack is hit out of bounds or hit into the net leading to a four hit
Attack Blocked	The ball is blocked down by the opposition on the same side as the attacker and cannot be kept in play
Attack Point	An attack point is any ball that is sent over the net to the opponent and gets success
Attack Point Percent	Attack points minus attack errors divided by total attacks
Block	The block is the skill of stopping or altering an opponent's attack by players standing at the net. An offensive block aims at keeping the ball into the opponent's court, while a defensive block aims at getting the ball under control by slowing it down
Opponent Error	It is the acquisition of numbers that are considered to benefit the team because it does not go through the process of the activities of the team itself. It also called 'Free Score'

Subjects

The study sample consisted of a total of 212 matches for men and 214 matches for women of the 2017 & 2019 FIVB Men and Women Beach Volleyball World Championships held at Vienna & Hamburg from 28 July to 6 Aug 2017 and 28 June to 7 July 2019. The matches were played by 192 teams (both men and women combined) consisting of 384 numbers (both men and women combined) of players from different nations. The data for the present study was extracted from the official website of FIVB (http://vienna2017.fivb.com/en/schedule#/d20170806) for 2017 for Beach Volleyball World Championship and (http://hamburg2019.fivb.com/en/schedule#/d20190708) for the 2019 Beach Volleyball World Championship.

Statistical Analysis

All the statistical analyses were performed with IBM SPSS (version 20.0.0). The data were analyzed using Binary Logistic Regression (Forward: LR Method) with the result of the game as the dependent variable and predictor variables as covariates. β, standard error β, Wald's χ^2, odds ratio with 95% confidence interval were calculated. Model evaluation was conducted using the likelihood ratio test, Cox & Snell (R^2), and Nagelkerke (R^2) tests. The goodness of fit test for the models was conducted using the Hosmer & Lemeshow

Table 2. Logistic Regression Analysis of beach volleyball matches for match outcomes as win or loss

Men's matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	e^{β} **(odds ratio)**	**95% C.I.** (e^{β})
Constant	-13.005	1.741	55.781	1	<0.001	-	-
Break point	0.321	0.60	28.711	1	<0.001	1.378	1.226-1.550
Service point	0.230	0.066	12.158	1	<0.001	1.259	1.106-1.433
Reception error	-0.279	0.069	16.165	1	<0.001	0.756	0.660-0.867
Attack error	-0.176	0.073	5.646	1	0.017	0.839	0.726-0.968
Attack point percentage	0.141	0.024	34.206	1	<0.001	1.151	1.098-1.207
Block	0.219	0.092	5.676	1	0.017	1.245	1.040-1.492
Opponent error	0.240	0.045	28.822	1	<0.001	1.272	1.165-1.388
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			324.290	7	<0.001		
Cox & Snell						0.535	
Nagelkerke						0.713	
Goodness-of-fit test							
Hosmer & Lemeshow			4.893	8	0.789		
Women's matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	e^{β} **(odds ratio)**	**95% C.I.** (e^{β})
Constant	-7381	1.398	27.874	1	<0.001	-	-
Break point	0.228	0.49	21.991	1	<0.001	1.256	1.142-1.382
Reception error	-0.361	0.080	20.456	1	<0.001	0.697	0.596-0.815
Attack error	-0.310	0.66	21.913	1	<0.001	0.733	0.644-0.835
Attack blocked	-0.276	0.087	10.058	1	0.002	0.759	0.640-0.900
Attack point percentage	0.111	0.023	22.555	1	<0.001	1.117	1.067-1.169
Block	0.197	0.098	4.039	1	0.44	1.217	1.005-1.474
Opposition error	0.214	0.43	24.484	1	<0.001	1.239	1.138-1.349
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			338.938	7	<0.001		
Cox & Snell						0.547	
Nagelkerke						0.729	
Goodness-of-fit test							
Hosmer & Lemeshow			14.524	8	0.069		

test. In addition, observed and predicted frequencies by the regression model were also calculated with a cut-off of 0.50. The statistical level of significance was set at $p \leq 0.05$.

Results

Men

A total of 424 observations were analyzed for men and the logistic regression analysis found the following variables as significant in determining the model for winning of matches: break point, service point, reception error, attack error, attack point percentage, block, and opponent error.

Predicted logit of Winning (men) = -13.005 + 0.321·(break point) + 0.230·(service point) + (-0.279)·(reception error) + (-0.176)·(attack error) + 0.141·(attack point percentage) + 0.219·(block) + 0.240·(opponent error)

The Likelihood ratio test of the model resulted in χ^2 value of 324.29 with $p < 0.001$. In addition, the Cox and Snell resulted in R^2 value of 0.535 and Nagelkerke resulted in R^2 value of 0.713. Goodness of fit test using Hosmer and Lemeshow resulted in a p value of 0.789 (Table 1). The overall correct predicted percentage using the model was found to be 87.5% (Table 2, Figure 1a).

Table 3. The observed and the predicted frequencies for match results by Logistic Regression model with the cut-off of 0.50

Observed	**Predicted**		**% correct**
	Loss	**Won**	
Men's matches			
Loss	179	31	85.2
Won	22	192	89.7
Overall % correct			87.5
Women's matches			
Loss	185	25	88.1
Won	28	190	87.2
Overall % correct			87.6

Table 4. Logistic Regression Analysis of league matches for match outcomes as win or loss

Men's league matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	e^{β} **(odds ratio)**	**95% C.I.** (e^{β})
Constant	-18.316	2.320	62.338	1	<0.001	-	-
Break point	0.309	0.085	13.176	1	<0.001	1.363	1.153-1.611
Reception error	-0.648	0.124	27.441	1	<0.001	0.523	0.410-0.667
Attack blocked	-0.087	0.040	4.652	1	0.031	0.916	0.847-0.992
Attack point	0.268	0.037	53.219	1	<0.001	1.307	1.216-1.405
Block	0.263	0.112	5.472	1	0.019	1.301	1.044-1.622
Opposition error	0.352	0.062	32.032	1	<0.001	1.422	1.259-1.606
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			308	6	<0.001		
Cox & Snell						0.582	
Nagelkerke						0.785	
Goodness-of-fit test							
Hosmer & Lemeshow			9.496	8	0.302		
Women's league matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	e^{β} **(odds ratio)**	**95% C.I.** (e^{β})
Constant	-7.415	1.479	25.137	1	<0.001	0.001	-
Break point	0.243	0.048	25.843	1	<0.001	1.275	1.161-1.4
Reception error	-0.351	0.087	16.320	1	<0.001	0.704	0.593-835
Attack error	-0.263	0.069	14.628	1	<0.001	0.769	0.672-0.880
Attack point percentage	-0.242	0.093	6.839	1	0.009	0.785	0.655-0.941
Attack point	0.113	0.025	20.089	1	<0.001	1.119	1.066-1.176
Opposition error	0.207	0.046	19.923	1	<0.001	1.230	1.123-1.347
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			287.509	6	<0.001		
Cox & Snell						0.544	
Nagelkerke						0.726	
Goodness-of-fit test							
Hosmer & Lemeshow			19.542	8	0.012		

In addition, the total observations were further subgrouped into the league and knockout stages and analyzed. The following variables were found significant in determining the model for winning league matches: break point, reception error, attack blocked, attack point, block, and opposition error.

Predicted logit of winning (men league round) = -18.316 + 0.309·(break point) + (-0.648)·(reception error) + (-0.087)·(attack blocked) + 0.268·(attack point) + 0.263·(block) + 0.352·(opposition error)

The Likelihood ratio test of the model resulted in a χ^2 value of 308 with $p < 0.001$. In addition, the Cox and Snell resulted in an R^2 value of 0.582 and Nagelkerke resulted in an R^2 value of 0.785. The goodness of fit test using Hosmer and Lemeshow resulted in a p-value of 0.302 (Table 4). The overall correct predicted percentage using the model was found to be 87.6% (Table 5, Figure 1c).

In knockout matches following variables were found significant in determining the model: break point, reception error, attack error, and attack point.

Table 5. The observed and the predicted frequencies for league match results by Logistic Regression model with the cut-off of 0.50

Observed	**Predicted**		**% correct**
	Loss	**Won**	
Men's matches			
Loss	150	21	87.7
Won	22	154	87.5
Overall % correct			87.6
Women's matches			
Loss	158	21	88.3
Won	22	165	88.2
Overall % correct			88.3

Predicted logit of winning (men knockout round) = -0.989 + 0.734·(break point) + (-0.787)·(reception error) + (-0.459)·attack error + 0.116·(attack point)

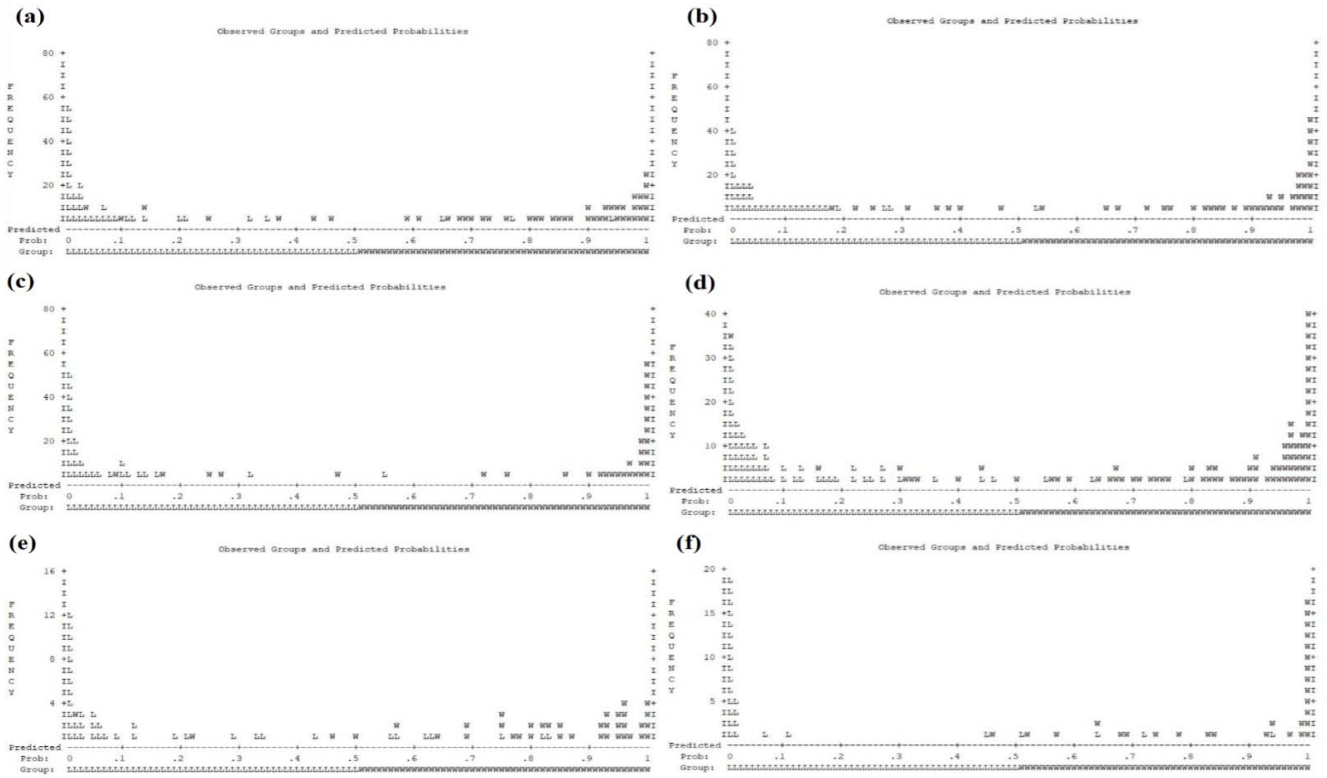

Fig. 1. Predicted probability for membership for winning a match in beach volleyball using the model. (a) men's overall matches, (b) women's overall matches, (c) men's league matches, (d) women's league matches, (e) men's knockout matches, and (f) women's knockout matches. Note: The cut-off value is 0.50. Symbols 'L' represents Lost and 'W' represents Win and each symbol represents 5 cases.

The Likelihood ratio test of the model resulted in a χ^2 value of 59.498 with $p < 0.001$. In addition, the Cox and Snell resulted in an R^2 value of 0.538 and Nagelkerke resulted in an R^2 value of 0.718. The goodness of fit test using Hosmer and Lemeshow resulted in a p-value of 0.122 (Table 6). The overall correct predicted percentage using the model was found to be 85.7% (Table 7, Figure 1e).

Women

A total of 428 observations were analyzed for women and the logistic regression analysis found the following factors as significant in determining the model for wining of the match: break point, reception error, attack error, attack blocked, attack point percent, block, and opponent error.

Predicted logit of winning (women) = -7381 + 0.228 (break point) + (-0.361)·(reception error) + (-0.310)·(attack error) + (-0.276)·(attack blocked) + 0.111·(attack point percent) + 0.197·(block) + 0.214·(opposition error)

The Likelihood ratio test of the model resulted in a χ^2 value of 338.938 with $p < 0.001$. In addition, the Cox and Snell resulted in an R^2 value of 0.547 and Nagelkerke resulted in an R^2 value of 0.729. The goodness of fit test using Hosmer and Lemeshow resulted in a p-value of 0.069 (Table 2). The overall correct predicted percentage using the model was found to be 87.6% (Table 3, Figure 1b).

In addition, the total observations were further subgrouped into the league and knockout stages and analyzed. The following variables were found significant in determining the model for winning league matches: break point, reception error, attack error, attack point percentage, attack point, and opposition error.

Predicted logit of winning (women league matches) = -7.415 + 0.243·(break point) + (-0.351)·(reception error) + (-0.263)·(attack error) + (-0.242)·(attack point percentage) + 0.113·(attack point) + 0.207·(opposition error)

The Likelihood ratio test of the model resulted in a χ^2 value of 287.509 with $p < 0.001$. In addition, the Cox and Snell resulted in an R^2 value of 0.544 and Nagelkerke resulted in an R^2 value of 0.726. The goodness of fit test using Hosmer and Lemeshow resulted in a p-value of 0.012 (Table 4). The overall correct predicted percentage using the model was found to be 88.3% (Table 5, Figure 1d).

In knockout matches following variables were found significant in determining the model: break point, service point, reception error, attack error, attack blocked, attack point, and opposition error.

Predicted logit of winning (women knockout matches) = -18.564 + 1.846·(break point) + (-1.537)·(service point) + (-1.167)·(reception error) + (-1.011)·(attack error) + (-0.542)·attack blocked + 0.473·(attack point) + 0.346·(opposition error)

The Likelihood ratio test of the model resulted in a χ^2 value of 63.929 with $p < 0.001$. In addition, the Cox and Snell resulted in an R^2 value of 0.643 and Nagelkerke resulted in an R^2 value of 0.858. The goodness of fit test using Hosmer and Lemeshow resulted in a p-value of 1 (Table 6). The overall correct predicted percentage using the model was found to be 91.9% (Table 7, Figure 1f).

Table 6. Logistic Regression Analysis of knockout matches for match outcomes as win or loss

Men's knockout matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	**e^{β} (odds ratio)**	**95% C.I. (e^{β})**
Constant	-0.989	4.169	5.623	1	0.018	-	
Break point	0.734	0.196	14.048	1	<0.001	2.084	1.420-3.060
Reception error	-0.787	0.265	8.855	1	0.003	0.455	0.271-0.764
Attack error	-0.459	0.225	4.152	1	0.042	0.632	0.406-0.983
Attack point	0.116	0.063	3.402	1	0.065	1.123	0.993-1.270
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			59.498	4	<0.001		
Cox & Snell						0.538	
Nagelkerke						0.718	
Goodness-of-fit test							
Hosmer & Lemeshow			12.705	8	0.122		
Women's Knockout matches							
Predictor	**β**	**SE β**	**Wald's χ^2**	**df**	**p**	**e^{β} (odds ratio)**	**95% C.I. (e^{β})**
Constant	-18.564	8.671	4.583	1	0.032	-	
Break point	1.846	0.765	5.821	1	0.016	6.333	1.414-28.371
Service point	-1.537	0.719	4.565	1	0.033	0.215	0.053-0.881
Reception error	-1.167	0.581	4.040	1	0.044	0.311	0.1-0.971
Attack error	-1.011	0.497	4.147	1	0.042	0.364	0.137-0.963
Attack blocked	-0.542	0.277	3.833	1	0.050	0.582	0.338-1.001
Attack point	0.473	0.227	4.335	1	0.037	1.605	1.028-2.504
Opposition error	0.346	0.152	5.208	1	0.022	1.414	1.050-1.903
Test			**χ^2**	**df**	**p**	**R^2**	
Overall model evaluation							
Likelihood ratio test			63.929	7	<0.001		
Cox & Snell						0.643	
Nagelkerke						0.858	
Goodness-of-fit test							
Hosmer & Lemeshow			0.280	8	1		

Discussion

The purpose of this study was to identify important skill related factors that were significantly responsible for winning in the beach volleyball championships using a logistic regression approach. A forward step method indicated seven factors (out of ten) were related to winning in men's competition. In addition, five factors were positively related (break point, service point, attack point percentage, block, opponent error) while two factors (reception error and attack error) were negatively related to winning. In the case of women's competition, a forward step method indicated seven factors (out of ten) were related to winning. In addition, four factors (break point, attack point percentage, block, and opposition error) were positively related while three factors (reception error, attack error, and attacked blocked) were negatively related to winning.

Further classification of the observations into the league and knockout rounds resulted in an indication of six factors (out of ten) related to winning in the league round, while four factors (out of ten) were related to winning in knock out round in men's competition. In the case of women's competition, six factors (out of ten) were related to winning in the league round, and seven factors (out of ten) were related to winning in the knockout round.

Table 7. The observed and the predicted frequencies for knockout match results by Logistic Regression model with the cut-off of 0.50

Observed	Predicted		% correct
	Loss	Won	
Men's matches			
Loss	32	7	82.1
Won	4	34	89.5
Overall % correct			85.7
Women's matches			
Loss	27	4	87.1
Won	1	30	96.8
Overall % correct			91.9

Our study suggests few factors to be significantly responsible for winning in beach volleyball competition, such as break point, service point, attack point percentage, block, opponent's error, reception error, attack error, and attack blocked. Break points include one's own service aces, counterattack points, and a number of winning blocks, and the opponent's errors, although these factors did not explain the

outcomes of matches by themselves in our model. In this competition, the number of points obtained in the break point phase was the factor that made the greatest contribution to the final outcomes. This factor is completely related to the performance of the opponent's reception and the opponent's attack (Peña, Rodríguez-Guerra, Buscà, & Serra, 2013). The service point was also found to be an important factor in determining success in both men and women beach volleyball competition. A previous similar study conducted on volleyball supports our findings (Silva, Lacerda, & João, 2014). The teams are evenly balanced at the world championship level, and when the match gets close to end the serve skill may be associated with victory. The service is the only moment of the game when the players have 100% control over the ball and the way events unfold. The players need to choose the type of service, the force, and the area of the opponent's court to which the service will be directed (Martinez & Abreu, 2003). Service is an opportunity to create the maximum number of problems for the receiving opponent and also score a direct point if possible. Thus, the service is the team's one of the most pre-eminent offensive weapons, causing a range of problems for the receiving team, restricting, forestalling, and even eliminating the possibility of an effective attack on the part of the opponents. A study by Quiroga et al. (2012) analyzed 1300 services and divided them into four components. The components with the greatest influence were related to the type of service used, highlighting the importance of the technical execution and the characteristics of the chosen action, as well as the speed imparted to the service ball. It was found that the players tried to execute a service that secures a direct point or that at least impedes the opposing team from mounting an attack, and to this end, they aim for a service that is accurate, difficult to receive, and very often powerful. The points gained through attack were also found to be the most important skill in volleyball (Lobietti, Di Michele, & Merni, 2006). A previous study also found a significant association between the attack efficiency and the set outcome (Monteiro, Mesquita, & Marcelino, 2009). The reason may be that the teams that win the sets make fewer errors and have higher efficiency in the counter attack. In the similar vein, the attack error and attacks blocked also plays a significant role in winning a match in beach volleyball.

Blocking is an important skill in any format of volleyball to stop the attack at the net and blocking successfully is one of the crucial features of winning in volleyball (Lobietti, 2009). Previous studies (Lobietti et al., 2006) also investigated the importance of block to win the game using cluster analysis in the Italian volleyball professional league and results suggest the block to be the second most important skill after the attack. The points gained using block were also found to be highly correlated to the final ranking (Lobietti et al., 2006). The nature of every sport is such that teams try to find the weaker link in the opponent team to gain benefits. Team tactics are always such that the opponents are forced to commit an error. Our study findings suggest that the opponent's error is linked to winning in elite beach volleyball competition. Previous studies suggest the quality of reception as an important factor in winning a volleyball match (Paulo, Zaal, Fonseca, & Araújo, 2016; Peña et al., 2013; Silva et al., 2014). During the reception, many task-related functional constraints might influence the behavior of the receiver (Barsingerhorn, Zaal, De Poel, & Pepping, 2013). The jump-float serve takes about 1 second to reach the receiver, who needs about 300 milliseconds to initiate his first movement (Benerink, Bootsma, & Zaal, 2015). The receiver's position and movement have effects on how to pass a serve (Paulo et al., 2016), and a player not able to flexibly adapt to varying constraints results in loosing points.

Differences between winning and losing teams have been of particular interest to researchers, and previous studies indicate that attack efficiency and error percentage were the primary factors in winning a match (Giatsis & Zahariadis, 2008; Michalopoulou et al., 2005). This could explain why there is more offensive than defensive movements and vertical advance movements in professional women's beach volleyball (Pérez-Turpin, Cortell-Tormo, Suárez-Llorca, Chinchilla-Mira, & Cejuela-Anta, 2009).

In addition to this, there was some significant reflection in our findings when the observations were further divided based on league matches or knockout matches. In men's competition, six factors were found to significantly affect the winning of matches in the league round, whereas only four factors were found significant in knockout rounds. One reason for this finding may be attributed to the fact that only the best teams qualify to the knockout rounds through the league matches. With the best teams playing in the knockout stages, it becomes evident that only a few factors will be contributing to the winning. Giatsis and Zahariadis (2008) could observe that 2:0 winning teams on an international level (FIVB) have superior skills in almost all techniques, especially in avoiding attack errors. During close games (2:1 wins) only the amount of points discriminated winners from losers. Michalopoulou et al. (2005) identified the effectiveness of attack and serve as key predictors for winning teams on the Greek national level.

Similarly, in women's competition, seven factors were found contributing to winning in league rounds, while six factors were contributing to winning in knockout rounds. Although not similar to men, women teams also showed one factor less contributing during the knockout rounds than league rounds. The differences in the factors between men and women for winning league or knockout may be explained by the fact that males are significantly different from females with respect to physical, physiological, psychological aspects (Lewis, Kamon, & Hodgson, 1986). Previous studies observed differences in the type of techniques used between gender (Koch & Tilp, 2009b; Yiannis, 2008). Women's beach volleyball is considered to employ more effective defense strategies, due in part to their lower levels of strength, speed, and jump height and causes their attacks to not to be as dynamic as in men's volleyball (Macial et al., 2009). A previous study also observed significant sex differences in frequencies of techniques applied for service, reception, setting, attack, and block and defense, which may indicate differences in movement pattern between men and women (Koch & Tilp, 2009b).

Conclusion

Our study concludes that there is a significant association of important factors with respect to winning a match in an elite beach volleyball championship. The coaches and players can take note of the important factors responsible for winning in the elite beach volleyball championship, with different factors playing important role in men and women

competition during league and knockout rounds as well. This may also help the coaches design their training periodization considering the factors that are important for their team.

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ІДЕНТИФІКАЦІЯ ЧИННИКІВ, ЩО ВИЗНАЧАЮТЬ ПЕРЕМОГУ У ПЛЯЖНОМУ ВОЛЕЙБОЛІ СЕРЕД ЧОЛОВІКІВ ТА ЖІНОК: ЛОГІСТИЧНИЙ РЕГРЕСІЙНИЙ ПІДХІД

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Реферат. Стаття: 10 с., 1 рис., 7 табл., 47 джерел.

Метою дослідження було ідентифікувати чинники, що визначають перемогу в чемпіонаті з пляжного волейболу серед чоловіків та жінок.

Матеріали і методи. Вибірка дослідження складалася із 212 поєдинків для чоловіків та 214 поєдинків для жінок на чемпіонаті світу з пляжного волейболу FIVB для чоловіків та жінок 2017 та 2019 років, що відбувся у Відні та Гамбурзі з 28 липня по 6 серпня 2017 року та з 28 червня по 7 липня 2019 року. Матчі зіграли 192 команди (як чоловіки, так і жінки разом), що складалися з 384 номерів (як чоловіків, так і жінок разом) гравців з різних країн. Дані аналізували за допомогою бінарної логістичної регресії (прямий: метод LR) з результатом гри як залежною змінною та змінними предиктора як коваріатами. Розраховували β, стандартну похибку β, χ^2 Вальда, коефіцієнт шансів із 95% довірчим інтервалом. Оцінка моделі проводилася за допомогою тесту коефіцієнта ймовірності, тестів Кокса і Снелла (R^2) та Нагелькерке (R^2). Тест на придатність моделей проводився за допомогою тесту Хосмера та Лемешоу.

Результати. Аналіз показав, що сім чинників були пов'язані з перемогою у змаганнях серед чоловіків та жінок. У ході турів ліги шість чинників у чоловічих та сім чинників у жіночих змаганнях були пов'язані з перемогою. Крім того, у плей-оф таких чинників було чотири у чоловічих та шість у жіночих змаганнях.

Висновки. Дослідження показує, що існує суттєва асоціація важливих чинників щодо перемоги в матчах елітного чемпіонату з пляжного волейболу. Тренери та гравці можуть взяти до уваги важливі чинники, що відповідають за перемогу в елітному чемпіонаті з пляжного волейболу, при цьому різні чинники так само відіграють важливу роль у змаганнях чоловіків та жінок під час плей-оф раундів Ліги.

Ключові слова: нотаційний аналіз, шанси, FIVB, прогнозування, чемпіонат світу, майстерність.

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ORIGINAL SCIENTIFIC ARTICLE

HIGH INTENSITY INTERMITTENT EXERCISE PLAYS A ROLE IN IMPROVING BRAIN ACTIVATION DURING COMPLEX EXECUTIVE FUNCTIONAL TASKS

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Abstract

Several neuroimaging studies have examined the effect of different types and combinations of exercises on activation of brain associated with cognitive testing but none of these studies have examined the role of high intensity intermittent exercise (HIIE) in altering cortical activation from simple to complex cognitive tasks.

The purpose of this study was to find if HIIE has a role in modulating executive functions related to inhibitory control as expressed by changes in prefrontal cortex (PFC) activation.

Materials and methods. 40 healthy adults aged between 18-30 years volunteered for the study. They were randomly divided into HIIE a (n = 20) group and a control (n = 20) group. The HIIE group performed 4*4 min of high intensity exercise on a cycle ergometer with 3 minutes of active recovery at lower intensities between the bouts, whereas the control group performed no exercise. Prefrontal hemodynamics (oxy and deoxy haemoglobin) were assessed using functional near infrared spectroscopy (fNIRS) during the Colour Word Stroop test (CWST) on two sessions: pre-session and post-session (1 week after pre-session).

Results. The results indicate a significant difference in CWST scores which coincided with a significant difference in hemodynamics of PFC between a congruent and a complex incongruent task in the HIIE group. There was a greater activation of the right frontopolar area, the left ventrolateral prefrontal cortex, and the left frontopolar area during the incongruent task in response to acute HIIE.

Conclusion. HIIE plays a role in changing brain activation during more complex interference related tasks.

Keywords: HIIE, fNIRS, prefrontal cortex, Colour Word Stroop test, cognition.

Introduction

A growing body of literature has reported that exercise has an effect on brain activation during cognitive testing (Hyodo et al., 2012; Chang et al., 2012; Bediz et al., 2016). Cognition improvement is related to the type of exercise, improvement is smaller with low to moderate intensity exercise and larger with high intensity exercise (Hashimoto et al., 2017; Tsukumoto et al., 2016, 2017). The colour word Stroop test (CWST) has been widely used to assess changes in cognitive performance as a result of acute (Tsujii et al., 2013; Yanagisawa et al., 2010) as well as long term exercise (Martinsen et al., 2018).

CWST is a robust test which is used to assess executive functions including processing speed, selective attention and the degree of automaticity (Martinsen et al., 2018). It has two types of stimuli: congruent, testing fluency of reading words and incongruent, testing the ability to inhibit the interference (Scarpina & Tagini, 2017). The latter is a more complex task and needs involvement of more neural substrate (Floden et al., 2011). SCWT assesses executive functions that are mediated by changes in the hemodynamics in prefrontal cortex (Moriguchi & Hiraki, 2013). Executive functions involve activation of many brain sites, such as the prefrontal cortex (PFC), anterior cingulate, and parietal cortex (Scarpina & Tagini, 2017). Acute exercise enhances the activity of prefrontal cortex and involves activation in dorsolateral prefrontal cortex and frontopolar area of prefrontal cortex (Byun et al., 2014).

Previous literature shows that exercise increases neuronal activity (Dalsgaard et al., 2002, Endo et al., 2013; Cooper, 1973), improves cognitive performance (Cooper, 1973; Tsukamoto et al., 2016, 2017; Hashimoto et al.; 2018) and exercise with sufficient intensity and duration prolongs the exercise-induced improvement in executive functions. In particular, high intensity intermittent exercise

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(HIIE) facilitates neuronal activation and excitation levels (Hashimoto et al., 2018). HIIE is an exercise regime which includes number of bouts of exercising at high intensities (85-95% of HR max) (Helgerud et al., 2007) interspersed with intervals of exercise at lower intensities (40-50% of HR max) (Kravitz, 2014). HIIE is an exercise regime which motivates young adults for continued engagement in exercise for its behavioural, affective and cognitive outcome (Burn & Niven, 2018). Literature suggests that participation in high intensity exercise is positively associated with existing cognitive health and produces broader benefits on cognition (Tsukumoto et al., 2016). However, studies determining the effect of HIIE on brain areas involved in cognitive tasks are few.

Changes in the brain activation, associated with cognitive improvement have been recently assessed by Functional near infrared spectroscopy (fNIRS). It is an optical, non-invasive method which measures changes in the cortical hemodynamics and is suitable for assessing the effect of acute exercise on changes in brain activation (Yanagisawa et al., 2010). Kujach et al. (2018) examined the effect of short duration transferable high intensity intermittent exercise on CWST associated prefrontal cortex activation and they found increased corticalactivation related to Stroop interference on the left-dorsal-lateral prefrontal cortex (DLPFC) with improved cognitive performance. However they could not explain the difference in the activation during congruent and incongruent task. Brain activation from simple to complex tasks are needed to be evaluated as it may provide valuable information about sports performance enhancement through HIIE during formation of complex game strategies. To our knowledge the studies determining the difference in brain activation during congruent and more challenging incongruent task as an effect of HIIE are less and needed to be studied. Thus the aim of our study was to find if HIIE has a role in modulating executive functions related to inhibitory control as expressed by changes in prefrontal cortex activation.

Materials and methods

Study Setup and Participants

The setup of the study was the Neuro Physiology Lab, MYAS-GNDU Department of Sports Sciences and Medicine, Guru Nanak Dev University, Amritsar, Punjab. Participants were asked to volunteer from various departments of the University. The study was randomized two group pre post design. The procedure of testing protocol was explained to the participants thoroughly and written informed consent was obtained from all participants. 40 healthy adults (24 females and 16 males) aged between 18 to 30 years volunteered for the study. They were randomly divided into HIIE group and control group (Table 1). The study was approved by Institutional Ethical committee of Guru Nanak Dev University, Amritsar, Punjab, India. (No. 158/HG; Dated 01/10/2019)

Study Criteria

Males and females participants between 18-30 years of age were included for the study. All subjects were in intellectual norm measured by measured by Multidimensional Aptitude Battery-II and had IQ between 90-119. Participants were excluded if they answered yes to any of the questions of Physical activity readiness questionnaire (PARQ), had a history of cardio-respiratory or cerebro-vascular disease, had a history of psychiatric or neurological disease, had done strenuous activity or had a history of use of tobacco/nicotine products such as cigarettes or chewing tobacco, had a history of alcohol consumption 24 hours prior to the test, had poor sleep (measured by Pittsburgh Sleep Quality Index) or had consumed 2 or more than 2 cups of caffeine on that day or a large meal for 2 hours before exercise.

Table 1. Descriptive characteristics of participants

Descriptive characteristics of participants	Control group n = 20	HIIE group n = 20	p
Age (years)	24.12 ± 0.64	24.11 ± 1.53	0.981
BMI	23.05 ± 3.59	22.25 ± 2.40	0.458
Resting HR (beats/min)	81.00 ± 2.72	79.22 ± 6.09	0.460
PSQI score	3.12 ± 1.64	4.00 ±1.65	0.293
IPAQ (MET·min/week)	1743.76 ± 1353.81	2559.58 ± 1475.99	0.115
IQ score	92.50 ± 9.47	92.55 ± 13.56	0.992

Values of above variables are presented as mean ± standard deviation. There was no significant difference ($p > 0.05$) found on comparison with independent t-test for the above mentioned variables between control and HIIE group.

Exercise protocol

HIIE protocol was of 4 bouts of 4 minutes (4×4) at 90-95% HRmax with 3min active recovery at 70% HRmax (Helgerud et al., 2007). HRmax (beats/min) was calculated by the formula: (Fox et al., 2013; McArdle., 2010 p. 473)

$$HRmax = 206.9 - 0.67 \cdot age\ (y)$$

Before training, 3 minutes of warm up was done and training was followed by 2 minutes of cool down at the pedalling frequency and intensity according to participant preference between 8-12 grading of 20 pointed Borg's Rating of Perceived Exertion (RPE) scale. Participants cycled on Lode Corival BV Groningen, The Netherlands against a work load of 100-150 W and between 15-18 Borg's RPE during each high intensity bout and with no work load, average 89 RPM and 8-12 Borg's RPE during recovery period. Heart rate was monitored using Polar heart rate Monitor (Polar Vantage V Pro Multisports Watch). Borg's RPE grading was noted after one minute of start of each high intensity bout and after the end of each high intensity bout session. All training sessions were conducted in neurophysiology lab of MYAS-GNDU department of Sports Sciences and Medicine, Guru Nanak Dev University, Amritsar, Punjab, India.

Cognitive testing

Cognitive functions were tested by Stroop Colour and Word test. There was a gap of at least one week between pre and post session in order to dilute the effect of learning of the cognitive test.

Colour and Word Stroop test

Colour-word Stroop test was used to assess executive functions. It is a paper pencil based test which has 4 pages of 5 by 20 matrixes of colour- word items (total 100 items). First and second page included congruent stimuli, whereas third and fourth page included incongruent stimuli. Subjects were instructed to read the words across the column on each page. On the first page participants were instructed to read the words written with black inc above downwards. On the second page participants were instructed to read the colours by which 'XXXX' are printed. The third page had 5 columns of colour names (red, green, and blue), which were printed in different colours. For this participants were instructed to name the ink of each word, ignoring the word that was spelled out. For example, if the printed word "red" appeared in blue colour font, the word should be read "blue". For the fourth page participants were instructed to name the ink by which the words were printed, ignoring the word which is written but to read the word which is highlighted with the box, ignoring its colour. The time taken and errors during reading the 100 items were noted. Stroop testing was done on following sessions: Pre HIIE and Post 10-15 min of HIIE. These raw scores were converted into the variables of time interference score, Average reaction time score and error interference scores using following formulae:

Stroop interference score = CWS - [(CS+WS)/2]

Where, CWS – Colour word score, CS – Colour score and WS – Word Score

Average reaction time = Summation of total time taken to complete individual sheets/400

Error Interference score = CWE - [(WE + CE)/2]

Where, CWE – Colour word error, CE – Colour error and WE – Word error

Evaluation of brain hemodynamics

A continuous wave functional near infrared spectroscopy (fNIRS) System Brite Artinis 24, Netherlands, was used to assess oxy and deoxy haemoglobin concentration of prefrontal cortex during colour-word Stroop test. Hemodynamic changes were recorded as oxy haemoglobin (oxy-Hb) and deoxyhemoglobin (deoxy-Hb) in μ mol, measured during congnitive testing, before and after HIIE with participants in sitting position. In order to establish a baseline (Fox et. al 2013) 10 s of fNIRS data was also be collected immediately prior to starting of cognitive tests and also before HIIE session. For baseline data acquisition participants were asked to sit quietly and relax.

The fNIRS data was collected using a 24 channel BriteArtinisfNIRS system configured into 3×3 optodes patterns on each lateral side of prefrontal cortex. The optodes were placed on head according to topographic probe layout map along with the standard EEG 10/20 coordinate system 24 channel grids were placed to cover following Regions of Interest (ROI) for each hemisphere: the dorsolateral prefrontal cortex (DLPFC), ventrolateral prefrontal cortex (VLPFC) and fronto-polar area (FPA) over prefrontal cortex (figure 1). Participants' heads were individually fitted with a retaining cap (which was selected by measuring the circumference of each participant's head) and contained all of the source and detector fibers (yellow: emitter and blue: detector). This arrangement gave a total of 24 (12 on each side) measurement channels, with an overall emitter-detector separation of ~3 cm (Kalia et al., 2018) (figure 2). A differential path length factor was calculated on the basis of the exact age of the participant. There was a delay of at least 10 minutes after the HIIE cessation before taking the post Hemodynamic data to ensure fading of physiological noises. The Oxy-HB and DeOxy-Hb data was collected separately for congruent and incongruent task.

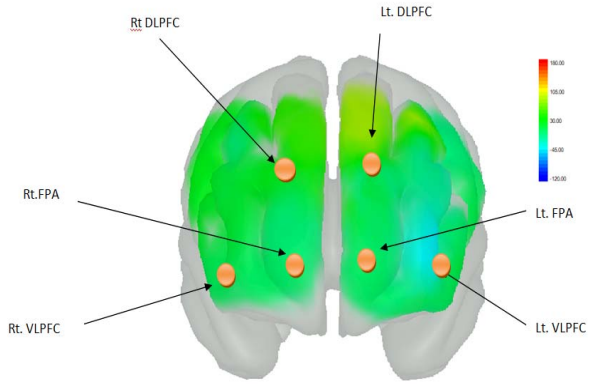

Fig. 1. Region of interest in right and left Prefrontal cortex shown by 3D cortical mesh view. (Rt. - right, Lt.-left)

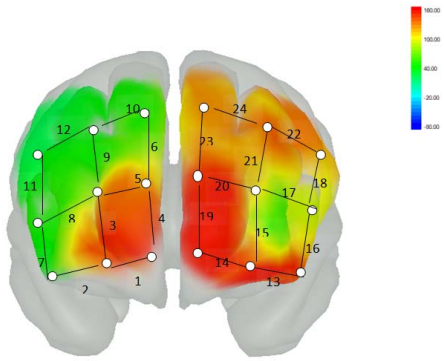

Fig. 2. Schematic representation of arrangement of 24 channels of fNIRS on prefrontal cortex shown on cortical 3D Mesh view. Optodes were arranged according to topographic probe layout map along with the standard EEG 10/20 coordinate system

The area over the scalp was identified as 6 region of interests (ROI) for analysis with an area for the right DLPFC which included channel number 5, 6, 9, 10, 11 and 12, a second one over the right VLPFC which included channel number 2, 3, 7 and 8, a third area over the right FPA which included channel number 1 and 4, a fourth area over the left DLPFC which included channel number 18, 20, 21, 22, 23 and 24, a fifth area over the left VLPFC which included channel number 13, 15, 16 and 17 and finally a sixth area over the left FPA which included channel number 14 and 19 over the prefrontal cortex.

For fNIRS data, the pre-processing was conducted using the open-source software HOMER2 implemented in MATLAB. All recorded signals were first converted to optical density for processing in the HOMER2 software. Channels with low amplitude were excluded from group processing. Signals were then processed by the principal component

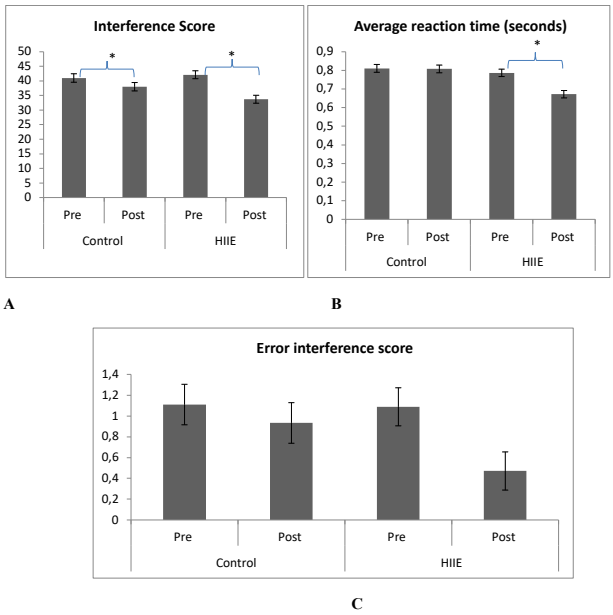

Fig. 3. Graphical Representation of the results showing changes in the cognitive score of Colour word Stroop test in pre and post session of control and HIIE group. The bars shows mean values of (A). Interference score, (B). Average reaction time score and (C). Error interference score. The error bars show standard error values

analysis method to remove systematic artifacts according to methods described in previous literature (Tak & Ye, 2014). The motion artifact threshold of more than 15 standard deviations from the mean were identified and replaced with spline interpolation based on preceding and subsequent segment of the signals. Wavelet filtering was used to remove motion induced sharp spikes as suggested by previous literature (Jahani et al., 2018) such as wavelet filtering, are excellent in removing motion-induced sharp spikes, the baseline shifts in the signal remain after this type of filtering. Methods, such as spline interpolation, on the other hand, can properly correct baseline shifts; however, they leave residual high-frequency spikes. We propose a hybrid method that takes advantage of different correction algorithms. This method first identifies the baseline shifts and corrects them using a spline interpolation method or targeted principal component analysis. The remaining spikes, on the other hand, are corrected by smoothing methods: Savitzky-Golay (SG. After this processing, the signals were then band pass filtered with frequencies between 0.02 to 0.5 Hz to remove baseline drift and physiological noises. Finally, these filtered signals were converted to oxy and deoxy haemoglobin concentration (μ Mol.) data using modified Beer-Lambert law (Cope & Delpy, 1988). Block averaging method was used to infer changes in hemodynamic response across the participants.

Statistical analysis

Cognitive data of colour word Stroop test was analysed for normality distribution using Shapiro-Wilk test. The data was normally distributed hence two way ANOVA was done to find interaction of stroop interference score; average reaction time and error interference score for group (control/ HIIE) and sessions (Pre/post).

Thepre-processed data obtained from fNIRS was subjected to Shapiro-Wilk test in order to determine the normality distribution of the data. The data was normally distributed and oxy and deoxy haemoglobin concentration data associated with cognitive task was subjected to three way ANOVA test with group (control/HIIE), sessions (pre/post) and condition (congruent/Incongruent) as factors to examine the interaction between.

Results

Cognitive results

Two way ANOVA (figure 3) results showed a significant difference between pre and post scores of Stroop interference scores, shown by a significant interaction of group*session ($F_{1, 39} = 7.35$, $p = 0.008$, partial $\eta^2 = 0.76$) for interference score between the subjects. Average reaction time scores showed a significant difference between the scores shown by a significant effect of group ($F_{1, 39} = 20.85$, $p < 0.001$, partial $\eta^2 = 0.588$), and a significant interaction of group*session

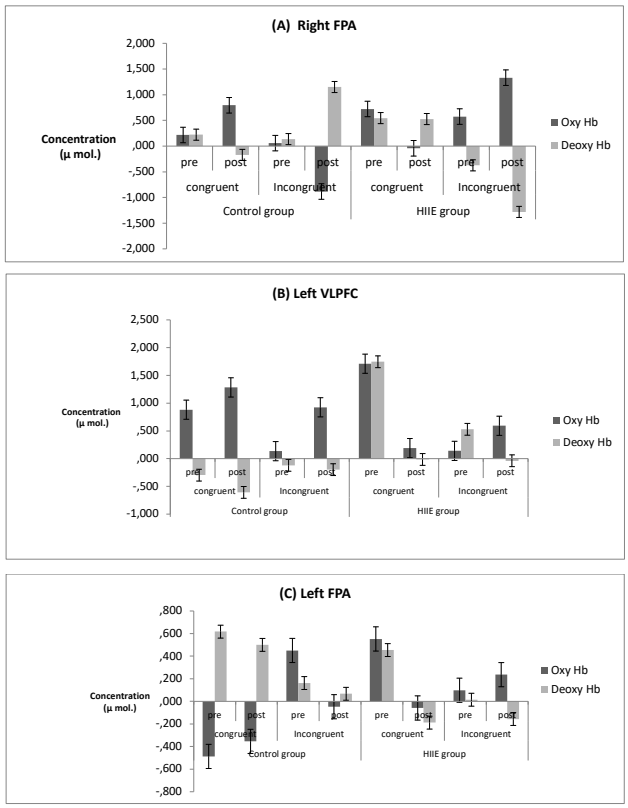

Fig. 4. Graphical Representation of the results showing the comparison of oxy and deoxy haemoglobin concentration during congruent and incongruent conditions of pre and post sessions of control and HIIE group. The hemodynamic variables (oxy and deoxy haemoglobin concentration) were compared using three way ANOVA. We found a significant interaction of group (control/ HIIE), session (pre/ post) and condition (congruent/ incongruent) in the three areas of pre frontal cortex which are shown in the above figure. (A) showing changes in the hemodynamic variables of right FPA. (B) showing changes in the hemodynamic variables of left VLPFC. (C) showing changes in the hemodynamic variables of left FPA

($F_{1, 39}$ = 10.791, p = 0.001, partial η^2 = 0.107). Error interference scores showed a significant main effect of session ($F_{1, 39}$ = 4.558, p = 0.035, partial η^2 = 0.048) and showed no interaction of group with session.

Changes in cortical activation between congruent and incongruent task

Three way ANOVA (figure 4) indicated a significant interaction of group (control/HIIE), session (pre/post) and condition (congruent/ incongruent) of only three (out of 6) areas of PFC; right FPA($F_{oxy\ (1, 152)}$ = 31.45, p = 0.0001, $F_{deoxy\ (1, 152)}$ = 39.39, p = 0.0001), left VLPFC ($F_{oxy\ (1, 152)}$ = 101.11, p = 0.0001, $F_{deoxy\ (1, 152)}$ = 131.01, p = 0.0001) and left FPA ($F_{oxy\ (1, 152)}$ = 56.34, p = 0.0001, $F_{deoxy\ (1, 152)}$ = 58.14, p = 0.0001). The results demonstrated a greater activation (increased oxy haemoglobin and decreased deoxy haemoglobin concentration) in incongruent condition in response to HIIE. There was a decreased activation (decreased oxy haemoglobin and increased deoxy haemoglobin concentration) during congruent condition as compared to control group.

Discussion

The current study was aimed to explain the role of HIIE in enhancing brain activation during a more complex Stroop interference task. The focus of the study was to find the differences in brain activation during congruent and incongruent task during CWST as a result of HIIE. The result of the study indicate that there is a significant increase in brain activation, shown by increase in Oxy-Hb and decrease in DeOxy-Hb in right frontopolar area (FPA), left ventrolateral prefrontal cortex (VLPFC) and left frontopolar area (FPA).

The HIIE group showed improved executive function performance with decreased interference and decreased reaction time after the HIIE intervention reflecting a greater speed of processing with improved accuracy in response. These results are consistent with the findings of previous studies (Yanagisawa et al., 2010; Kujach et al., 2018; Hyodo et al., 2012; Tsukamoto et al., 2016) which explained a greater improvement in Stroop incongruent performance as a result of exercise intervention in young adults. These behavioural results coincided with increased activation of PFC areas in our study.

The increased activation is demonstrated in the current study by increased Oxy-Hb and decreased DeOxy-Hb in the region of interest. The information regarding both Oxy-HB and DeOxy-Hb is imperative as Oxy-Hb gives the information about delivery of oxygen in the particular area and DeOxy-Hb provides information about oxygen utilization by the neural tissue during activity (Lambrick et al., 2016; Herold et al., 2018). Moreover changes in DeOxy-Hb is considered a more sensitive indicator of overall neural process since unlike Oxy-Hb it is less affected by extra-cerebral processes (Seidel et al., 2019) like heart beat and increase in scalp blood flow. Thus both Oxy-Hb and DeOxy-Hb variables of the hemodynamics were included for the evaluation of cortical activation.

The fundamental mechanism of the acute exercise effect has been explained by a sudden increase of neural substances such as lactate, cortisol, neurotrophins, neurotransmitters, and neuromodulators (Basso & Suzuki, 2017), as well as increases in regional cerebral blood flow (CBF) following acute exercise (Bae & Maasaki, 2019; Querido & Sheel, 2007; Pontifex et al., 2009b). Exercise interventions with various modulations such as low intensity exercise (Byun et al., 2014), moderate intensity exercises (Hyodo et al., 2012), resistance exercises (Herold et al., 2019)physical capabilities (e.g., muscular strength and transferable high intensity intermittent exercise (Kujach et al., 2018) have been used previously to examine the effect of acute exercise interventions on the hemodynamic functions of the cortical areas related to CWST performance. All these studies have found an increase in the activation in areas of PFC associated with an improved CWST performance, specific to the type of exercise intervention used.

Our study was the first to examine the difference in the activation during congruent and incongruent CWST task in response to HIIE and we found a significant increase in the activation during the incongruent task indicating the facilitation effect of HIIE on executive function. Our results showed a decreased activation during the easier task whereas increased the activation during a complex task in response to HIIE.Further work is required to understand the changes in brain activation while performing simple to complex cognitive tasks in the population of different age groups and various sports disciplines.

Conclusions

We conclude that introduction of HIIE intervention causes greater activation of prefrontal cortex areas involved in maintenance of executive functions. We found evidences of increased cortical hemodynamics in the area of right FPA, left VLPFC and left FPA during incongruent CWST in response to HIIE session. Thus it is suggested that the HIIE protocol plays a role in increasing activity of prefrontal cortex while performing more complex executive functional tasks and hence recommended to improve the cognitive performance.

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Conflict of Interest

The authors declare no conflict of interest.

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ВПЛИВ ПЕРЕРИВЧАСТИХ ВПРАВ ВИСОКОЇ ІНТЕНСИВНОСТІ НА ПОЛІПШЕННЯ АКТИВАЦІЇ МОЗКУ У ВИКОНАННІ СКЛАДНИХ ФУНКЦІОНАЛЬНИХ ЗАВДАНЬ

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Реферат. Стаття: 7 с., 1 рис., 4 табл., 33 джерел.

Кілька досліджень нейровізуалізації вивчали вплив різних типів та комбінації вправ на активацію мозку, пов'язані з когнітивним тестуванням, але жодне з цих досліджень не вивчало роль високоінтенсивних інтермітуючих вправ (HIIE) у зміні активації кори від простих до складних когнітивних завдань.

Метою цього дослідження було з'ясувати, чи відіграє роль HIIE в модуляції виконавчих функцій, пов'язаних з інгібуючим контролем, що виражається змінами в активації префронтальної кори (PFC).

Матеріали і методи. У дослідженні взяли участь 40 здорових дорослих людей віком від 18 до 30 років. Вони були випадковим чином розділені на групу HIIE (n = 20) та контрольну (n = 20) групу. Група HIIE виконувала 4 * 4 хв вправ високої інтенсивності на велоергометрі з 3 хвилинами активного відновлення, тоді як контрольна група не виконувала вправ. Префронтальну гемодинаміку (окси- та дезоксигемоглобін) оцінювали за допомогою функціональної ближньої інфрачервоної спектроскопії (fNIRS) під час кольорового тесту Stroop (CWST) на двох сеансах: перед сеансом та після сеансу (через 1 тиждень після сеансу).

Результати. Результати вказують на значну різницю в показниках CWST, яка співпала зі значною різницею в гемодинаміці PFC між конгруентними та складними невідповідними завданнями у групі HIIE. Під час інконгруентного завдання у відповідь на гострий HIIE спостерігалася більша активація правої лобово-полярної області, лівої вентролатеральної префронтальної кори та лівої лобово-полярної області.

Висновки. HIIE відіграє роль у зміні активації мозку під час більш складного завдання, пов'язаного з втручаннями.

Ключові слова: HIIE, fNIRS, префронтальна кора, кольоровий тест Stroop, пізнання.

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ORIGINAL SCIENTIFIC ARTICLE

CHARACTERISTICS OF THE SPECIAL PHYSICAL FITNESS OF PADDLERS AT A DISTANCE OF 200 M

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

The aim of the study. The overall goal of this manuscript was to gain a better understanding of differences in the level of functional support for special endurance for paddlers of uniform groups (in terms of sports qualification): men kayakers, men canoeists, and women kayakers who specialize in a distance of 200 m.

Material and methods. 20 qualified paddlers' level of functionality is being assessed, among them are a group of elite athletes, the members of the Chinese national team and winners of the 2018 Asian Games.

Results. The important feature of the analysis is the evaluation of the structure of the ergonomic power of a 30-second maximum load. Estimating the average value of the ergometric power of work for 25-30 seconds of operation in accordance with the average power of the entire 30-second load made it possible to determine the ratio of the anaerobic alactic and lactic abilities of the athletes, taking into account the requirements of a 200-meter race for canoe and kayak paddlers.

A significant range of individual differences in the indices of reactive properties of the cardiorespiratory system, which are determined by the ratio of the partial pressure of CO_2 and the maximum level of pulmonary ventilation ($V_E/PaCO_2$) during the10 and 30 second test task, attracts attention.

The range of $V_E/PaCO_2$ indicators was: the relation of partial pressure CO_2 to pulmonary ventilation in the 10 s test – 2.3 ± 0.8 for men kayakers; 2.3 ± 0.7 for men canoeists; 2.2 ± 0.5 for women kayakers; the relation of partial pressure CO_2 to pulmonary ventilation in the 30 s test – 3.9 ± 1.0 for men kayakers; 3.8 ± 1.1 for men canoeists; 3.6 ± 0.7 for women kayakers.

Conclusion. The results of the study indicate differences in the level of functional support for special endurance for paddlers of uniform groups (in terms of sports qualification): kayakers and canoeists who specialize in a distance of 200 m.

Keywords: paddlers, aerobic energy supply, anaerobic energy supply, special performance.

Introduction

At present, there is no doubt that all athletes who have achieved high sports results have a high functional potential, which is characteristic for the kind of competition in canoe and kayak rowing (Kong et al., 2018; López-Plaza et al., 2019; Kong et al., 2020). In many respects, the functional potential of paddlers on canoes and kayaks is determined by the availability of high capacity energy supply systems (Tesch, 1983; Sheykhlouvand et al., 2018; Pickett et al., 2018; Paquette et al., 2018). The system for diagnosing the power of the energy supply system for paddlers of high qualification at different distances is presented before (García-Pallarés et al., 2009; Guo et al., 2020; Diachenko et al., 2020).

Previous research has shown the predictive power of $\dot{V}O_2$ max, maximal aerobic power (MAP), lactate threshold (LT_2), the energy cost of kayaking per unit distance for 1000, 500 and 200-m performance in Kayak athletes from national to international level (Fry & Morton, 1991; Bishop et al. 2002; van Someren & Howatson, 2008; Zamparo et al., 1999; Borges et al., 2015). In addition to a large contribution of the aerobic system, Kayak athletes, also benefit from higher anaerobic capacities. Indeed, Sprint Kayak intensities are typically contested above lactate threshold, showing that energy is also provided from non-oxidative sources.

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Elite level paddlers have a lactate threshold ~80% VO_2max and a high VO_2 max. In addition, the contribution of the aerobic system to the energy production has been estimated as ~37, 65 and 84% for 200, 500 and 1000-m respectively (Borges et al., 2015).

Moreover, several studies have shown that anaerobic capacities such as peak power, total work and peak lactate concentration in a 30-s "all-out" effort on kayak ergometer all have large-to-very large correlations with 200, 500 and 1000-m on-water performance (van Someren & Palmer, 2003; van Someren & Howatson, 2008; Borges et al., 2015).

However, the relationship of other fitness variables such as the respiratory system reactance to the increase of metabolic acidosis parameters and 200 -m Sprint Kayak performance in well-trained athletes has yet to be explored (Borges et al., 2015).

The training practices require review, especially in the case of qualified paddlers, as this group may begin to specialise their training toward this new format (Dyachenko, 2007; Kong et al., 2019).

The aim of the study: gain a better understanding of differences in the level of functional support for special endurance for paddlers of uniform groups (in terms of sports qualification) for men-kayak, for men-canoe and for women-kayak that specialize in a distance of 200 m.

Material and methods

Subject

Depending on the purpose of the research phase, the theoretical and experimental parts of the research were conducted at different training periods at the national aquatic sports training centers in Beihai, Zhizhao (PRC). 20 qualified paddlers are in the process of assessing the level of functionality, among them a group of elite athletes, the members of the Chinese national team and winners of the 2018 Asian Games.

Research protocol

Physical Characteristics, Gas exchange, HR, and blood lactate measurements.

Minute ventilation ($\dot{V}_E$), oxygen consumption ($\dot{V}O_2$), CO_2 production ($\dot{V}CO_2$), were determined on a breath-by-breath basis using an Oxycon mobile (Jaeger) metabolimeter. The metabolic unit was calibrated a gas of known composition (16.00% O_2, 4.00% CO_2), respectively.

HR was recorded every 5 s with an HR monitor (S610 Polar Electro, Kempele, Finland).

The blood lactate concentration ([La]b) was determined using a portable lactate analyzer (Biosen S. line lab +) on a blood sample obtained from the ear lobe at the end of the test.

A modified kayak-ergometer (Dansprint PRO, Denmark) was used. Ergometric power (EP) of work were recorded.

All the sportsmens performed an incremental exercise test on separate days, with at least 24 hours and no longer than 3 days between.

Depending on the purpose of the research phase, the theoretical and experimental parts of the research were conducted at different training periods at the national aquatic sports training centers in Beihai, Zhizhao (PRC).

The testing program is built in the form of test battery, each test solving a task to assess certain component of anaerobic abilities of athletes and cardiorespiratory system response. Test tasks were performed in a strictly determined sequence. It was important to preserve the parameters of the ergometric power of work which provided for the energy release in anaerobic alactate and anaerobic lactate (glycolytic) way, as well as the length of the rest intervals. The rest interval between 30 s and 90 s and work with maximum intensity provided the conditions for the release of lactic acid into the blood and the increase of the concentration of blood lactate in the muscles before the final maximum work.

Table 1 presents the control system and the content of test tasks to determine the quantitative characteristics of the main components of functional support of sprint paddlers.

Table 1. Characteristics of the indicators of functional support for special endurance of paddlers at a distance of 200 m

Indicators	Test or period of indicator measurement	Characteristics of the indicators
Training impulse, TI, c.u.	Standard work, 6 min	The degree of intensity of functional support of work
Watts mean 10 s	Test 10 s, maximum work	Paddlers' work release during the realization of anaerobic alactate energy supply
Watts mean 30 s	Test 30 s, maximum work	Paddlers' work release during the realization of the power of anaerobic lactate (glycolitic) energy supply
Watts mean 25-30 s		Work release during the peak period of the power of anaerobic lactate (glycolitic) energy supply
Watts mean 90 s	Test 90 s, maximum work	Paddlers' work release during the realization of the capacity of anaerobic energy supply
Lactate, mmol·l^{-1}	after the test task	Integral physiological characteristics of power and capacity of anaerobic energy supply
$V_E/PaCO_2$	Test 10 s, maximum work Test 30 s, maximum work	Respiratory system reactance to the increase of metabolic acidosis
VO_2 max, ml·min^{-1}·kg^{-1}	Test 90 s, maximum work	The Paddlers' ability to reach maximal aerobic power under conditions of training and competitive loads of sprinting type
HR Restoration to 120 bps^{-1}	During 3-5 minutes of restoration period after the last test task	The degree of intensity of functional support of work

The testing program was built in the form of test battery, each test solving a certain task. Test tasks were performed in a strictly determined sequence.

It was important to preserve the individual maximum parameters of the ergometric power of work and the length of the rest intervals. The rest interval between 10 and 30 s work was one minute, between 30 s and 90 s work – five minutes. This provided for a full recovery and diagnostics of the structure of the reaction of anaerobic energy supply of sprint paddlers – anaerobic alactate and lactate (glycolytic) power, anaerobic capacity. The test program also created the conditions for the display of the cardiorespiratory system reactive properties and the power of aerobic energy supply for the work.

It is noteworthy that in the assessment system presented in the table there are no indices of the degree of stress of the cardiorespiratory system of the body in the process of work – the parameters of the training impulse and the rate of recovery of the organism. This is due to the fact that the evaluation criteria are of an individual character and are considered in the dynamics for each particular athlete. They indicate the state of the athlete's body in the process of monitoring their functional abilities.

The research related to human use has complied with al the relevant national regulations and institutional policies; has followed the tenets of the Helsinki Declaration, and has been approved by the authors' institutional review board or al equivalent committee. Informed consent has been obtained from all individuals included in this study.

Statistical Analysis

The following methods of mathematical statistics were applied: descriptive statistics, selective method, Shapiro-Wilk's normality test, non-parametric Mann-Whitney test. Methods of descriptive analysis were used, including tabular presentation of separate variables, calculation of mean arithmetic value (M), standard deviation (SD). The sample data for normality were tested with the normal distribution formula and the Shapiro-Wilks test. The level of $p \leq 0.05$ (the probability of error) was assumed statistically significant.

Results

The indicators of the functional abilities of sprint paddlers, presented in Table 2 characterize high (unique) requirements for the level of development of specific aspects of functional support for special performance efficiency of paddlers at a distance of 200 m. This is indicated by the average values of the indices of paddlers from a homogeneous group, as well as by the data characterizing the functional abilities of sprint paddlers who have the highest sport results in the international arena. These data are systematized as a result of long-term observations of the leading athletes of China.

The range of the three highest indicators was:

- aerobic power (VO_2 max) in the range of 68.3-70.1 ml·min^{-1}·kg^{-1} for men; 66.0-68.4 ml·min^{-1}·kg^{-1} for women;
- maximum lactate concentration in blood (La max) – 20.5-22.0 mmol·l^{-1} for men, 17.5-19.1 mmol·l^{-1} for women;

Table 2. Specific indicators of the functional abilities of highly qualified paddlers specializing in a distance of 200 m (n = 20), $p < 0.05$

Indicators	Values of indicators (M ± SD)	The highest values of indicators*	Reduced values of indicators**
Values of indicators for men – kayak			
VO_2 max, ml·min^{-1}·kg^{-1}	65.1 ± 2.6	65.1	56.9
$V_E/PaCO_2$ 10 s	2.3 ± 0.8	3.2	1.3
$V_E/PaCO_2$ 30 s	3.9 ± 1.0	5.1	2.5
La max, mmol·l^{-1}	18.0 ± 1.2	21.2	14.7
W10 s, Watt	555.8 ± 9.5	570.0	527.0
W30 s, Watt	495.0 ± 10.2	512.0	460.0
W25-30 s – 30 s of test, Watt	525.2 ± 9.0	542.0	475.0
W90, Watt	278.3 ± 13.1	295.0	256.0
Values of indicators for men – canoe			
VO_2 max, ml·min^{-1}·kg^{-1}	65.5 ± 2.4	65.5	55.3
$V_E/PaCO_2$ 10 s	2.3 ± 0.7	3.3	1.4
$V_E/PaCO_2$ 30 s	3.8 ± 1.1	5.2	2.9
La max, mmol·l^{-1}	17.3 ± 1.0	20.9	16.2
W10 s, Watt	460.1 ± 6.9	480.0	454.0
W30 s, Watt	425.6 ± 14.3	443.0	405.0
W25-30 s – 30 s of test, Watt	441.1 ± 9.0	466.0	425.0
W90, Watt	269.0 ± 10.0	290.0	246.0
Values of indicators for women – kayak			
VO_2 ma_x, ml·min^{-1}·kg^{-1}	60.4 ± 2.7	61.2	50.3
$V_E/PaCO_2$ 10 s	2.2 ± 0.5	3.0	1.4
$V_E/PaCO_2$ 30 s	3.6 ± 0.7	4.6	2.4
La max, mmol·l^{-1}	16.9 ± 1.2	19.0	11.2
W10 s, Watt	325.5 ± 3.0	333.0	303.0
W30 s, Watt	300.5 ± 9.0	321	266
W25-30 s – 30 s of test, Watt	315.5 ± 7.9	327.0	290
W90, Watt	177.5 ± 6.1	191.0	155.0

Note. * – the indicators of the most successful athletes on the domestic and international arena; ** – indicators of the least successful athletes in the group of athletes

- average energy power of the work during 10 s test 580.0-610.0 Watts for men– kayak, 470.0-490.0 Watts for men – canoe, 330.0-345.0 Watts for women;
- average energy power of the work during 30 s test for men-kayak 505.0-535.0 Watts, 430.0-450.0 Watts for men-canoe, 305.0-320.0 Watts for women;
- average energy power of the work during 25-30 s of 30 s test for men-kayak 530.0-540.0 Watts, 445.0-455.0 Watts for men-canoe, 320.0-330.0 Watts for women;
- average energy power of the work during 90 s maximal test for men-kayak – 380.0-400.0 Watts, 390.0-415.0 Watts for men-canoe, for women (60 s test) – 280.0-300.0 Watts.

The range of $V_E/PaCO_2$ indicators was:

- the relation of partial pressure CO_2 to pulmonary ventilation in 10 s test – 2.3 ± 0.8 for men-kayak; 2.3 ± 0.7 for men-canoe; 2.2 ± 0.5 for women-kayak;

- the relation of partial pressure CO_2 to pulmonary ventilation in 30 s test – 3.9 ± 1.0 for men-kayak; 3.8 ± 1.1 for men-canoe; 3.6 ± 0.7 for women-kayak.

The data presented in the table indicate that the group is homogeneous. This is evident from the low individual differences in the indices of the power supply system and the performance efficiency of the paddlers. At the same time, a significant range of individual differences in the indices of reactive properties of the cardiorespiratory system, which are determined by the ratio of the partial pressure of CO_2 and the maximum level of pulmonary ventilation ($V_E/PaCO_2$) during 10 and 30 second test task, attracts attention.

Analysis of individual paddlers' data has established a trend in which the highest level of performance of sprinter paddlers is displayed under the condition of high response of the cardiorespiratory system. In this case, we are talking about the initial "neural" part of the reaction (in the test of 10 seconds) and the respiration reaction on the increase in metabolic acidosis during the 30-second test task. It is important to note that the characteristics of CO_2 emissions (VCO_2, $l \cdot min^{-1}$) in the group of athletes did not differ significantly. The range of individual differences (CV) of VCO_2 was in the range of 6.3-6.7% for all categories of paddlers.

Analysis of the individual data of the five paddlers who had high scores (x > M) and five paddlers who had reduced scored (x < M) for performance as a result of execution of all the test tasks showed the differences in the performance of the paddlers, and the differences in physiological reactivity of the organism to the specific loads of sprinter paddlers.

They are presented on the basis of assessment of the performance and reactivity of the respiratory system of leading sprinter paddlers, prize-winners and participants in the finals of the world championships and the Olympic Games.

The analysis also showed that a decrease in the reactivity of the respiratory system to the growth of acidic shifts is a factor in reducing the possibility of realizing individual indices of aerobic and anaerobic power of energy reactions.

This is evident from the ratio of the indices of $PaCO_2$, VO_2 max (under special diagnostic conditions of VO_2 max) and the highest VO_2 value reached in the testing of the function of the sprinter paddlers ($VO_2 max_{sprinttest}$). The results of testing the paddlers, which had a ratio of $VO_2 max_{sprinttest}$/ VO_2 max at high – 90% and higher, reduced – 80.0% and lower than the indicator level, were being analyzed.

It is interesting to note that most of the leading athletes (6 out of 7) had higher levels of lactate concentration in special test tasks for sprinter paddlers. The level of lactate concentration in the seventh athlete as a result of the application of test tasks for the registration of VO_2 max and when performing the sprint test program was practically the same. A distinctive feature of the reaction of the organism of these athletes was a higher respiration rate on 10 s and 30 s of the load compared to the group of paddlers (n = 8), who had lower performance indicators. Differences were up to 41-52% in the test of 10 s and 49-63% in the test of 30 s.

An important feature of the analysis was the comparison of the ergometric power performance in 30 seconds and in the period of 25-30 seconds of execution. Athletes with a high level of functional preparedness, had all the performance characteristics presented at a pronounced high level. This indicated a balanced character of the manifestation of anaerobic alactate and anaerobic lactate capacity in the overall energy balance of execution.

Discussion

The Kayak program at the Olympic Games has changed with the inclusion of the 200-m events for both men and women. Up to and including the 2008 Beijing Olympics, male Sprint Kayak athletes had competed over 500 and 1000-m races and women over 500m only. However, at the 2012 games the 200-m for men and women was included at the expense of the men's 500-m program. Due to the larger difference in raced distances in the new program, male athletes were required to focus their training and specialize in either the 200-m or 1000-m event and to date, little is known if women can focus on both the 200-m and 500-m. However, there is presently relatively little available empirical data on the race profiles and physiological demands of these events to inform coaches and scientists to develop evidence-based training programs for young developing athletes to compete in these events (Hagner-Derengowska et al., 2014; Kong et al., 2019). At the elite level, the men's individual Sprint Kayak race durations are approximately 35 and 204 s for the 200 and 1000-m, respectively. Further, for women's the 200-m lasts 39 to 40 s and K1 500 m performances range from 107 to 120 s for the winners. Additionally, men and women also have crew competitions with faster performances in K2 and K4 crafts for all these distances (200, 500 and 1000-m). It Sprint Kayak is an Olympic sport that requires the athletes to compete over 200-m (~35 s), 500-m (~110 s) and 1000-m (~215 s) in individual, double and four-seat boats (Bishop, 2004; van Someren & Howatson, 2008; Borges et al., 2015).

Well-trained Kayak athletes complete maximal 200-m time trials ~36.9–43.1 s, maintaining a mean power output of ~546 W, with an accumulated oxygen deficit of ~48.8 ml O2 Eq.kg-1. Conversely, 1000-m time trials last ~216–248 s with a mean power and accumulated oxygen deficit of ~226 ± 30 W and an ~31.0 ml O_2 $Eq.kg^{-1}$, respectively (van Someren & Palmer, 2003; Borges et al., 2015). These findings suggest elite Kayak athletes require specialised training programs, which vary in effort duration and effort to help optimally prepare them for specific race distances. However, at present there is a poor understanding of the appropriate training sessions that meet the demands of each of Kayak racing.

Sprint Kayak athletes have presented scores for absolute VO_2 max of 3.9 ± 0.7 (2.9-5.0) $L \cdot min^{-1}$ and relative 56.9 ± 8.5 (44.6-68.6) $mL \cdot kg^{-1} \cdot min^{-1}$ (Bishop et al., 2002, Garcia-Pallares et al., 2010; Borges et al., 2015). Unfortunately, accurate comparison between studies is difficult as various exercise protocols, exercise modes and equipment have been used to measure these capacities. Nonetheless, based on current evidence, it seems that Sprint Kayak athletes would benefit from a well-developed aerobic system as the longer races are contested close to VO_2 max (Jones & Burnley, 2009; Bishop, 2004).

Many authors have shown that other aerobic characteristics, such as maximal power output at VO_2 max level and anaerobic traits like power produced during 30 s and 2-min and the accumulated oxygen deficit (Bishop, 2004; van Someren & Palmer, 2003, van Someren & Howatson, 2008) relate to Sprint Kayak performance, highlighting the importance of developing both metabolic pathways for competitive success.

Reports from laboratory studies showed that, despite similar blood lactate responses (~9.6 ± 1.6 $mmol \cdot L^{-1}$), the shorter duration events (30 s maximal efforts) have higher

anaerobic oxygen deficit (~29% higher) compared to 120 s maximal efforts (Bishop, 2004; van Someren & Palmer, 2003).

The results van Someren and Palmer (2003) demonstrate that superior upper body dimensions and anaerobic capacities distinguish international-level kayakers from national-level athletes and may be used to predict 200-m performance.

A training program with either excessive or insufficient training load may impair the training-induced adaptations. In order to monitor the athletes, there is the need first to objectively quantify the training loads with proper and valid methods (Carter et al., 2000; Impellizzeri et al., 2005; Nicolas et al., 2006; Poole et al., 2008; Simoneau, 1998).

An important feature of the assessment of the effect of the above-mentioned physiological stimuli of reactions is that paddlers with high qualifications and at the same high level of humoral stimulation, the kinetics of the reaction are distinguished by the rates of deployment and recovery of the cardiorespiratory system and aerobic energy supply, their mobility under conditions of increasing fatigue (Nakazono & Miyamoto, 1987; Miyamoto et al., 1987; Diachenko, 2004).

Conclusion

The important feature of the analysis is the evaluation of the structure of the ergonomic power of a 30-second maximum load. Estimating the average value of the ergometric power of work for 25-30 seconds of operation in accordance with the average power of the entire 30-second load made it possible to determine the ratio of the anaerobic alactate and lactate abilities of the athletes, taking into account the requirements of a 200-meter race for canoe and kayak rowing.

A significant range of individual differences in the indices of reactive properties of the cardiorespiratory system, which are determined by the ratio of the partial pressure of CO2 and the maximum level of pulmonary ventilation (VE/PaCO2) during 10 and 30 second test task, attracts attention.

The range of $V_E/PaCO_2$ indicators was:

- the relation of partial pressure CO_2 to pulmonary ventilation in 10 s test – 2.3 ± 0.8 for men-kayak; 2.3 ± 0.7 for men-canoe; 2.2 ± 0.5 for women-kayak;
- the relation of partial pressure CO_2 to pulmonary ventilation in 30 s test – 3.9 ± 1.0 for men-kayak; 3.8 ± 1.1 for men-canoe; 3.6 ± 0.7 for women-kayak.

Thus, the results of the studies indicate differences in the level of functional support for special endurance for paddlers of uniform groups (in terms of sports qualification) for kayaks and canoes that specialize in a distance of 200 m.

Conflict of Interest

Authors declare no conflict of interest.

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ХАРАКТЕРИСТИКИ ФУНКЦІОНАЛЬНОГО ЗАБЕЗПЕЧЕННЯ СПЕЦІАЛЬНОЇ ПРАЦЕЗДАТНОСТІ СПОРТСМЕНІВ, ЯКІ СПЕЦІАЛІЗУЮТЬСЯ НА ДИСТАНЦІЇ 200 м У ВЕСЛУВАННІ НА БАЙДАРКАХ І КАНОЕ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 7 с., 2 табл., 30 джерел.

Мета дослідження – визначити відмінності у рівні функціонального забезпечення спеціальної працездатності веслувальників однорідних груп (за спортивною кваліфікацією) для чоловіків-байдарочників, чоловіків-каноїстів і жінок – байдарочниць, які спеціалізуються на дистанції 200 м у веслуванні на байдарках і каное.

Матеріали і методи. У досліджені брали участь 20 кваліфікованих веслувальників, серед яких елітні спортсмени, члени збірної команди Китаю та переможці Азіатських ігор 2018 року.

Результати. Важливою особливістю аналізу є оцінка структури ергометричної потужності 30-секундного мак-

симального навантаження. Оцінка середнього значення ергометричної потужності роботи за 25-30 секунд роботи відповідно до середньої потужності всього 30-секундного навантаження дозволила визначити співвідношення анаеробних алактатних і лактатних спроможностей спортсменів з урахуванням вимог змагальної дистанції 200 м у веслуванні на байдарках і каное.

Заслуговує уваги діапазон індивідуальних відмінностей показників реактивних властивостей кардіореспіраторної системи, які визначаються співвідношенням парціального тиску CO_2 і максимального рівня легеневої вентиляції (V_E / $PaCO_2$), зареєстрованих під час виконання 10 і 30 секундних тестових завдань.

Діапазон показників $V_E/PaCO_2$ становив: відношення парціального тиску CO_2 та легеневої вентиляції за 10 с – 2,3 ± 0,8 для чоловіків-байдарочників; 2,3 ± 0,7 для чоловіків-каноїстів; 2,2 ± 0,5 для жінок – байдарочниць; відношення парціального тиску CO_2 та легеневої вентиляції за 30 с – 3,9 ± 1,0 для чоловіків-байдарочників; 3,8 ± 1,1 для чоловіків-каноїстів; 3,6 ± 0,7 для жінок-байдарочниць.

Висновок. Результати досліджень вказують на відмінності в рівні функціонального забезпечення спеціальної працездатності веслувальників однорідних груп (за спортивною кваліфікацією) байдарочників і каноїстів, які спеціалізуються на дистанції 200 м.

Ключові слова: гребці, аеробне енергозабезпечення, анаеробне енергозабезпечення, спеціальні характеристики.

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ORIGINAL SCIENTIFIC ARTICLE

ASSESSMENT OF MYOELECTRIC MANIFESTATIONS OF MUSCLE FATIGUE DURING REPETITIVE ISOMETRIC VOLUNTARY CONTRACTION IN BOYS AGED 12-14

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

Aim: To study the peculiarity of electromyography signal characteristics alternation using different sEMG parameters during repetitive voluntary isometric fatiguing contraction in adolescent boys.

Materials and methods. 12 subjects with height 148.75 ± 10 cm; Mass 38.9 ± 7.9 kg; age –12 to 14 years were recruited. The sEMG signal alteration of external oblique, rectus abdominis, erector spinae muscles during a fatiguing plank were analyzed. A separate one-way repeated measures ANOVA was used to test the statistical significance of task time and electromyography parameters of the global core muscle in the pre-, during- and post-fatigue plank test. One-way Friedman ANOVA was applied for Shapiro-Wilk $p < 0.05$. The Pearson product-moment correlation coefficient with bivariate linear regressions analysis was performed between the pre-pre fatigue and post-post fatigue amplitude mean and standard deviation values. The Spearman correlation coefficient between amplitude and endurance time both in the pre- and post-fatigue state was conducted.

Results. The mean value of rectified amplitude increased ($p < 0.05$) for all muscles, the standard deviation of amplitude and total spectral power increased significantly ($p < 0.05$) for all muscles except the erector spinae muscle ($p > 0.05$). The power at normalized low frequency significantly changed ($p = 0.05$) in the erector spinae muscle. A significant change in normalized low frequency for agonist/synergist ($p = 0.02$) and agonist/antagonist muscles ($p = 0.05$) was observed. The average amplitude value had a significant positive and linear relationship with the amplitude variability both in the pre- to post-fatigue state, except the erector spinae muscle. The time to task failure was not correlated ($p > 0.05$) with the sEMG amplitude.

Conclusions. Increased sEMG amplitude resulted mainly from rapid additional motor unit recruitment and rate coding during muscle fatigue. The reduction of conduction velocity might affect the spectral power with a spectral shift towards low-frequency. Increased variability, agonist/antagonist co-activity during fatiguing contraction might extend the holding time. The postural fatiguing task/plank increases multiarticular joint function by involving several joints and muscles, increases variability in the contribution of synergist muscles. This factor provides an intuitive explanation about the absence of a relationship between endurance time and sEMG amplitude changes.

Keywords: motor-unit, rate coding, conduction velocity.

Introduction

The Surface Electromyography (sEMG) based measurement of "myoelectric manifestations of muscle fatigue" is meaningless if the receiver has a lower potential to understand the reliability and the information contained in the electrophysiological signals viz. muscle fiber propagation velocity, sEMG amplitude or frequency spectrum etc. as it also required technological proficiency. Significant gap between engineers and exercise physiologist/physical education teachers often observed in terms of barriers in sEMG signal interpretation is concern. The gap resulted mainly from non-familiar language and lack of technical background related to the application, signal processing and information extraction algorithms. Lack of knowledge in mathematics and biophysics is a significant educational barrier among physical education teachers often make it challenging for basic signal interpretation (Campanini, Disselhorst-Klug, Rymer, & Merletti, 2020; Felici & Del Vecchio, 2020).

Muscular strength and endurance (static) is fundamental motor abilities developed significantly among adolescents in

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the age group of 12-14 yrs. (Ivashchenko, Cieślicka, Nosko, & Malyshev, 2019; Ivashchenko, Kapkan, Khudolii, & Yermakova, 2017; Khudolii, Ivashchenko, Iermakov, Veremeenko, & Lopatiev, 2019). The global axial skeleton stabilizing muscles play an important role during physical activities. The weakness of these postural muscles may contribute to the progression of low back pain as it is crucial to lumbopelvic stability. It is important to understand the central/peripheral system approach on neuromuscular fatigue with the growth and maturation effect on it in sports science. Inflation in sEMG amplitude usually observes during submaximal fatiguing contraction (Cardozo, Gonçalves, & Dolan, 2011) with conflicting results varying from increase (Gentil, Oliveira, de Araújo Rocha Junior, do Carmo, & Bottaro, 2007), no difference (Lindstrom, Stefan, & Lexell, 2006), to decrease muscle activation (Gerdle B, Karlsson S, Crenshaw, Elert, & Friden, 2000). Increase in agonist-antagonist co-contraction during isometric fatiguing contraction among children might be caused by lower strength (Grosset, Mora, Lambertz, & Perot, 2008) but not accepted by another study (Kellis, & Unnithan, 1999).

The measurements of muscle fatigue usually performed during isometric contraction with a constant force, which is considered the "bench-test" condition. The "myoelectric manifestations of muscle fatigue" can be defined as the inability to maintain a given isometric contraction level and it is related to the endurance time with a relative sEMG features alteration from the very beginning of the contraction (Campanini, Disselhorst-Klug, Rymer, & Merletti, 2020). The retention time of the plank task could reliably estimate isometric core muscle endurance and test core stability in children (Boyer, Tremblay, Saunders, McFarlane, Borghese, Lloyd, & Longmuir, 2013). First time De Blaiser et al. (2018) reported that the plank test is valid and reliable to measuring global core muscle fatigue. They also stated that the past research studies intended to measure the validity and reliability of plank test was implemented sEMG as a reference technique designed to evaluate the parameters that failed to represent muscle fatigue.

Objectives: Despite the importance, few studies on exercise induced muscle fatigue in children and adolescents are available that makes it difficult to understand the neuromuscular components of pediatric muscle fatigue. Patikas et al. (2018) reported in their systematic review that previously cited research articles associated with exhaustive sub/maximal contraction induced muscle fatigue in children and adolescents revealed the requirement of more research in pediatric fatigue. The most study used only the normalized Root Mean Square value for muscle fatigue analysis. But the sEMG signal waveform cannot provide a valid conclusion about 'Muscle Fatigue' if we use a single sEMG parameter for a heterogeneous muscle group (Duchêne & Goubel, 1990). To our best information about existing literature on sEMG based muscle fatigue assessment, there are no such studies which evaluated myoelectric manifestation of core muscle fatigue extensively in children using exhaustive Plank test. Therefore we aimed to study the peculiarity of electromyography signal characteristics alternation using different sEMG parametres during repetitive voluntary isometric fatiguing contraction in adolescent boys.

Hypotheses:

Based on the analysis of previous sEMG fatigue studies we hypothesized that:

1. $\mathbf{H_0: X_{1st\ Plank} = X_{2nd\ Plank} = X_{3rd\ Plank}}$; **H1:** At least one mean value on these selected parameters would be statistically distinguishable. The temporal alteration of selected sEMG signal parameters (Average Rectified EMG (ARV) [μV], EMG Standard Deviation (SD EMG) [μV], Total Spectral Power (TSP) [μV2], Normalized Low Frequency (N.LF) [%]) of External Oblique (EO), Rectus abdominis (RA) and Erector Spinae (ES) muscle, RA/EO (Agonist/Synergist) N.LF Ratio, RA/ES (Agonist/Antagonist) N.LF Ratio and the endurance plank time during fatiguing isometric voluntary contraction were analyzed separately.

2. $\mathbf{H_0: R = 0.}$ $\mathbf{H_1}$**:** The mean amplitude value of the sEMG signal was expected to have Gaussian probability distribution and it may show a significant positive and linear relation with absolute variability of sEMG amplitude. Pearson product-moment correlation coefficient (R). sEMG undergo non-uniform changes with increase variability (phase shift) during isometric fatiguing contractions.

3. $\mathbf{H_0: r = 0.}$ $\mathbf{H_1}$**:** Significant Spearman correlation coefficient (r) between ARV amplitude with Endurance time both in pre and post fatigue state was expected.

Materials and methods

Study participants

Sample size calculation: The sample size (n) was calculated based on the Average Rectified Value (ARV) of the Rectus abdominis muscle activity acquired in a pilot study with three children (Silva et al. 2020). We used ARV for sample size calculation because ARV is significantly less variable and reliable when measuring the core muscle activity (Hibbs et al. 2011). We included the pilot data in the main data set. The sample size was calculated using the G*Power (Version 3.1.9.2, Kiel University, Germany) application, for 80% power at an alpha level of 0.05. This calculation provided a sample size of 12 for this study.

Power Analysis: We also analysed post hoc power based on 12 samples sEMG ARV amplitude data G*Power (SPSS η_p^2): Statistical test = ANOVA: Repeated Measures, within factors; α err probability = 0.05; Number of group = 1; Number of measurements = 3; Nonsphericity correction ε = 1. Effect size (G*Power-f) and estimated Power (1 − β err probability) were for EO-(f) = 1.49, 1 − β err probability = 0.99; RA-(f) = 1.06, 1 − β err probability = 0.99; ES-(f) = 0.58, 1 − β err probability = 0.61. Moalla et al. (2007) also reported that twelve healthy male children is necessary to find a mean difference in sEMG parameters during the postural fatiguing task.

Therefore a total of 12 subjects were included in the study. The subjects were school-going children aged between age-12 to 14 years (Khudolii, Ivashchenko, Iermakov, Veremeenko, & Lopatiev, 2019) (height 148.75 ± 10 cm; Mass 38.9 ± 7.9 kg) and they had more than three months of previous experience with the practice of different yogic exercises. The children were randomly selected from Ram Krishna Vidya Mandir Ashrama (RKVM)-Sharada Balgram, Gwalior (M.P).

Inclusion criteria: Prior to the collection of data, the children were requested to recognize their preferred writing hand, which was contemplated their dominant arm. All children were right-hand dominant (Silva et al., 2020). We collected the sEMG data of core muscle only from the right

side in subjects with dominant right-hand for fatigue analysis because: 1. The fatigue indexes are significantly sensitive and evident in the right than left-handed subjects. The fatigue indexes are also less apparent in left than in right-handed subjects (Merletti, De Luca, & Sathyan, 1994). 2. The adaptation of the Motor Unit (MU) pool in the dominant muscle due to daily preferential use allows for more effective force production at low firing rates by increase the percentage of Type-I fibers resulting in twitch fusion at lower MU firing rates (Adam, De Luca, & Erim, 1998), although the previous study on hip-abductor fatigability reported non-significant results between dominant and nondominant side (Jacobs, Uhl, Seeley, Sterling, & Goodrich, 2005).

No previous history of Neuro/Myo pathological disorders and Postural Spinal deformities were reported during data collection. Those boys were clinically tested in (RKVM)-Sharada Balgram Health facility.

Consent (Reg. No. PH2010-114, Consent no.-HOD/Ex.Phy./26/2018-19): Full written advice about the possible risks and discomfort associated with the study was given to the children and local guardian/school principal, they signed the written informed consent form. The study was approved previously by the Departmental Research ethics board of Lakshmibai National Institute of Physical education, Gwalior, India and was conducted following the ethical principles for human research proposed in the Helsinki Declaration.

Study organization

Fatiguing Plank Protocol: Each child received verbal and visual instructions about the correct posture to perform plank to ensure comfort and familiarity. It may provide better sEMG signal quality during data collection. The Traditional plank protocol used in this study: face lied down and fists on the surface/floor, feet were placed at shoulder width apart, the spine and pelvis in a neutral position. The space between elbows were also shoulder width apart just below the glenohumeral joint. Lift the body up on the forearms and toes (Cortell-Tormo, García-Jaén, Chulvi-Medrano, Hernández-Sánchez, Lucas-Cuevas, & Tortosa-Martínez, 2017; Schoenfeld, Contreras, Tiryaki-Sonmez, Willardson, & Fontana, 2014; Bohannon, Steffl, Glenney, Green, Cashwell, Prajerova, & Bunn, 2018). Participants maintained the proper plank position and throughout the whole period we recorded the sEMG activity of the respective muscles until the test terminated, if the participants could not hold/continue with the correct position because of fatigue and pain. Maximum time limits were recorded with a stopwatch. In summary the children were asked to perform 5 consecutive Surya Namashkara with self-reported pace for warming up, followed by 5 mins. rest. After 5 min. rest they completed three planks (i.e. pre-fatigue (1st plank), during (2nd plank), and post fatigue (3rd plank) with a resting period of 3 mins. in between every plank. Strong verbal encouragements were given to make them motivated to hold a plank to their maximum potential limit. The 3 min rest or interval periods were given between every plank, because: Previous study reported that sufficient recovery from attenuated motoneuron excitability of the muscles induced by low/submaximal isometric fatiguing contraction requires ≤ 240 sec., resting period (Heroux, Butler, Gandevia, Taylor, & Butler, 2016).

Instrument: Preparation of Skin –A single-use cotton-wool ball with 60-70% alcohol-based solution (isopropyl alcohol) was used for clean the surface of the skin (hair saved) for better conductance.

sEMG-Instrument: ENCEPHALAN – MPA Autonomous Patient Transceiver-Recorder ABP-10. (Medicom MTD Ltd. Research & Development Limited Company, RUSSIA) sEMG machine was used in this study. We used the "REHACOR" and "MEDICOM" software (British Standard – Reg. No. DE/CA37/POL044A4) for sEMG signal processing and raw data analysis. sEMG Electrodes and technical Specifications:: The disposable, oval-shaped, bipolar EMG/ECG surface Electrodes (ANSI/AAMI standard EC12:2000, ISO-13485, Medico India) were used. Product Code: MSGLT-05MG, Solid, Baking Adhesive – Foam, Enhanced. Dimension: 40×36×1 mm, Ag/AgCl (silver/ silver chloride) sensor, Latex-free, patented gel formula. The inter-electrode distance/spacing were 20 mm (2 cm.) in Bipolar fashion. Electrodes and wires were fixed with one-sided white adhesive tape to reduce skin friction and motion artefacts. No sEMG electrodes placement set-up was changed for amplitude estimation during the three planks for each subject. sEMG signals were visually inspected for heartbeat artefacts.

sEMG Settings: The panel of Sweep speed of sEMG was set at 5mm/s. sEMG measurement unit: EMG signal amplitude mean and SD – "μV", Power Spectra "μV^2" and Low frequency "%". Analog to digital Convert resolution = 24; Sampling rate = 1024 Hz; Input dynamic range > 8 mV (p-p); Allowable voltage shift > ±300 mV; Noise < 1.4 μV (p-p); Sensitivity = 200 μV/mm; Common Mode Rejection Ratio = 120 dB. Processor – Intel Core(TM) 2 Duo CPU E7500 @ 2.93GHz; Memory (RAM) – 2047 MB; System Type – 32-bit offline operating system; LENOVO-PC.

sEMG Parameters: 1. A. ARV-EMG: The addition of all the multiplied values of an arbitrary parameter X and the probability of these values decide the centroid position in Gaussian distribution. B. SD EMG: Mean-squared deviation of the arbitrary parameter X- the positive square root of the squared deviation of a random parameter X from its mean value denote the scattering distribution. The whole EMG signal was full-wave rectified, smoothed. 2. N.LF - Normalized low-frequency index was the ratio of the area under the curve in the range of 10-30 s (LF), to the area under the curve in the range of 2-30 s. LF = N.LF/(TSP-VLF)·100 %. 3. Total Spectral Power: The frequencies were evaluated using Discrete-Time Fourier series analysis, with graphs of power or amplitude ratio (Y-axis-Power μV^2) of the oscillation period (X-axis Hz/Sec.). Total Spectral Power (TSP) = High Frequency (HF) + Low Frequency (LF). sEMG signal processing: The EMG linear envelope and power spectral density (PSD) was calculated using Welch and Bartlett's averaged modified periodogram (Non-parametric) method with 1024 sample analysis, 50% overlapping windows. In the power spectral density, the sEMG frequency cut-off or the band-pass filter was 10–512 Hz. Further, the energy/power alteration at normalized Low-frequency band 10Hz–70Hz was taken for fatigue analysis. As the attenuation of mean power frequency in Spectral parameters from 70 Hz to 60 Hz is considered as the progression of myoelectric manifestation of fatigue. The mean power of the frequency below 70 Hz increases significantly during fatigue. The low frequency increases linearly during the progression of myoelectric manifestation of fatigue (Cardozo, Gonçalves, & Dolan, 2011). Automated Linear spectrum interpolation algorithm was used to remove

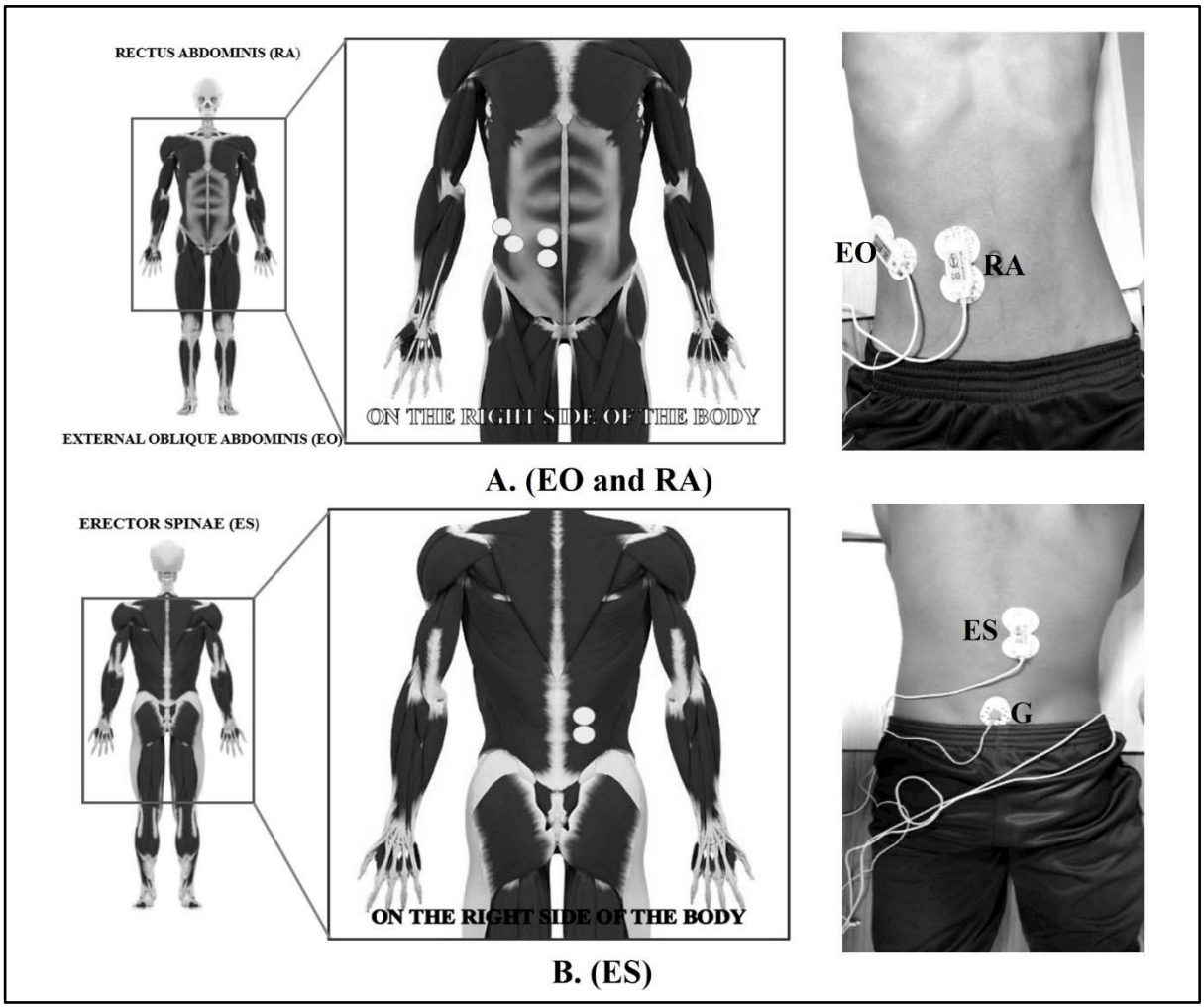

Fig. 1. Electrodes Placement Points: (A) EO and RA; (B) ES muscle. All the sEMG signals were recorderd form the right side of the body

sinusoid interference frequency (cosine function) and time-correlated power line noise contamination.

Electrodes placement (Right Side dominance): EO-lateral portion of rectus abdominis muscle (~15 cm lateral to the umbilicus), situated straight over the anterior superior iliac spine, midway between the crest and ribs with oblique or 45˚ angle inclination. RA- ~2 cm lateral to the umbilicus. ES- ~2 cm parallel from the midline of the spine over the muscle. Ground electrode was placed over the midline of the lumbosacral bony landmark (Fig. 1) (Silva et al., 2020; Criswell, 2011).

Statistical analysis

The "Consensus for Experimental Design in Electromyography-2020" (CEDE) project provided the recommendations and guidelines for recording, analysis, interpretation and specific applications of EMG, published in the Journal of electromyography and kinesiology (International Society of Electrophysiological Kinesiology) (Besomi et al., 2020) reported to use non-maximal voluntary isometric contraction induced non-normalized sEMG data for interpretation as no method available for sEMG normalization in study dealing with pediatric population. Therefore sEMG signals (non-normalized) were used for fatigue analysis as per the instructions given by Besomi et al. (2020) and Halaki et al. (2012). The relative sizable inter-individual variability in the global core muscle activation pattern would be due to the diversity of anatomical and fiber type distributions. Therefore LOG(10) transformation procedures were applied for all sEMG Parameters and the alteration of sEMG activity of these three muscles was analyzed separately (Falla & Farina, 2007) as between muscle activity could not possible to calculate with non-normalized sEMG data (Besomi et al., 2020).

For the Normality distribution assumption, the Shapiro-Wilk test was used and a significant ($p \leq 0.05$) value would be considered as the departure from normality. Separate one-way repeated measures ANOVA was used to test the differences across the pre-, during and post fatigue with relative alteration of different sEMG parameters of EO, RA, ES muscles, N.LF ratio for RA (Agonist)/ ES (Antagonist), RA (Agonist)/ EO (Synergist) muscles and plank/endurance time (T_{lim}). For each ANOVA, if those parameters were found significantly distinguishable, Bonferroni corrected paired t-test was used to identify differences (Post Hoc) for pairwise comparison. In case the assumptions for parametric statistics were not

met, nonparametric one-way Friedman ANOVA was used and statistically significant values were further analyzed with Dunn-Bonferroni test for multiple pairwise comparisons. The Sphericity assumption was tested by Mauchly's test and a significant ($p \leq 0.05$) value would be considered as sphericity violation. The sphericity violation was treated with an appropriate degree of freedom (df) correction by applying either Greenhouse-Geisser ($\varepsilon < 0.75$) or Huynh-Feldt ($\varepsilon > 0.75$) correction. The level of significance was set at $p \leq 0.05$. η_p^2 was used as the effect size index. The values of η_p^2 were interpreted as small effect (d = 0.20), medium effect (d = 0.50) and large effect (d = 0.80). For nonparametric Friedman ANOVA, Kendall's W coefficient was used for effect size, assuming the value from 0 (no relationship) to 1 (perfect relationship) (Silva et al. 2020).

The Pearson product-moment correlation coefficient (R) was used in normally distributed (LOG(10)-transformed, Shapiro-Wilk $p > 0.05$) data. The R value between an independent and dependent parameter was tested with bivariate linear regressions analysis (Verma, 2016) and it was performed between the Pre-Pre fatigue and Post-Post fatigue LOG(10) SD EMG-(μV) with LOG(10) ARV EMG-(μV) of EO, RA, ES muscle separately. The Spearman correlation coefficient (r) of ARV EMG (μV) with Endurance time (T_{lim}-Sec.) of EO, RA and ES muscle were applied for both in pre and post fatigue.

ICC Analysis: The Interclass correlation coefficient (ICC) within 95% confidence interval with three consecutive measurements (without sEMG electrodes displacement), absolute-agreement and 2-way mixed-effect model was used for test-retest reliability in this present study, and the degree of reliability (ICC) estimation was based on the following guideline: 0.00 to 0.25 – little; 0.26 to 0.49 – low; 0.50 to 0.69 – moderate; 0.70 to 0.89 – high and 0.90 to 1.00 – very high reliability (Silva et al., 2020; Mathur, Eng, & MacIntyre, 2005). IBM SPSS statistics for windows, version 20.0, (IBM Corp., Armonk, NY, USA) was used for Statistical analysis and graphical representations.

Results

The One-way Repeated ANOVA revealed a significant difference in the selected sEMG Parameters ($p \leq 0.05$) with low to large effect sizes (η_p^2) (Table 1). Larger effect sizes in selected sEMG Parameters were observed when compared with the baseline in the muscles with steeper fatigue level during repetitive fatiguing plank.

The predictive Linear regression model reveled (Fig. 4): A. For EO muscle the Pre fatigue showed significant p = 0.001, linear steepness [R = 0.84, R^2 = 0.70, $F_{(1,10)}$ = 23.68, y = 1.02x+ (-0.60)], for post fatigue model p = 0.009 [R = 0.72, R^2 = 0.51, $F_{(1,10)}$ = 10.44, y = 0.68x+0.06]. B. For RA muscle the Pre fatigue p = 0.002, linear steepness [R = 0.80, R^2 = 0.64, $F_{(1,10)}$ = 17.91, y = 0.82x+ (-0.29)], Post fatigue p = 0.001 [R = 0.82, R^2 = 0.67, $F_{(1,10)}$ = 20.09, y = 0.78x+ (-0.19)]. C. For the ES muscle Pre fatigue p = 0.004, linear steepness [R = 0.76, R^2 = 0.58, $F_{(1,10)}$ = 13.67, y = 0.75x+ (-0.14)] but for Post fatigue model the p = 0.457, linear flatness [R = 0.24, R^2 = 0.06, $F_{(1,10)}$ = 0.59, y = 0.4x+0.11].

Table 1. The Summary of Endurance/Time-to-task and sEMG values across muscles during three consecutive fatiguing plank. The mean value of rectified EMG amplitude increased for EO, RA, ES muscles. The standard deviation of amplitude and Total Spectral power increased for all muscles except ES muscle. Power at Normalized Low Frequency changed in ES muscle. changes in Normalized Low Frequency for Agonist (RA)/Synergist (EO) and Agonist (RA)/ Antagonist (ES) muscles is also observed.

	PLANK						
	1st	2nd	3rd				
Variables	**M±SD**	**M±SD**	**M±SD**	**F-value**	**p-value**	**η_p^2-value**	**ICC-value**
T_{lim} (SEC.)$^{\$}$	56.50 ± 21.07	70.50 ± 25.36	71.50 ± 14.06	1.17†	0.56	0.05††	0.06
EO ARV	1.73 ± 0.19	1.78 ± 0.17	1.84 ± 0.16	24.76	0.00	0.69	0.96
EO SD EMG	1.17 ± 0.24	1.26 ± 0.18	1.31 ± 0.16	4.46	0.02	0.29	0.83
EO N.LF	1.78 ± 0.08	1.75 ± 0.17	1.78 ± 0.09	0.40*	0.56	0.04	0.58
EO TSP	2.53 ± 0.50	2.67 ± 0.41	2.82 ± 0.33	5.09	0.02	0.32	0.86
RA ARV	1.55 ± 0.21	1.59 ± 0.19	1.69 ± 0.22	12.25**	0.00	0.53	0.92
RA SD EMG	0.98 ± 0.21	1.01 ± 0.18	1.13 ± 0.21	4.37	0.03	0.28	0.77
RA N.LF	1.74 ± 0.09	1.74 ± 0.16	1.81 ± 0.05	2.45	0.11	0.18	0.36
RA TSP	2.07 ± 0.44	2.19 ± 0.31	2.44 ± 0.41	6.13	0.01	0.36	0.72
ES ARV	0.54 ± 0.14	0.55 ± 0.14	0.61 ± 0.09	3.65	0.04	0.25	0.85
ES SD EMG$^{\$}$	0.27 ± 0.13	0.26 ± 0.09	0.35 ± 0.15	3.51†	0.17	0.15††	0.31
ES N.LF	1.77 ± 0.09	1.78 ± 0.13	1.67 ± 0.09	3.29	0.05	0.23	0.52
ES TSP$^{\$}$	0.35 ± 0.29	0.34 ± 0.23	0.76 ± 0.72	2.17†	0.34	0.09††	0.06
RA/EO N.LF$^{\$}$	0.97 ± 0.05	1.00 ± 0.14	1.02 ± 0.05	8.17†	0.02	0.34††	0.20
RA/ES N.LF$^{\$}$	0.98 ± 0.06	0.98 ± 0.11	1.09 ± 0.07	5.66†	0.05	0.24††	0.02

NOTE: T_{lim} – Time to task failure, ARV EMG – Average Rectified EMG, SD EMG – EMG Standard Deviation, TSP – Total Spectral power, N.LF – Normalized Low frequency, EO – External Oblique, RA – Rectus abdominis, ES – Erector Spinae. The Mean ± SD. Nonparametric Friedman ANOVA$^{\$}$, F(df-2,22) (Nonparametric $\chi^{2\dagger}$), p value, η_p^2 (Nonparametric Kendall's $W^{\dagger\dagger}$), ICC values (95%-CI). EO N.LF (Greenhouse-Geisser) F1.14, 12.52*, RA ARV (Greenhouse-Geisser) F 1.34, 14.78**. Significant $p \leq 0.01$, 0.05 in Bold. LOG(10) Transformation was applied for all the sEMG values of EO, RA and ES muscle

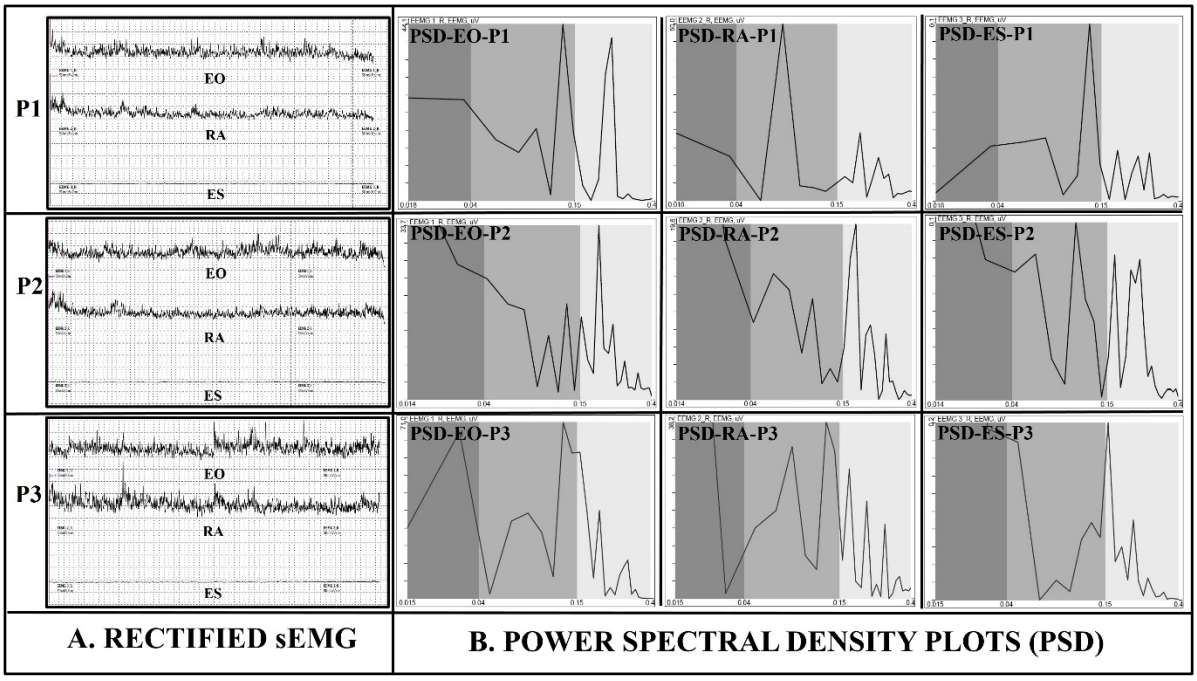

Fig. 2. Simultaneous sEMG activities were recorded of External Oblique (EO), Rectus abdominis (RA), Erector Spinae (ES) muscles during fatiguing isometric voluntary contraction. Continuous sEMG recordings for the entire time to task failure during three consecutive plank (P1, P2 and P3 respectively) holding test (with 3 minutes interval in between). A. sEMG signals were full-wave rectified, smoothed. B. Power spectral density plots were obtained from EO, RA, ES muscles during static fatiguing plank task. The energy changed only at normalized Low-frequency band of 10Hz-70Hz was taken for fatigue analysis.

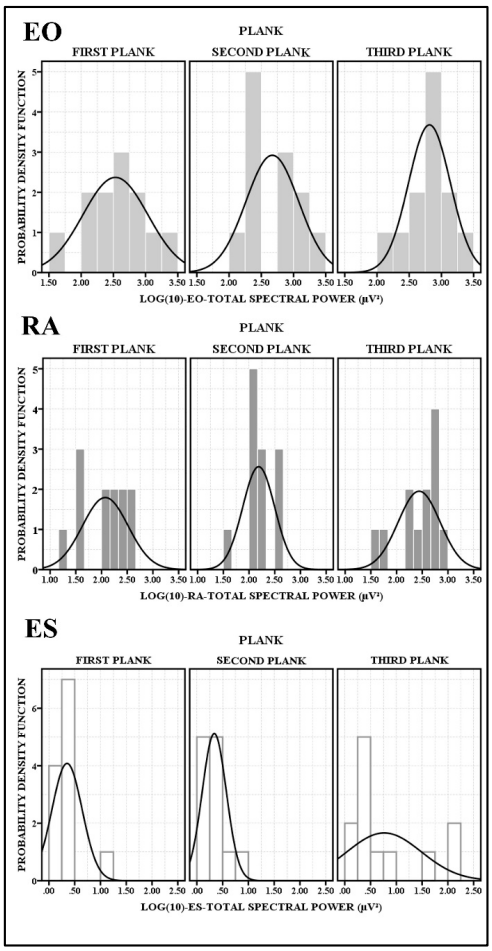

Fig. 3. Probability Density plots of log10TSP of EO, RA and ES muscle during fatiguing plank. The pre to post fatigue EO log10TSP leptokurtic (0.182 vs. 1.374), RA log10TSP changed the kurtosis pattern (-1.202 vs. 0.975) also, and ES LOG(10)TSP platykurtic (7.884 vs. 0.016) transition observed.

The Spearman correlation coefficient (r) of ARV EMG (μV) of EO, RA and ES muscle were not significantly correlated with Endurance time (T_{lim}-Sec.) both in pre and post fatigue as the EO pre r = 0.39 (p = 0.22) vs. post r = -0.494 (p = 0.103); RA pre r = 0.30 (p = 0.34) vs. post r = -0.501 (p = 0.097); and ES pre r = 0.26 (p = 0.42) vs. post r = - 0.385 (p = 0.216) at 5% significance level.

Discussion of Hypotheses: According to the research hypotheses, some of the most important observations were that during sustained fatiguing contraction/plank the sEMG amplitude and the Total Spectral Power of the signal increased rapidly (Fig. 2A), power spectra intensified/shifted towards low frequency power spectra (inflation in low frequency band) (Fig. 2B). The positive linear relationship between average amplitude values with amplitude standard deviations of the sEMG signal was altered by fatigue (Fig. 4). The non-significant relationship between the time to task failure with sEMG amplitude was influenced by complex multiarticular joint function.

Discussion

The myoelectric manifestations of muscle fatigue are diverse and depend on several complex physiological factors which make it difficult to understand. The findings of this present study revealed that the acute adaptation to fatigue

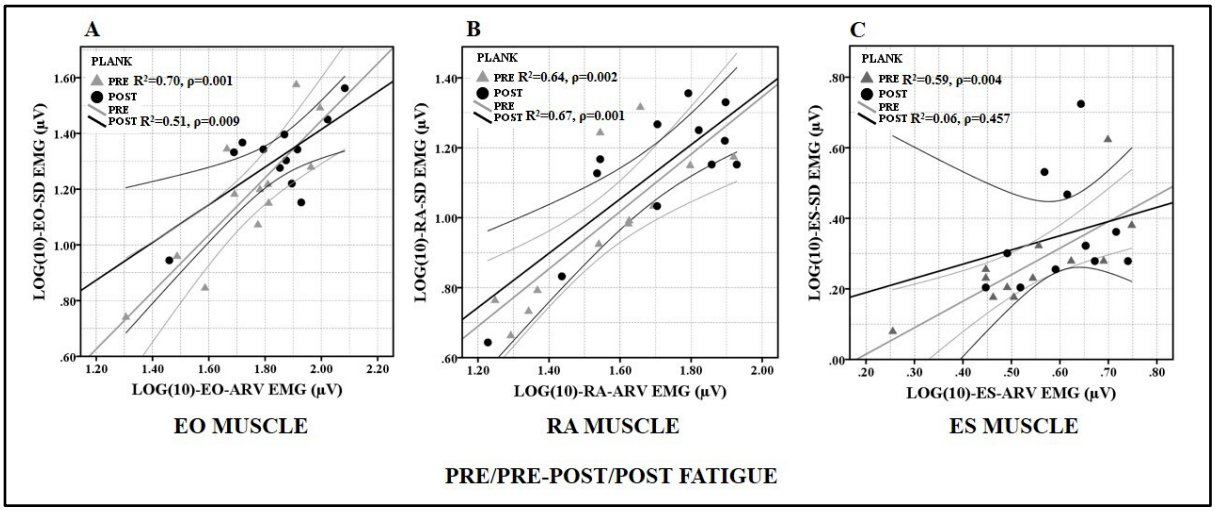

Fig. 4. LOG(10)-Indicates Logarithm with base 10. Linear regression model between pre fatigue LOG(10) ARV EMG (μV) with LOG(10) SD EMG (μV) and post fatigue LOG(10) ARV EMG (μV) with LOG(10) SD EMG (μV) of EO, RA and ES muscle ($p \leq 0.05$)

by altered muscle activation pattern intended to compensate the force reduction (Shrawan et al., 1996). Statistical significance p-value with effect size $\eta_p^2 > 0.22$ indicates a more pronounced or meaningful fatigued state (Table 1) (Jacobs, Uhl, Seeley, Sterling, & Goodrich, 2005).

Increased sEMG amplitude (Fig. 2 A, Table 1) resulted from rapid additional motor unit recruitment and rate coding. During fatiguing contraction, additional motor units recruited progressively as per Henneman's sizes principle. Firing off these motor units interfere and briefly inhibit the firing rate of previously recruited motor units, which might increase the variability (Table 1).

The concept of stretch reflex inflation during a postural fatiguing task is based on some basic theory: 1. The rapidly deteriorating in the inhibition of presynaptic transmission and feedback modulation by Ia afferents group. 2. Active dendritic actions modulated by descending pathway and supraspinal drive 3. Increase in motoneuronal α-γ coactivation. More pronounced postsynaptic than presynaptic activation mechanism was reported during fatigue if the pressor response absent. The motor neuron excitability during postural fatiguing task-induced pressor response activation was influenced by: 1. Group III-IV afferent input acquired by interneurons which excited the γ-motor neurons (Maluf & Enoka, 2005). 2. Variations in motor unit firing rate and recruitment pattern, increased synchronization, most importantly decreased muscle fiber conduction velocity, all of these factors might be acted as a compensatory mechanism during fatigue-induced force loss among muscles. It might change the shape of the action potential (Fig. 2), increase the magnitude (Mean) and Variation (SD) of ARV amplitude (Table 1). The primary effects of motor-unit synchronization were proposed during fatigue as: Augmentating the magnitude and variability of AVR EMG (intense-synchrony condition), intensification of low frequency in EMG power spectra, attenuation of the cancellation in overlapped positive and negative phases of action potentials (Yao, Fuglevand, & Enoka, 2000). Predominant muscle fiber-type (Type-I, 57-62%) and recruitment strategies (viz. increased motor-unit synchronization and decreased propagation velocity) of motor units might also be responsible for sEMG Spectral power alteration and amplitude augmentation. The motor units of type I (low threshold) muscle fiber generates action potentials with higher power at the lower frequency during fatiguing contraction. Both the myoelectric signal of muscle tissue and surface EMG electrodes act as low-pass filters, rapid energy of the signal travel through the tissue when the lower frequency intensifies or prominent leftward shift (Fig. 2) in signal eventuated in the power spectrum during fatigue (Fig. 2B) (Hagberg, 1981). Ischemia resulted from hemodynamic occlusion therefore anaerobic glycolysis during isometric contraction increases the production of lactate, pyruvate, inorganic Pi, resulted in intramuscular pH and conduction velocity to reduce. Studies reported lacking the significance of lactate production during fatiguing contraction proposed extracellular K+ accumulation and Na+ depletion in extracellular space could be the possible reason for sEMG signal alteration during fatigue (Linssen, Stegeman, Joosten, Binkhorst, Merks, Ter Laak, & Notermans, 1991).

Relatively less prominent antagonist muscle activity (Fig. 2A) during the positional task was controlled by spinal interneurons, which further influenced by descending pathways to enhance the stability at the multiarticular joint level. The concurrent augmentation of agonist/synergistic ($p = 0.02$), agonist/antagonist ($p = 0.05$) N. LF ratio (Table 1) during fatigue resulted from either supraspinal descending drive or differentiated motor neuronal pool. The changes in excitability of motor neuronal pool in antagonist muscle usually observed with a substitute spinal pathway of disynaptic reciprocal inhibition from muscle's spindle afferents to the motor neurons as fatigue developed. An increase in sEMG amplitude ($p = 0.04$) of antagonist muscle stipulated a net increase in excitatory synaptic input to the spinal motor neurons and inherent characteristics of supraspinal mechanisms modulated by Ia presynaptic inhibition which further influenced different peripheral inputs parallelly as fatigue progressed. Researchers often reveal doubts about the reliability of antagonist sEMG (Low ICC in ES muscle) (Table 1). But with strict sEMG recordings protocol, it may produce an acceptable and meaningful antagonist coactivation even

though the signal does not dispense a precise estimate of its mechanical contribution (Duchateau & Baudry, 2014). The modulation of antagonist coactivation during fatiguing contraction might extend the T_{lim} ($p = 0.56$) (Table 1) (Shrawan et al., 1996). Motor units that innervate the number of muscle fibers reveal a Non-Gaussian distribution in sEMG Spectral power, uniquely the LOG(10)TSP showed unique alteration of kurtosis pattern among three muscles across the three consecutive fatiguing plank also might extend the T_{lim} (Fig. 3).

The failure to detect any statistically significant difference ($p > 0.05$) in sEMG parameters (Table 1) during fatiguing contraction might falsely be concluded as no specific alteration of rate coding and motor-unit activity. It was also possible that sEMG amplitude or power spectral frequency might show a lower potential to identify small changes efficiently of the neural drive against time of muscles with multiarticular joints functions, which further affected by signal contamination due to volume conduction, cross talk and electromagnetic interferences (Farina, Arendt-Nielsen, Merletti, & Graven-Nielsen, 2004). Although more repetitions with less resting or interval periods during standardized exercise (Kapkan, Khudolii, & Bartík, 2019) may increase the chance for significant sEMG signal alteration due to fatigue at this age group of this present study. Further studies where the children are involved in different exercise interventions may use different sEMG parameters with cautions to observe neural recruitment strategies alteration, overload/muscle fatigue level and training progression.

The average amplitude values of the sEMG signals usually have Gaussian probability distribution, often show a linear relationship with sEMG amplitude standard deviations of the signals. We also observed the average sEMG amplitude value produced a steeper and linear relationship with the amplitude variability with the relative alteration of the relationship from pre to post fatigue state of three core muscle (Fig. 4). Henneman's size principle stated small motor units (low recruitment threshold) have initial fatigue response, recruited to fire at low force level, shows small variability, where the larger motor units (high recruitment threshold) recruited at higher fatigue level indicated large variability. The subjects with larger variability showed a longer time to task capacity with more heterogeneous muscle activation pattern and smaller localized muscle fatigue. The neuronal mean firing rate alters sinusoidally and variability in spike generation is proportionately related to the mean firing rate during fatiguing contraction (Stein, Gossen, & Jones, 2005).

The non-significant ($p > 0.05$) Spearman correlation coefficient between the time to task failure with sEMG amplitude might influenced by multiarticular joint function, volume conduction, cross talk by the synergistic muscles or electrical interferences (Boyas, et al., 2009).

Limitations

Due to the complexity of MVIC induced sEMG amplitude normalization protocol for core muscle, clinicians usually avoid it, as it is also not recommended for the children less than 15 years age (Nicholson, 2000). The electromagnetic interferences, crosstalk by surrounding muscles could never be replaced completely but tried to reduce it with high signal-to-noise ratio in sEMG setting.

Conclusions

Increased sEMG amplitude resulted from rapid additional motor unit recruitment and rate coding while performing the fatiguing plank task. Variation in motor unit firing rate and recruitment pattern, increased synchronization and deterioration in the muscle fiber conduction velocity, all of these factors influenced the shape of action potential and made the sEMG amplitude increase during fatigue. Recruitment strategies of motor units and predominant I-type muscle fiber, these two factors caused sEMG Spectral power to change and spectral shift towards low-frequency band during fatigue. The longer time to task or Endurance capacity was observed by heterogeneous muscle activity during isometric contraction. Postural fatiguing task/plank increases multiarticular joint function by involving several joints and muscles, increases variability in the contribution of synergist muscles. This factor provide an intuitive explanation about the absence of a relationship between endurance time and sEMG amplitude changes.

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Conflict of interest

The authors certify that there is no conflict of interest with any financial organization regarding the material discussed in the manuscript. We confirm that this work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere. Furthermore, I accept responsibility for the scientific integrity of the work described in this manuscript. This paper was not presented as oral/poster at the any Congress or conference.

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ОЦІНКА МІОЕЛЕКТРИЧНИХ ПРОЯВІВ М'ЯЗОВОЇ ВТОМИ ПІД ЧАС ПОВТОРНИХ ІЗОМЕТРИЧНИХ ДОВІЛЬНИХ СКОРОЧЕНЬ У ХЛОПЧИКІВ У ВІЦІ 12-14 РОКІВ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 11 с., 4 рис., 1 табл., 41 джерело.

Мета дослідження – вивчити особливості чергування характеристик сигналів електроміографії за допомогою різних параметрів sEMG під час повторного довільного ізометричного втомлюючого скорочення у хлопчиків-підлітків.

Матеріали і методи. У дослідженні брали участь 12 випробовуваних (зріст – 148,75 ± 10 см; маса тіла – 38,9 ± 7,9 кг; вік – від 12 до 14 років). Аналізували зміну сигналу sEMG зовнішнього косого, прямого м'язів живота, м'язів Erector Spinae під час тесту планка на виснаження. Окремі односторонні повторні вимірювання ANOVA використовували для тестування статистичної значущості часу виконання завдання та параметрів електроміографії сумарної активності м'язів перед, під час та після тесту планка на виснаження. Односторонній метод Friedman ANOVA застосовувався

для Шапіро-Вілка p < 0,05. Коефіцієнт кореляції продукту-моменту Пірсона з аналізом двовимірної лінійної регресії проводили між середнім значенням амплітуди стомлення до попереднього та попереднього часу та стандартними значеннями девіації. Розраховувався коефіцієнт кореляції Спірмена між амплітудою та часом витривалості як у стані до, так і після втоми.

Результати. Середнє значення випрямленої амплітуди збільшилось для всіх м'язів (p < 0,05), стандартне відхилення амплітуди та загальної спектральної потужності значно зросло для всіх м'язів (p < 0,05), крім м'язів Erector Spinae (p > 0,05). Потужність при нормалізованій низькій частоті суттєво змінилася у м'язі Erector Spinae (p = 0,05). Спостерігалися суттєві зміни нормалізованої низької частоти для м'язів агоністів / синергістів (p = 0,02) та м'язів агоністів / антагоністів (p = 0,05). Середнє значення амплітуди мало значущу позитивну та лінійну залежність від варіабельності амплітуди як до стану після втоми, за винятком м'язів Erector Spinae. Час до невиконання завдання не корелював (p > 0,05) з амплітудою sEMG.

Висновки. Збільшення амплітуди sEMG відбулося в основному внаслідок швидкого набору додаткових рухових одиниць та швидкості кодування під час втоми м'язів. Зменшення швидкості провідності може вплинути на спектральну потужність із спектральним зсувом у бік низькочастотних. Підвищена мінливість, спільна активність агоніста / антагоніста під час втомлюючого скорочення може продовжити час витримки. Постуральне втомлювальне завдання / планка збільшує багатосуглобову суглобову функцію, залучаючи кілька суглобів і м'язів, збільшуючи мінливість внеску синергічних м'язів. Цей фактор дає інтуїтивне пояснення відсутності зв'язку між часом витривалості та змінами амплітуди sEMG.

Ключові слова: рухова одиниця, блок кодування, швидкість провідності.

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VALIDATION OF THE SOFTWARE-HARDWARE COMPLEX "RYTM" FOR MEASUREMENT OF THE RR INTERVALS AND HEART RATE VARIABILITY ANALYSIS DURING EXERCISE AND RECOVERY PERIOD

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

The study purpose was estimation of the accuracy of RR time series measurements by SHC "Rytm" and validity of derived heart rate variability (HRV) indexes under physical loads and recovery period.

Materials and methods. The participants were 20 healthy male adults aged 19.7 ± 0.23 years. Data was recorded simultaneously with CardioLab CE12, Polar RS800, and SHC "Rytm". Test protocol included a 2 minute step test (20 steps per minute, platform height – 40 cm) with the next 3 minute recovery period. HRV indexes were calculated by Kubios HRV 2.1.

Results. The RR data bias in the case of physical loads was -0.06 ms, it increased to 0.09-0.33 ms during the recovery period. The limits of agreement for RR data ranged from 3.7 ms to 22.8 ms, depending on the period of measurements and pair of compared devices. It is acceptable for the heart rate and HRV estimation. The intraclass correlation coefficients (0.62-1.00) and Spearman correlation coefficient (0.99) were high enough to suggest very high repeatability of the data. We found no significant difference ($p > 0.05$) and good correlation ($r = 0.94$-1.00) between the majority of HRV indexes, calculated from data of Polar RS800 and SHC "Rytm" in conditions of physical loads (except for LF/HF ratio) and in the recovery period. The only one index (RMSSD) was different ($p < 0.05$) in case of Polar RS800 and SHC "Rytm" data, obtained in the recovery period. The largest numbers of different HRV indexes have been found during the comparison of CardioLab CE12 and Polar RS800 – RMSSD, pNN50, and SD1. Correlation between HRV indexes ($r = 0.81$-1.00) was very high in all pairs of devices in all periods of measurements.

Conclusions. The SHC "Rytm" appears to be acceptable for RR intervals registration and the HRV analysis during physical loads and recovery period.

Keywords: electrocardiography, Polar RS800, Bland-Altman analysis, intraclass correlation coefficient.

Introduction

To date, the emphasis of many studies is placed on the study of changes in functions of the human organism in stress conditions – diseases, emergency situations, competitive and training activities. These researches aimed at monitoring the indexes of the loads' intensity to track the time course of training adaptation or illness progression in order to avoid pathological changes. To do this, the devices of remote (telemetry) control of the physiological functions are used (Dunn et al., 2018). Such devices are in many cases based on the monitoring of heart rate and other parameters of the cardiovascular system, which could be used as indicators of the intensity and adequacy of physical loads, and as the predictors of pathological changes (Dias & Cunha, 2018; Majumder et al., 2017).

One of the most effective methods to evaluate the physiological changes which occur in the response to physical loads (Dong, 2016) is an analysis of heart rate variability (HRV). Many observations have shown that HRV indexes may serve for monitoring the exercise intensity, level of cardiovascular autonomic adaptations, and provide a powerful tool for diagnosis of early pathological changes (Dong, 2016; Silva et al., 2014; Vovkanych et al., 2014; Hrynkiv et al., 2012; Vovkanych & Kachmar, 2010). Thus, the remote monitoring of HRV, combined with the evaluation of main indexes of the cardiovascular system, is of great benefit and offers a possibility of greatly improve the level of physical loads and

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adaptation to them. That is why the research team of the Lviv State University of Physical Culture (LSUPhC, Lviv, Ukraine) has elaborated the software-hardware complex "Rytm" (SHC "Rytm"). This complex is designed for the automatic analysis of HRV and some indexes of human hemodynamic according to methods elaborated by Mukalov I.O. (Drozd et al., 2014). To use the newly elaborated device for the correct analysis of HRV, the high accuracy of the RR intervals registration must be confirmed. The accuracy of the registration can be estimated by comparison of the data, obtained from two devices, one of which is considered to be a reference ("golden standard") one. Such studies have been performed for the Garmin 920 XT (Cassirame et al., 2017), PolarS810 (Braga et al., 2016; Barbosa et al., 2014; Nunan et al., 2008), Polar RS800 in various modifications (Hernando et al., 2018; Barbosa et al., 2014; Montaño et al., 2016), Polar V800 (Caminal et al., 2018; Giles et al., 2015; Giles & Draper, 2018), Equivital EQ02 (Akintola et al., 2016) and Suunto t6 (Weippert et al., 2010) monitors. The same studies have been done for the SHC "Rytm" (Vovkanych et al., 2020). As the reference devices, the medical ECG recorders or holter ambulatory ECG recorders were used. In previous research, the comparisons have been performed in conditions of physiological rest (Gamelin et al., 2008; Giles & Draper, 2018; Vovkanych et al., 2020), and in the case of exercise performance (Braga et al., 2016; Cassirame et al., 2017; Giles & Draper, 2018). In most of the studies, researchers compared both RR intervals and HRV indexes, calculated based on RR intervals time series (Gamelin et al., 2008; Giles & Draper, 2018; Giles et al., 2015). A large number of studies testify the necessity of the investigation of the accuracy of RR data and derived HRV indexes by the newly developed devices. Our previous research (Vovkanych et al., 2020) revealed a good agreement between RR data and most of the HRV indexes, based on data of SHC "Rytm" and both the medical electrocardiographic system and Polar RS800, in the condition of physiological rest.

The presented paper aims at assessing the accuracy of RR time series measurements by SHC "Rytm" and validity of derived from them HRV indexes in conditions of physical loads and recovery period.

Materials and methods

Study participants

Study participants were twenty healthy male adults (aged 19.7 ± 0.23 years, height 179.9 ± 1.6 cm, weight 73.8 ± 1.9 kg), non-smokers, and none was taking any medication. All subjects provided informed consent to participate in the study. The procedures were accorded to the ethical standards of the relevant national, institutional or other body responsible for human research and experimentation, and the principles of the World Medical Association's Declaration of Helsinki. This study was approved by the Ethical Committee of Lviv State University of Physical Culture named after Ivan Boberskyj.

Study organization

Data was recorded simultaneously with an ECG recorder (CardioLab CE12, XAI-Medica, Kharkiv, Ukraine), Polar RS800 (Polar Electro Oÿ, Kempele, Finland), and SHC "Rytm" (LSUPhC, Lviv, Ukraine). Polar RS800 was used as the "golden standard" device for RR intervals measurements during the physical loads and recovery period. The high level of accuracy of this device was previously confirmed in several studies (Hernando et al., 2018; Barbosa et al., 2014; Montaño et al., 2016; Wallén et al., 2011). The Polar H7 (Polar Electro Oÿ, Kempele, Finland) served as a heart rate sensor at SHC "Rytm", data was transmitted by Bluetooth and registered with the "Rytm" software.

The electrode belts of Polar RS800 and SHC "Rytm" sensor were placed just below the chest muscles as described by the manufacturer. We used a 3-electrode system for ECG recording. The electrodes were placed on the chest wall equidistant from the heart. Test protocol included a 2 minutes step test (20 steps per minute, platform height – 40 cm) with the next 3 minutes recovery period. Data were recorded continuously during the step-test and the recovery period.

Statistical analysis

Obtained by SHC "Rytm", CardioLab CE12, and Polar RS800 the RR intervals series were analyzed by Kubios HRV 2.1 (Kuopio, Finland) software for artifacts correction (low level of correction). The corrected data were synchronized and analyzed by MS Excel version 2010 (Microsoft Inc., USA). Standard statistical methods were used to calculate the means and standard deviations. A paired t-test or, when appropriate, a paired Wilcoxon test, was used to detect the presence of systematic difference. The Bland–Altman statistical analysis with calculation of bias and limits of agreement (LoA), along with a determination of intraclass correlation coefficient (ICC) were used for comparison. Statistical analysis was carried out by MS Excel 2010 and OriginPro 9.1 software. Statistical significance was set at $p = 0.05$ level for all analyses.

Results

Data of table 1 reveals that the number of detected RR intervals and the mean values of the RR intervals were the same for all tested devices both under the physical loads and during the recovery period. The results of CardioLab CE12 are not included in analyses in the case of physical loads because of a large number of artifacts, generated by contracted muscles. Most probably, the artifacts could not be effectively removed by device hardware and software means because the CardioLab CE12 was designed for the ECG recording at rest.

As the normality of data distribution was rejected by Kolmogorov-Smirnov approach, the median values and quartiles (Q1 and Q2) were also analyzed. We have found no difference in the median values of RR intervals and a very small (1 ms) difference in quartile values for all devices (Table 1). These findings strongly support the good repeatability of the HSC "Rytm" data as compared to medical devices or well-approved sports devices.

The most common approaches to analyzing the repeatability of data obtained by different devices are plotting of the Bland–Altman diagram, determination of the limits of agreement (LoA), and the calculation of intraclass correlation coefficient (ICC) (Doğan, 2018; Montenij et al., 2016). The Bland–Altman plots for Polar RS800 and SHC "Rytm" are presented in Fig. 1. Data showed at the plots confirm the good agreement among the devices.

Table 1. Statistical description of the sets of RR intervals recorded by different devices during the physical loads

Index	Step-test performance		Recovery period		
	Polar RS800	HSC "Rytm"	CardioLab	Polar RS800	HSC "Rytm"
Number of intervals	4707	4707	4785	4785	4785
Mean (ms)	489.65	489.71	731.00	730.91	731.23
SEM (ms)	0.90	0.90	3.13	3.13	3.13
SD (ms)	61.46	61.46	216.84	216.70	216.85
Median (ms)	484.00	484.00	704.00	704.00	704.00
Q1 (ms)	484.00	484.00	557.00	557.00	558.00
Q3 (ms)	441.00	441.00	876.00	876.00	877.00

Note: M – arithmetical mean; SEM – standard error of the mean; SD – standard deviation, Q1 – 1st quartile; Q3 – 3rd quartile.

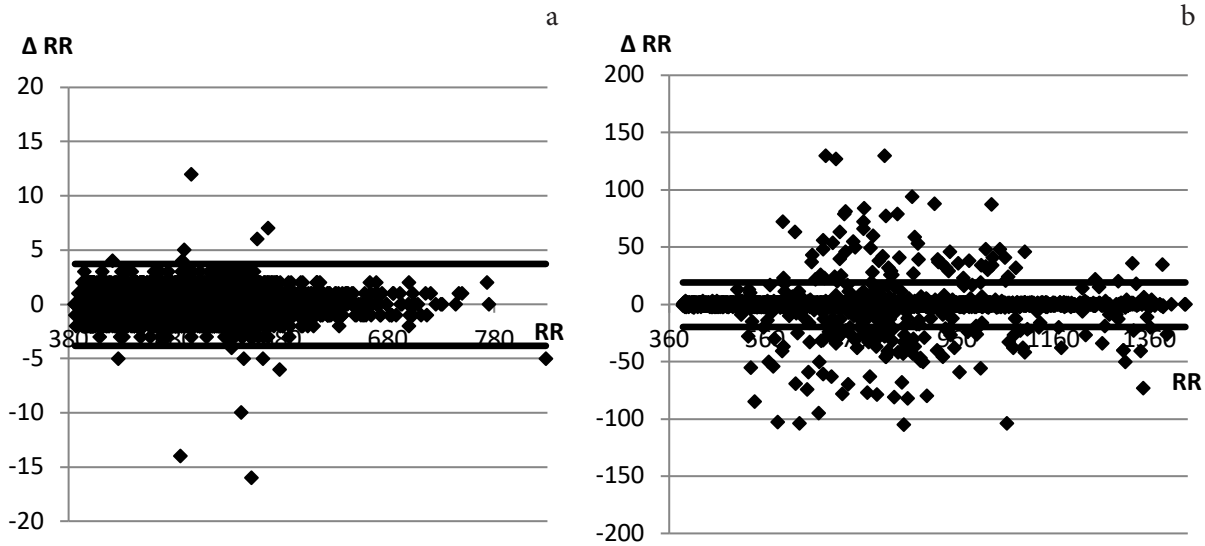

Fig. 1. Bland–Altman plot of RR intervals comparison between Polar RS800 and SHC "Rytm" during the step-test (a) and during the recovery period (b). Limits of agreement are indicated by horizontal lines

Table 2. Analysis of the repeatability in RR time series measured by different devices during the step-test (n = 4707) or recovery period after the test (n = 4785)

Index	Pairs of compared devices			
	Step-test	Recovery period		
	Polar RS800 – HSC "Rytm"	CardioLab – Polar RS800	CardioLab – HSC "Rytm"	Polar RS800 –HSC "Rytm"
Mean ΔRR (ms)	-0.06	0.09	-0.24	-0.33
SEM ΔRR (ms)	0.03	0.17	0.12	0.14
LoA (ms)	-3.83 – 3.72	-22.60 – 22.79	-16.18 – 15.71	-19.74 – 19.09
ICC	1.000	0.620	0.621	0.620
r	0.999	0.998	0.999	0.999

Note: Mean ΔRR – bias in the duration of the RR interval recorded by two different devices; SEM – standard error of the mean; LoA – limits of agreement; ICC – intraclass correlation coefficient; r – Spearman correlation coefficient

The RR data bias in the case of physical loads was very low (-0.06 ms), while during the recovery period is increased to 0.09-0.33 ms (Table 2). As the bias in all cases was less than 1 ms it could be considered acceptable for the heart rate and HRV estimation. Calculated LoA ranged from 3.7 ms to 22.8 ms, depending on the period of measurements and pair of compared devices. The LoA tended to be larger for the measurements, performed during the recovery period. The possible explanation for this is the higher level of the variability of RR intervals and higher duration of RR intervals during recovery, which causes the proportional increase in both bias and LoA.

We determine the intraclass correlation coefficients (ICC) according to the Weir model 3.1 (Koo & Li, 2016). Both values of ICC (0.62-1.00) and Spearman correlation coefficient (0.99) were high enough to suggest very high re-

Table 3. Comparison of heart rate variability indexes (M ± SEM), derived from the RR data from different devices during the step-test

HRV index	Recording device		Polar RS800 – HSC "Rytm"			
	Polar RS800	HSC "Rytm"	r	p	bias	LoA
Mean RR (ms)	494.61±10.73	495.91±10.81	1.00	0.15	-0.06	0.03 – -0.14
Mean HR (1/min)	123.15±2.73	122.85±2.75	1.00	0.15	0.30	2.04 – -1.44
STD RR (ms)	37.68±2.97	37.96±3.03	1.00	0.13	-0.03	0.32 – -0.38
RMSSD (ms)	8.78±1.27	9.08±1.35	0.98	0.25	0.002	0.58 – -0.58
pNN50 (%)	0.44±0.27	0.54±0.30	0.97	0.24	-0.03	0.34 – -0.39
RR tri index	5.69±0.39	5.47±0.34	0.94	0.12	0.22	1.41 – -0.97
VLF (ms^2)	382.27±71.43	386.82±72.62	1.00	0.25	0.24	3.50 – -3.02
LF (ms^2)	39.82±12.76	39.80±12.74	1.00	0.98	0.04	1.26 – -1.17
HF (ms^2)	24.33±11.41	24.23±11.20	1.00	0.85	-0.34	2.45 – -3.14
VLF (%)	79.73±5.05	79.88±5.00	1.00	0.62	0.13	1.01 – -0.76
LF (%)	13.81±3.73	13.71±3.72	1.00	0.48	0.004	0.27 – -0.28
HF (%)	6.42±1.99	6.37±1.93	1.00	0.76	-0.11	0.61 – -0.82
LF/HF ratio	3.69±0.61	3.48±0.57	0.99	0.05	0.21	1.10 – -0.67
SD1 (ms)	6.25±0.90	6.47±0.96	0.98	0.24	0.001	0.41 – -0.41
SD2 (ms)	51.99±4.21	52.33±4.29	1.00	0.16	0.003	0.17 – -0.18

Note: LoA – limits of agreement; HR – heart rate; STD RR – standard deviation of RR intervals; RMSSD – square root of the mean squared differences between successive RR intervals; pNN50 – percentage of successive intervals with a difference greater than 50 ms compared to the previous interval; RR tri index – the integral of the RR interval histogram divided by the height of the histogram; VLF, LF and HF – absolute (ms2) or relative (%) powers from very low frequency, low frequency and high frequency bands respectively; LF/HF – ratio of LF to HF; SD1 and SD2 – from Poincaré plot the standard deviation perpendicular to or along to the line-of-identity respectively

Table 4. Heart rate variability indexes (M ± SEM), derived from the RR data from different devices during recovery period

HRV index	Recording device		
	Cardio Lab	Polar RS800	HSC "Rytm"
Mean RR (ms)	754.46±32.45	754.23±32.47	754.29±32.37
Mean HR (1/min)	86.92±3.54	86.90±3.55	86.87±3.55
STD RR (ms)	165.61±12.53	165.17±12.48	165.12±12.45
RMSSD (ms)	56.77±4.35	55.56±4.30	56.20±4.34
pNN50 (%)	33.08±3.71	32.27±3.60	32.70±3.60
RR tri index	22.11±1.59	21.63±1.61	20.45±1.47
VLF (ms^2)	10696±1798.51	10816±1852.22	10765±1835.21
LF (ms^2)	2091.77±464.70	1902.54±370.65	2090.19±465.92
HF (ms^2)	1920.12±212.90	1840.49±209.59	1913.42±211.74
VLF (%)	66.59±3.46	67.43±3.53	66.69±3.47
LF (%)	16.66±2.82	16.12±2.75	16.62±2.82
HF (%)	16.71±1.68	16.42±1.73	16.67±1.68
LF/HF ratio	1.27±0.27	1.26±0.25	1.28±0.27
SD1 (ms)	40.26±3.09	39.40±3.05	39.85±3.08
SD2 (ms)	229.95±17.51	229.56±17.46	229.40±17.41

Note: legend – as in the table 3

peatability of the data (Koo & Li, 2016). Nevertheless, some differences in the duration of RR intervals, registered by different devices, may cause deviations in the estimation of HRV indexes. Therefore, the final conclusion should be made based on the calculation and analysis of HRV indexes, derived from the obtained data.

On the next stage of the analysis, we intended to test if the obtained values of bias and LoA for RR data were narrow enough to avoid substantial differences in the HRV indexes, derived from the data. For this purpose, the HRV indexes were calculated by Kubios HRV 2.1 software (Kuopio, Finland) from the RR time series, recorded by different devices, with the next comparative analysis (Tables 3–5). The significance of the difference was determined by paired t-test or paired Wilcoxon test, depending on the Shapiro–Wilk criterion of data distribution normality.

Table 5. Comparison of heart rate variability indexes (M ± SEM), derived from the RR data from different devices during recovery period

HRV index	CardioLab CE12 – Polar RS800			CardioLab CE12 – HSC "Rytm"			Polar RS800 – HSC "Rytm"		
	r	p	bias (LoA)	r	p	bias (LoA)	r	p	bias (LoA)
Mean RR (ms)	1.00	0.43	0.33 (2.80; -2.15)	1.00	0.55	0.23 (2.80; -2.34)	1.00	0.80	-0.06 (1.89; -2.01)
Mean HR (1/min)	1.00	0.80	0.01 (0.46; -0.45)	1.00	0.32	0.002 (0.18; -0.18)	1.00	0.18	0.03 (0.23; -0.17)
STD RR (ms)	1.00	0.10	0.24 (1.90; -1.43)	1.00	0.16	0.50 (3.49; -2.49)	1.00	0.86	0.11 (2.40; -2.17)
RMSSD (ms)	1.00	0.01	1.21 (4.63; -2.21)	1.00	0.08	0.34 (2.22; -1.53)	1.00	0.05	-0.64 (2.09; -3.37)
pNN50 (%)	0.99	0.05	0.81 (4.17; -2.56)	1.00	0.22	0.39 (3.04; -2.27)	1.00	0.21	-0.42 (2.43; -3.27)
RR tri index	0.89	0.53	0.48 (7.07; -6.11)	0.81	0.09	1.01 (7.11; -5.09)	0.93	0.07	1.18 (6.53; -4.17)
VLF (ms^2)	1.00	0.32	5.73 (59.63; -48.167)	1.00	0.38	2.15 (77.51; -73.20)	1.00	0.40	14.52 (93.05; -64.00)
LF (ms^2)	1.00	0.08	10.99 (122.81; -100.82)	1.00	0.86	-1.42 (43.13; -45.97)	1.00	0.09	-17.08 (56.25; -90.40)
HF (ms^2)	0.96	0.22	18.363 (167.01; -129.78)	0.96	0.47	7.65 (65.24; -49.94)	1.00	0.26	-20.71 (30.24; -71.65
VLF (%)	0.99	0.06	-0.51 (1.73; -2.75)	1.00	0.36	-0.12 (0.74; -0.98)	0.99	0.07	0.42 (2.33; -1.48)
LF (%)	0.99	0.08	0.37 (2.60; -1.86)	1.00	0.52	0.002 (0.50; -0.49)	1.00	0.08	-0.33 (1.64; -2.30)
HF (%)	0.99	0.19	0.13 (1.43; -1.16)	1.00	0.68	0.12 (0.80; -0.57)	0.99	0.23	-0.25 (1.51; -2.01)
LF/HF ratio	0.96	0.87	0.06 (0.67; -0.56)	0.95	0.44	-0.01 (0.07; -0.08)	1.00	0.81	-0.02 (0.70; -0.74)
SD1 (ms)	1.00	0.01	0.70 (2.75; -1.34)	1.00	0.08	0.25 (1.28; -0.78)	1.00	0.06	-0.21 (0.91; -1.33)
SD2 (ms)	1.00	0.23	0.09 (1.85; -1.67)	1.00	0.22	-0.19 (1.51; -1.88)	1.00	0.66	-0.16 (1.05; -1.39)

Note: legend – as in the table 3.

Data of Tables 3 confirmed the absence of significant differences between the majority of HRV indexes, calculated from RR intervals data, obtained by Polar RS800 and HSC "Rytm" during the physical loads. The only exception was LF/HF ratio, for which a significant difference in values along with a high range of LoA was found.

Results, presented in Table 4 and 5, revealed the absence of a significant difference between HRV indexes, based on data of CardioLab CE12 and HSC "Rytm". Comparison of Polar RS800 and HSC "Rytm" found only one case of statistically significant difference – the RMSSD value. However, the small bias (-0.64 ms) and a range of LoA (2.09 – -3.37 ms) seemed to be acceptable for the correct estimation of RMSSD (56–57 ms). The largest numbers of different HRV indexes have been found during the comparison of CardioLab CE12 and Polar RS800. Differences were found between RMSSD, pNN50, and SD1. Correlation between HRV indexes was very high in all pairs of devices.

Discussion

Most studies dealing with the agreement between RR intervals data, obtained by Polar S810 and other devices, have reported the bias of 0.41-2.4 ms (Caminal et al., 2018; Cassirame et al., 2017; Braga et al., 2016). In the present study, the bias in RR intervals is found to be only -0.06 ms during the step-test performance and ranges from 0.09 ms to -0.33 ms for different devices in the recovery period. These results suggested the very low level of the systematic error of RR interval measurements by HSC "Rytm". The suggestion is strongly supported by values of LoA, obtained during comparison of HSC "Rytm" with other devices. The lowest LoA values, found in the case of step-test performance (-3.83-3.72 ms), are comparable with findings of Porto et al. (2009) – -6.37-2.67 ms. Although the LoA are found to be larger in the recovery period (up to -19.74-19.09 for the pair Polar RS800–HSC "Rytm"), they remain in the range, reported by other authors – -23.40-24.9 ms (Braga et al., 2016). The values of the Spearman correlation coefficient for HSC "Rytm" data and data from other devices is 0.99 and reach the highest levels, mentioned in other studies (0.97–1.00) (Nunan et al., 2008; Caminal et al., 2018). The ICC is also very high (1.000) in the case of Polar RS800 and HSC "Rytm" comparison during step-test. The levels of ICC (0.62) in a recovery period are not as high, as obtained by other researchers (0.98 to 0.9994) (Nunan et al., 2008; Hernando et al., 2018). Despite this, they are high enough to support the suggestion of a good data agreement. In summary, these results provided strong evidence of good repeatability of RR intervals data, obtained under the physical loads by SHC "Rytm" and "gold standard" devices – CardioLab CE12 and Polar RS800.

Because the final goal of the time series of RR intervals registration is the analysis of heart rate variability, we have examined the possible difference between the HRV indexes, calculated from the data of HSC "Rytm" and other devices. First of all, it is advisable to mention the RMSSD index, as it is analyzed in many studies (Nunan et al., 2008; Wallén et al., 2011; Caminal et al., 2018). The ranges of LoA for RMSSD, reported in these researches, in most cases do not exceed 2 ms, although values of 26 and 60 ms are also registered. Our results reveal the 0.58 ms range of LoA during the step-test, and up to 4.63 ms range in the recovery period. Although our data show a low level of LoA, a significant difference is found between RMSSD, obtained in the recovery period from Polar RS800 and both HSC "Rytm" and CardioLab CE12. There is no significant difference between RMSSD, derived from the data of CardioLab CE12 and HSC "Rytm". The correlation coefficient is high (r = 1.00) in all cases. Thus, we can suppose the good reproducibility of the results of time-domain HRV analysis, based on the data of HSC "Rytm" and medical ECG device.

Past research revealed the LoA up to 22.6 ms^2 for VLF, 68.0 ms^2 for LF, and 47.0 ms^2 for HF indexes of frequency-domain HRV analysis based on Polar S810 data ECG data (Vanderlei et al., 2008; Wallén et al., 2011; Weippert et al., 2010). Despite the larger ranges of the LoA, obtained in our study during the rest period, we show an absence of significant difference and very high correlation between the VLF,

LF, and HF indexes, based on the data of HSC "Rytm" and other devices. In the case of physical loads, our data is close to the ranges of 5-7 ms^2, reported by other authors (Nunan et al., 2008; Giles & Draper, 2015). In summary, this finding may indicate the high accuracy of the reproduction of the frequency-domain HRV indexes, based on HSC "Rytm" data.

There are very few studies on the differences in the indexes of nonlinear HRV analysis (SD1 and SD2), derived from the data of Polar S810 and other devices (Gamelin et al., 2006, 2008; Cassirame et al., 2017; Giles et al., 2015). The reported LoA ranged from -0.2-0.24 ms to -0.85-1.55 ms. Our research shows the LoA less than 0.41 ms in conditions of physical loads, and up to 1.88 ms during the recovery period. There is no significant difference in the SD1 and SD2, derived from the data of HSC "Rytm" and other devices. Hence, we can suppose the high reproducibility of the nonlinear HRV analysis, derived from the data of HSC "Rytm" and well-approved devices.

The HSC "Rytm" and other devices show very high correlations (r = 0.81-1.00) between time-domain, frequency-domain, and nonlinear HRV indexes, similar to levels found in previous research with the Polar S810 (Gamelin et al. 2006, 2008; Nunan et al. 2009; Vanderlei et al. 2008). The high correlation is found both in conditions of physical loads and recovery period.

In summary, our results clearly suggest that in conditions of physical loads performance both the mean values and variability of RR intervals, registered by SHC "Rytm", do not differ significantly from those registered by the ECG systems (CardioLab CE12) and sports device with a high level of accuracy (Polar RS800).

Conclusions

Obtained data confirm the absence of significant differences between the RR time series, registered during the physical loads by SHC "Rytm" and two well-approved devices – ECG recorder CardioLab CE12 and Polar RS800.

Our research provided strong evidence of a good agreement between the HRV indexes (except for the LF/HF ratio) based on SHC "Rytm" and Polar RS800 data in conditions of step-test performance. No differences are found between HRV indexes derived from SHC "Rytm" and CardioLab CE12 data in the recovery period, although some differences are present in RMSSD, pNN50, and SD1 between CardioLab CE12 and Polar RS800. The SHC "Rytm" appears to be acceptable for RR intervals registration and the HRV analysis in conditions of physical loads.

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Conflict of interest

The authors declare that there is no conflict of interest.

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АПРОБАЦІЯ ВИКОРИСТАННЯ ПРОГРАМНО-АПАРАТНОГО КОМПЛЕКСУ «РИТМ» ДЛЯ ВИМІРЮВАННЯ КАРДІОІНТЕРВАЛІВ ТА АНАЛІЗУ ВАРІАБЕЛЬНОСТІ СЕРЦЕВОГО РИТМУ В УМОВАХ ФІЗИЧНИХ ВПРАВ ТА ВІДНОВЛЕННЯ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 1 рис., 5 табл., 30 джерел.

Метою дослідження була оцінка точності вимірювань часових рядів кардіоінтервалів та отриманих на їхній основі показників варіабельності серцевого ритму (ВСР) за допомогою програмно-апаратного комплексу (ПАК) «Ритм» в умовах фізичних навантажень та періоду відновлення.

Матеріали і методи. Учасниками досліджень були 20 осіб віком 19,7 ± 0,23 років, чоловічої статі, без виявлених патологій. Дані реєстрували одночасно з використанням CardioLab CE12, Polar RS800 та ПАК «Ритм». Досліджувані виконували 2-хвилинний степ-тест (20 кроків на хвилину, висота сходинки – 40 см) з наступними 3-хвилинним періодом відпочинку. Показники ВСР розраховували з використанням Kubios HRV 2.1.

Результати. Середнє відхилення тривалості кардіоінтервалу в умовах фізичних навантажень становило -0,06 мс, у період відновлення ця величина зростала до 0,09-0,33 мс. Межі довірчих інтервалів коливались від 3,7 мс до 22,8 мс, залежно від періоду вимірювань та пари порівнюваних пристроїв. Ці величини можна вважати прийнятними для коректного оцінювання частоти серцевих скорочень та ВСР. Значення внутрішньокласових коефіцієнтів кореляції (0,62-1,00) та коефіцієнтів кореляції Спірмена (0,99) були досить високими, щоб припустити дуже високу відтворюваність даних. Нами не виявлено вірогідної різниці ($p > 0,05$) та показана тісна кореляція ($r = 0,94$-$1,00$) між більшістю індексів ВСР, розрахованих за даними Polar RS800 та ПАК «Ритм», як в умовах фізичних навантажень (окрім LF/HF), так і в період відновлення. Порівняння даних Polar RS800 та ПАК «Ритм», отриманих у період відновлення, вказує на наявність відмінності ($p < 0,05$) лише для одного показника (RMSSD). Найбільша кількість відмінностей у показниках ВСР виявлена під час порівняння CardioLab CE12 та Polar RS800 – RMSSD, pNN50 та SD1. Виявлена тісна кореляція між показниками ВСР ($r = 0,81$-$1,00$) для всіх пар приладів та у всі періоди вимірювань.

Висновки. ПАК «Ритм» характеризується прийнятним рівнем точності вимірювання кардіоінтервалів та аналізу ВСР в умовах фізичних навантажень та в період відновлення.

Ключові слова: електрокардіографія, Polar RS800, аналіз Бленда–Альтмана, коефіцієнт кореляції внутрішньокласового зв'язку.

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ORIGINAL SCIENTIFIC ARTICLE

A PROSPECTIVE COHORT STUDY TO PREDICT RUNNING-RELATED LOWER LIMB SPORTS INJURIES USING GAIT KINEMATIC PARAMETERS

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Abstract

The study purpose was to follow a prospective cohort study design to use gait kinematic parameters to identify the risk factors and to develop a statistical model to predict running-related lower limb injuries of sportspersons.

Materials and methods. BTS G-WALK® gait analysis system was used to collect gait kinematic data of 87 subjects from an institute of physical education and sports science.

The subjects were followed for a full academic season after which the researcher inquired about their injury occurrences. Binary logistic regression was used to develop a prediction model to predict lower limb injuries of sportspersons.

Results. The result of the study revealed that increasing Range of Obliquity, Range of Tilt and Range of Rotation were associated with increased likelihood of future running-related lower limb injury. However, the lower Symmetry Index was associated with increase in the likelihood of future running-related lower limb injury.

Conclusions. The study confirmed that it is possible to predict injury, but for practical implication further research is essential with a bigger sample size.

Keywords: sports injury, lower limb injury, gait kinematics, cohort study, injury prediction, logistic regression.

Introduction

> "Whether one is a professional athlete or a weekend warrior, almost every participant in sports incurs physical injury at one time or another"
>
> *By Conrad (2006)*

Despite the fact that there is no widely recognised definition for sports injury, the injuries sustained by exercising are considered as "sports injuries" (Bahr & Krosshaug, 2005; McCrory, 2006). For certain people, the analytical conversation over the concept of an injury is an excessive over-complication of a basic problem. But for an in-depth clinical report for a study on a particular condition, deciding what injury entails might not be so straightforward (Verhagen & Mechelen, 2010). Injury types determined by different scholars have had different meanings. Definition by the International Olympic Committee (IOC) is the most suitable which describe sports injury as damage to body tissues resulting from sports, exercises, or from other physical activities (Roald Bahr et al., 2012).

Regardless of the injury's diagnosis, an athlete will face varying degrees of expected effects depending on his degree of participation in the sport (Kraemer et al., 2009). Professional athletes may have a high risk of losing their money, losing their contracts, and even losing their lives. A team's loss of a significant player at a time of competition is the worst moment result in loss of financial resources and a loss of the team's growth. Young and growing athletes may need to shut down their sports career even before they get the opportunity for actual begin. The results may lead to significant issues with family members, social interactions and losing the ability for daily activities.

Researchers have cited several factors that may contribute to sports-related injuries (Saragiotto et al., 2014). A single specific and identifiable event can cause acute injury, while chronic and overuse injuries can occur without evidence of a single identifiable event due to repeated micro-trauma (Knight, 2008; Verhagen & Mechelen, 2010). Numerous researches have also been conducted to predict injuries and appropriate precautions have been suggested to prevent it. Slobounov (2008) observed a correlation between postural

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instability and sports injury. Apart from various internal factors, external factors such as a biomechanical pattern of movement, training schedule, or the training surface are indictors for sports injuries (Harris-Hayes et al., 2016). Studies conducted on running injury have identified several factors to understand the root cause of running injuries. Zhang et al. (2017) said abnormal gait kinematics is associated with overpronated feet, resulting in overuse injuries. Zhang et al. (2017) also suggested that foot kinematics of persons with overpronated feet must be examined for better understanding about the mechanism of overuse injuries. Powell and Barber-Foss (1999) and Sorenson (2009) had explored the possible utility of pre-participation screening methods to identify athletes who are at higher risk of suffering sports injury. Physical trainers or coaches can identify biomechanical deficits of their trainees, build preventative strategies, and can minimise the number of injuries (Kruse & Lemmen, 2009; Sorenson, 2009). Mokha et al. (2016) found asymmetry functional movement screen (FMS) score as a better predictor of musculoskeletal injuries. Springer et al. (2016) found that gait analysis can be used in the diagnosis of shoulder overuse injury. Azzam et al. (2015) and Whittaker et al. (2017) had suggested to focus on high-quality cohort studies to find the most relevant results of movement quality in the prediction of risk of injury.

Injuries induce health care cost for young athletes. More of it, if after investing so much time, resources, and effort, if the player gets injured; all their hard work will go in vain. If someone could predict injury; he/she can take proper action to mitigate it. Prediction is an integral aspect of statistical analysis. There are several approaches to statistical prediction. Generally, statistics provides knowledge of population based on sample population; but for predictive statistical analysis, it is not necessarily the same (Johnson et al., 2012; Verma, 2013). The process of prediction is called forecasting and it requires time series data (Verma, 2013). Various regression analysis methods and their subcategories are used for predictive studies. Prediction is mainly an extrapolation of a problem (Steyerberg, 2009). For example, "which team is going to win the next soccer tournament?" Or, "how long it will take Usain Bolt to complete the upcoming 100-meter race?" Steyerberg (2009) feels that the researcher should also be concerned about hypothesis testing. For example, is the height of an athlete a predictor of high jump performance. Or in general: what are the factors responsible for high jump performance?

A prospective cohort study is a longitudinal cohort study that observes a group of similar individuals over time who may vary with respect to certain factors, to determine how these factors influence a certain outcome (Mann, 2012; Rango, 2016). The prospective cohort studies are essential for understanding the causes of diseases and disorders (MacGill, 2018). The one distinguishing feature of a prospective cohort study is that it is a study that starts before the participants have established all the outcomes of interest (Setia, 2016). Subjects in a prospective cohort study are tracked over a long period to see if an outcome happens, and to establish any association between the exposures and the outcome (Song & Chung, 2010). This way, researchers will eventually use the data of exposures to address several questions about the associations between «risk factors» and the outcomes (Verma, 2016). The principal benefit of a prospective cohort study is that it allows for longitudinal observation of the risk factors in a case, and the compilation of results are at regularly scheduled intervals, so that recall error can be minimised.

Lower limb area is the most vulnerable to overuse injuries, most of which occur at, or below the knee, with the most frequent injuries being patellofemoral pain, medial tibial stress syndrome, achilles tendinopathy, and plantar fasciitis/plantar heel pain (Callahan, 2020). Running is the main components of any sports training and faulty running mechanics is the root cause of lower limb musculoskeletal overuse injuries. The latest study shows that examination of activity patterns can not only reflect the anomalies arising from complicated walking activities but can be used to anticipate musculoskeletal injuries (Aicale et al., 2018; Hreljac, 2004). Thijs et al. (2007) observed that anterior knee pain can be predicted by pressure distribution during initial contact and loading response. Another study concluded that gait-related risk factors were the root cause for exercise-related lower leg pain among 400 students (Willems et al., 2006). Research showed that participants who suffered from sports-related lower limb injury had a distinct running pattern relative to participants without injury (Hamill et al., 2012). Additionally, there is an increasing number of studies demonstrating that variability or fluctuation of gait favourably modulates injury risk for overuse injuries among runners (Ferber et al., 2009; Hamill et al., 2012; Messier et al., 2018).

Having gone through the related research, and recognising the potential use of gait parameters as predictors of lower limb musculoskeletal injuries, it can be speculated that analysing the gait pattern during running activities may help to categorise the sportspersons at risk of lower limb injuries and to find risk factors for injuries of the sportsperson. Therefore, the *purpose of the current study* was to follow a prospective cohort study design to use gait kinematic parameters to identify the risk factors and to predict running-related lower limb injuries of sportspersons.

Materials and methods

Study participants

All participants were purposively selected from an institute of physical education and sports science courses. Initially, a total of 87 participants were selected and all were 1st-semester students of the academic session 2017 & 2018. The average age of the participants was 18.39±1.02 years, weight 62.30±7.44 kg and height 171.19±5.87 cm. It was made sure that nobody was injured during the time of commencement of data collection for the study. The participants went through a common conditioning programme at the institute for an entire academic semester. All participants had been specialised in their games or sports. Apart from their regular and common conditioning program, the participants continued to take parts in their specialised games or sports practice.

Ethics and consent of data collection

All procedures for data collection were followed as per the decision and instruction of the review board of the institute. The supervisor of the researcher was constantly guiding and supervising the procedures throughout the data collection period. Prior consent to participate in the study was taken from the subjects before the collection of data. A consent

Table 1. List of variables

Sl. No.	Variables	Explanation
1.	Cadence (C)	Cadence is the average value of the number of steps per minute over the whole trial. The unit of measurement is 'steps/min'.
2.	Stance phase duration (STPD)	Stance phase duration is the average duration of the right and left foot support phase. It is measured in the unit of '% of the running cycle'.
3.	Swing phase duration (SWPD)	Swing phase duration is the average duration of the right and left foot swing phase. The unit of measurement is '% of the running cycle'.
4.	Float phase duration (FPD)	Float phase duration is the average duration of the phase in which none of the two feet is on the ground. The unit of measurement is '% of the running cycle'.
5.	Propulsion speed (PS)	Propulsion speed is the average pushing speed when the limb is in contact with the ground. It is measured in the unit 'm/s'.
6.	Range of pelvic tilt (RT)	Pelvic tilt is the rotation of pelvic in the sagittal plane. Range of pelvic tilt is the amount of variation between the highest and lowest angle of rotation of pelvic in the sagittal plane. The unit of measurement is 'degree'.
7.	Range of pelvic obliquity (RO)	Pelvic obliquity is the rotation of pelvic in the frontal plane. And the range of obliquity is the amount of variation between the highest and lowest angle of rotation of pelvic in the frontal plane. The unit of measurement is 'degree'.
8.	Range of pelvic rotation (RR)	Pelvic rotation is the rotation of pelvic in the transversal plane. Range of rotation is the amount of variation between the highest and lowest angle of rotation of pelvic in the transverse plane. The unit of measurement is 'degree'.
9.	Symmetry index (SI)	Symmetry index comes from the comparison between right and left running cycle. It is the index of similarity between right and left running cycle.

form was given to the subjects before the start of data collection which was comprised of information about the study and the rights of the subjects. The subjects were also provided with the right to withdraw from the study. Data were collected with the minimum risk of injury to the subjects.

Selection of variables

After careful review of the related literature and the authors own understanding, the following variables had been selected for the current study (Baker, 2013; Kirtley, 2006; Levine et al., 2012; Richards et al., 2013; Whittle, 1991) (Table 1).

Selection of equipments

The gait kinematic parameters were obtained using the BTS G-WALK® gait analysis system. The G-WALK system is composed of an inertial sensor, i.e., G-Sensor and a dedicated software named as G-Studio. The G-Sensor is made up of three different sensors, an accelerometer (±1.5 g, ±6 g), a magnetometer and a gyroscope (±300 gps, ±1200 gps) and are coupled with the sensor fusion technology. The triaxial accelerometer measures acceleration in three axes of movement, the triaxial gyroscope measures rotation in three axes, and the magnetic sensor provides a positional sense. The G-Studio software is a must to use when analysing and controlling the G-Sensor system. The entire BTS G-WALK® system can provide objective data and allows for comparisons between the left and right sides of the body as well as regular data. The system also provides kinematic data on the pelvis and lower limbs of the human body (BTS SpA, Milan, Italy).

Test protocol

The Run Protocol of the BTS G-WALK® system was implemented to acquire gait kinematic data. The sensor was positioned below the S1-S2 vertebra between the two dimples of venus. The device was centred on the vertebral line pointing upwards. The belt was tightened as much as required to deter displacement during the test.

The test was administered inside a laboratory which facilitated a treadmill. The test was started with the subject standing in a still position on the treadmill. The position was maintained for a few seconds until the end of the stabilization phase. Following the command from the operator, the subjects started to run on the treadmill. The operator steadily increased the treadmill speed until it reached 8 km/h. The subjects maintained this speed for at least 5 minutes. After completion of 5 minutes, the operator stopped the treadmill and manually enter the total distance travelled by the subject to the software. After entering the distance manually, BTS G-WALK® gait analysis system automatically generated values of spatio-temporal parameters, pelvic kinematics, and symmetry index which was further used for the study.

Experimental Protocol

The prospective cohort study design was used for the present study. A group of people with identical characteristics were observed over time. The differences among group individuals with respect to certain factors were identified and recorded initially and later it is analysed how these differences in selected factors affect certain outcomes. The subjects follow their general conditioning program for a full academic season after which the researcher inquired about their injury occurrences. Afterwards the researcher analyses how differences in gait kinematic affect the occurrence of injury among the subjects. The whole experimental protocol is explained using figure 1.

Statistical analysis

Binary logistic regression is generally used to predict the odds of occurrence of an event whose outcomes are binary

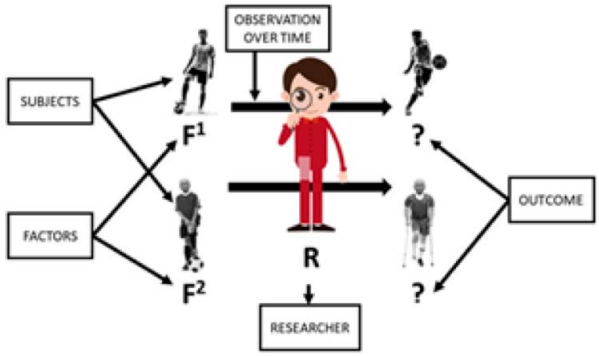

Fig. 1. Prospective cohort study design

in nature (Verma, 2013). Using binary logistic regression, a prediction model can be developed to predict a dichotomous dependent variable based on categorical or numerical independent variables (predictors). In the current study also, the researcher intended to develop a model to predict lower limb injuries of sports person based on some spatial-temporal gait kinematic parameters. Simple descriptive statistics were first used to summarize the data for the study. To find the factors affecting the occurrence of running-related lower limb sports injuries and to develop a predictive model, binary logistic regression was used employing IBM SPSS Version 25.0 (Armonk, 2017). All statistical tests were calculated at the significance level of 0.05.

Results

The initial investigation reported that out of 87 subjects, 2 subjects got accidental injuries, therefore those subjects were excluded from the study. The effective and final number of subjects became 85 (N = 85). The average age of the subjects was 18.40 ± 1.01 years, weight 62.35 ± 7.52 kg, Hight 171.22 ± 5.93 cm with an average BMI of 21.24 ± 2.05 (Table 2). Out of the effective 85 subjects, 20 (23.5%) subjects suffered from lower limb injuries (Table 3).

Before the application of binary logistic regression, simple descriptive statistics were calculated to summarise the values of independent variables (Table 4). The assumptions were also verified and it was found that all assumptions were fulfilled by the data set.

The omnibus tests of model coefficients (table 5) display that model 4 is statistically significant ($p < 0.05$) with the highest degree of freedom (df = 4). Therefore, it can be said that the overall model 4 is statistically significant in predicting future injury.

The results illustrated in table 7 indicates that the accuracy of the final model is 91.8%. The results also revealed that 80% of injured subjects were predicted correctly by the model to get running-related lower limb injuries. On the other hand, 95.4% of subjects who didn't get injury were also predicted correctly by the model not to get any running-related lower limb injuries.

The Wald test result column in table 8 revealed that the variables Range of Obliquity (RO), Range of Tilt (RT), Range of Rotation (RR) and Symmetry Index (SI) were added significantly to the final model ($p < 0.05$).

Based on the result from table 8 the following logistic regression model can be developed.

Table 2. Demographic Characteristics of the Subjects

Variables	Minimum	Maximum	Mean	Std. Deviation
Age	16	21.00	18.40	1.01
Weight	47	83.00	62.35	7.52
Hight	158	190.00	171.22	5.93
BMI	17.01	27.58	21.24	2.05

Table 3. Observed Injury Occurrence

	Value	Count	Percentage
Injury Occurrence	Yes	20	23.5%
	No	65	76.5%

Table 4. Comparative Descriptive Statistics of the Independent Variables

Variables	Injury Occurrence	Mean	Std. Deviation
Cadence	No	169.3154	9.69610
	Yes	168.8500	5.82784
	Overall	169.2059	8.90796
Stance Phase Duration	No	23.1908	3.34672
	Yes	22.5975	3.55141
	Overall	23.0512	3.38388
Swing Phase Duration	No	76.8092	3.34672
	Yes	77.4025	3.55141
	Overall	76.9488	3.38388
Float Phase Duration	No	26.5238	3.38865
	Yes	26.2875	3.08523
	Overall	26.4682	3.30335
Propulsion Speed	No	.7225	.18849
	Yes	.7795	.16767
	Overall	0.7359	0.18444
Range of Obliquity	No	7.8454	1.80205
	Yes	11.0000	1.26418
	Overall	8.5876	2.15583
Range of Tilt	No	7.5138	2.10484
	Yes	11.3975	1.54438
	Overall	8.4276	2.58092
Range of Rotation	No	8.6946	2.36883
	Yes	10.7000	1.17148
	Overall	9.1665	2.30607
Symmetry Index	No	98.3831	1.19211
	Yes	97.1450	1.49296
	Overall	98.0918	1.36602

$$\log(p/(1-p)) = 67.027 + 1.078 \cdot RO + 0.614 \cdot RT + 0.597 \cdot RR - 0.927 \cdot SI$$

(p = Probability of getting injury)

The logistic model was statistically significant as $x^2(4) = 63.42$; $p < 0.05$. The model explains 79.2% of the variability in running-related lower limb injury and correctly classified 91.8% of cases. It was found that increasing Range of Obliquity, Range of Tilt and Range of Rotation were associated with an increased likelihood of future running-related lower limb injury. However, lower Symmetry Index was associated with an increase in the likelihood of future running-related lower limb injury.

Table 5. Omnibus Tests of Model Coefficients (Method = Forward Stepwise)

		Chi-square	df	Sig.
	Step	5.511	1	0.019
Step 4	Block	63.420	4	0.000
	Model	63.420	4	0.000

Table 6. Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
4	29.331[a]	.526	.792

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than .001

Table 7. Classification Table[a]

	Observed		Predicted		
			Injury Occurrence		Percentage Correct
			No	Yes	
Step 4	Injury Occurrence	No	62	3	95.4
		Yes	4	16	80.0
	Overall Percentage				91.8

a. The cut value is .500

Discussion

Injury is a major cause of morbidity among young athletes. Previous studies indicated that future research is necessary to determine risk factors for injuries (Gogoi et al., 2020). Identifying factors that are contributing to sports injury may have tremendous significance in the athlete's health care. Therefore, the researchers intended to analyse gait kinematics to determine the risk factors and to develop a predictive model for lower limb injuries among sportsperson.

In the current study prospective cohort study design was employed by using an inertial sensor-based device to assess the gait kinematic factors. A similar kind of the previous study suggested application of inertial and GPS sensors combined with biometrics, nutrition and sleep data can be used to track movements and physical activity and can be used to describe injuries, anticipate future injuries, and then proactively assess which modifiable risk factors can be altered for optimum performance (Bourdon et al., 2017).

The result of the current study indicated that gait kinematic may be used to identify the elevated risks of lower limb injury among sportsperson. From table 6, 'Cox & Snell R square' indicates that 52.6% of the variation in the dependent variable can be explained by the final logistic model. And the Nagelkerke R Square indicates that 79.2% variability in the dependent variable can be explained by the independent variables in the final logistic model (table 6). Further, the table 7 reveals that the model may correctly distinguish 91.8% of the running-related lower limb injuries. The positive predictive value was (100·16/(16+3)) 84.21% which was the percentage of correctly predicted cases of all the observed injury cases. The negative predictive value was (100·62/(62+4)) 93.94% which was the percentage of correctly predicted cases of all non-injury cases (table 7). The value of Exp(B) (table 8) for the variable Range of Obliquity (RO) indicates that if we keep all the other independent variables constant, one unit increase in Range of Obliquity (RO) will increase the odds of having running-related lower limb injury by 2.938 times. Same way, keeping all other independent variables constant, if we increase one unit of Range of Tilt (RT), it will also increase the odds of having running-related lower limb injury by 1.848 times. For the independent variable Range of Rotation (RR), the odd of having running-related lower limb injury will increase by 1.816 times. But for one unit increment in Symmetry Index (SI) the odd of having running-related lower limb injury will decrease by 0.396 times (Table 8).

The comparative descriptive statistics (table 4) of the independent variables reveals that there was not much difference in the cadence of subjects with injury (168.85 ± 5.82) and without injury (169.31 ± 9.69). A study conducted by Burns et al. (2019) also reported a similar kind of result, cadence did not exhibit any significant impact on running efficiency. In contrast to Burns et al. (2019), several other studies have indicated that a faster running cadence helps runners to decrease their chances of injury over time (Kessler, 2020; Schubert et al., 2014; Wellenkotter et al., 2014). The overall swing phase duration (76.95 ± 3.38) of the subjects seemed to be higher whereas the stance phase duration (23.05 ± 3.38) was lower compared to normal running as the subjects were running at a higher speed (8 km/h) (Chumanov et al., 2011; Simonsen, 2013). For both the variables, there was not any noticeable difference between injured and without injury subjects. A similar trend also followed for the variable float phase duration and propulsion speed. The variables range of obliquity had exhibited a noticeable difference between injured (11.00 ± 1.26) and without injury subjects (7.85 ± 1.80). Benca et al. (2020) also observed increased pelvic obliquity in malalignments population. In the current study, injured subjects had shown a higher range of tilt. Alizadeh & Mattes (2019) suggested, pelvic tilt in the kinetic chain might have the potentiality to predispose injured soccer player. In addition to it, a recent finding indicated that distance runners may have an increased risk of running-related lower limb injury with increased hip adduction (Mokha & Gatens, 2018).

Table 8. Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 4[a]	Range of Obliquity	1.078	.440	5.989	1	.014	2.938
	Range of Tilt	.614	.266	5.326	1	.021	1.848
	Range of Rotation	.597	.293	4.141	1	.042	1.816
	Symmetry Index	-.927	.398	5.425	1	.020	.396
	Constant	67.027	36.282	3.413	1	.065	1.286E

a. Variable(s) entered on step 4: Range of Rotation

The current study also reveals that injury subjects have a higher degree of range of rotation (10.70 ± 1.17) with less symmetry index (97.14 ± 1.49).

Despite the limitation of the current study, the authors have developed the model to predict running-related lower limb sports injury. Since runners can modify their running mechanism. Therefore, the authors suggest the sportspersons to analyse their gait kinematics and take preventive gait modification to thwart future injury.

Conclusions

One of the major objectives of scientific sports training is to prevent players from injury but it may not be always possible for coaches to identify the injury-prone players on the field. Therefore, clinical prediction modelling may provide an objective estimate of injury identification. For example, a coach can use a predictive model to identify which athletes might be at risk for musculoskeletal injuries followed by a rehabilitation programme to help address their deficiencies (Hughes et al., 2018; Wilkerson et al., 2012) advised periodical health examination to identify, prevention and rehabilitation of athletes which may be at risk of future injury. A similar pattern of analysis may also be followed to periodically analyse gait kinematics to find the faulty action of movement to prevent future injury of a sportsperson.

The main limitation of any prediction model is that there are variations in the assessment of the factors. In addition, the reliability of the model derived from such cohort studies is strongly dependent on the number of cases in the study. If there are not enough samples, the data cannot be considered as representative for a larger group of athletes. Therefore, for future research, it is suggested to have a much larger data set to establish a reliable injury prediction model.

After completion of the current study, firstly we can ask ourself can we identify the risk factors of injury? Secondly, can we predict the injuries with certainty? For the first question, we can answer yes, we can identify the risk factors of lower limb injury within the limitation of the current study. And for the second question, based on the results, we can agree that prediction of injury is theoretically possible but for the practical implication, further research is essential with a bigger sample size. Apart from it, the research was conducted on male sports person, so the results may not be applicable to female sportspersons. Therefore, it is suggested to conduct future research on female sportspersons also.

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Conflict of interest

The authors declare that there is no conflict of interest.

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ПЕРСПЕКТИВНЕ КОГОРТНЕ ДОСЛІДЖЕННЯ ДЛЯ ПРОГНОЗУВАННЯ ПОВ'ЯЗАНИХ З БІГОМ СПОРТИВНИХ ТРАВМ НИЖНІХ КІНЦІВОК З ВИКОРИСТАННЯМ КІНЕМАТИЧНИХ ПАРАМЕТРІВ ХОДИ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 1 рис., 8 табл., 54 джерел.

Метою дослідження було слідувати плану перспективного когортного дослідження, щоб використовувати кінематичні параметри ходи для виявлення факторів ризику та розробити статистичну модель для прогнозування травм нижніх кінцівок спортсменів, пов'язаних із бігом.

Матеріали і методи. Система аналізу ходи BTS G-WALK® була використана для збору кінематичних даних ходи 87 суб'єктів з інституту фізичного виховання та спорту.

Випробовуваних спостерігали упродовж повного навчального сезону, після чого дослідник запитував про випадки їх травмування. Бінарна логістична регресія була використана для розробки моделі для прогнозування травм нижніх кінцівок спортсменів.

Результати. Результат дослідження показав, що збільшення діапазону косості, діапазону нахилу та діапазону обертання були пов'язані з підвищеною ймовірністю майбутніх травм нижньої кінцівки, пов'язаних з бігом. Однак нижчий індекс симетрії був пов'язаний із збільшенням ймовірності майбутніх травм нижньої кінцівки, пов'язаних із бігом.

Висновки. Дослідження підтвердило, що можна передбачити пошкодження, але для практичного значення подальше дослідження є важливим при більшому обсязі вибірки.

Ключові слова: спортивна травма, травма нижньої кінцівки, кінематика ходи, когортне дослідження, прогнозування травми, логістична регресія.

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ORIGINAL SCIENTIFIC ARTICLE

PATTERN RECOGNITION: IMPACT OF EXERCISES MODES ON DEVELOPING A SMALL BALL THROWING SKILL IN BOYS AGED 8

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Abstract

The purpose of the study was to determine the impact of exercises modes on developing a small ball throwing skill in boys aged 8.

Materials and methods. The study participants were 21 boys aged 8, who were randomly divided into three groups of 7 people. The children and their parents were fully informed about all the features of the study and gave their consent to participate in the experiment.

The study examined the influence of the number of repetitions on the effectiveness of teaching boys aged 8 throwing a small ball at a target. A pedagogical experiment examined the influence of 6, 12, and 18 repetitions with a 60-second rest interval on the increase in the level of proficiency in exercises of boys aged 8. In the first group, the boys repeated the task 6 times with a rest interval of 60 s, in the second group – 12 times with a rest interval of 60 s, in the third group 18 times with a rest interval of 60 s. When teaching throwing exercises during the class, the study evaluated the level of proficiency by the alternative method ("performed", "failed") and calculated the probability of exercise performance (p = n/m, where n is the number of successful attempts, m is the total number of attempts).

In teaching boys aged 8, the method of algorithmic instructions was used. The next exercise started after three successful attempts. Throwing a ball at a vertical target was taught.

The study materials were processed by the IBM SPSS 20 statistical analysis software. During discriminant analysis, a prognostic model for group membership was created.

Results. Discriminant analysis made it possible to determine the impact of the number of repetitions on the effectiveness of developing the skills of throwing a small ball at a target; answer the question as to how significantly the modes of repetitions differ by the effectiveness of motor skills development, what class the object belongs to based on the values of discriminant variables.

Conclusions. Based on the analysis of group centroids, it was found that in boys aged 8, six repetitions of the exercise (6 sets one time with a rest interval of 60 s) significantly influence the increase in the level of proficiency in exercises during physical education lessons.

The results of group classification show that 85.7% of the original grouped observations were classified correctly.

Keywords: boys aged 8, ball throwing, discriminant function.

Introduction

In the modern school, physical education is considered as a single process of motor skills formation, motor abilities development, and an increase in schoolchildren's motor activity (Chan, Ha, Ng, & Lubans, 2019; Chang, Ward, & Goodway, 2020; Barnett, Telford, Strugnell, Rudd, Olive, & Telford, 2019). Motor skills development is associated with the impact on children's and adolescents' health improvement (Bolger, L. A., Bolger, L. E., O'Neill, Coughlan, Lacey, O'Brien, & Burns, 2019; Bolger, L. E., Bolger, L. A., O'Neill, Coughlan, O'Brien, Lacey, Burns, & Bardid, 2020).

The learning process in physical education was studied in the following areas:

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- motor skills in the structure of schoolchildren's physical fitness (Petrov, Khudolii, & Cieślicka, 2020; Shevchenko, Khudolii, & Potop, 2020; Ivashchenko, Berezhna, & Cieślicka, 2020);
- gender-related peculiarities of motor skills development (Iermakov, Ivashchenko, & Khomiakov, 2020; Khudolii, Golovnin, & Bartík, 2020; Kelly, O'Connor, Harrison, & Ní Chéilleachair, 2019);
- regularities of motor skills development (Afrouzeh, Musa, Suppiah, & Abdullah, 2020; Khudolii, 2019; Hastie, Rudisill, Boyd, & Johnson, 2019);
- methods of assessing motor skills in children (Klingberg, Hoeboer, Schranz, Barnett, De Vries, & Ferrar, 2019; Lovric, Jelaska, Clark, Duncan, & Miletic, 2019; Nobre, Valentini, & Rusidill, 2020).

It was found that the conditions for motor skills development are one of the factors that determine the effectiveness of schoolchildren's learning (Ivashchenko, 2020; Ivashchenko, Nosko, M., Nosko, Y., & Chernenko, 2019; Kapkan, Khudolii, & Bartik, 2019a). The conditions for motor skills development are understood as the alternation of exercises and rest intervals (Marchenko & Taranenko, 2020; Ivashchenko, Khudolii, Iermakov, Chernenko, & Honcharenko, 2018). The importance of studying the process of teaching physical exercises is pointed out by Ivashchenko, Iermakov, Khudolii, Cretu, and Potop (2017), Marchenko, and Kovalenko (2020), Abhaydev, Bhukar, and Thapa (2020); the modes of physical exercises were also considered in the process of motor abilities development (Khudolii, Iermakov, Ivashchenko, & Nosko (2020); Iermakov, Ivashchenko, Khudolii, & Chernenko, 2020).

Studies on motor skills development used a probabilistic approach for motor skills assessment (Kapkan, Khudolii, & Bartik, 2019b; Ivashchenko, Khudolii, Iermakov, & Harkusha, 2017), factorial designs (Khudolii, 2019; Ivashchenko, 2020), and discriminant analysis to study the regularities of motor skills development (Gert-Jan de Bruijn & Benjamin Gardner, 2011; Lulzim, I., (2013), which make it possible to obtain new knowledge about the regularities of motor skills development in schoolchildren. Thus, the study of the effectiveness of teaching primary schoolchildren with the use of modern multivariate statistical methods is relevant.

The purpose of the study was to determine the impact of exercises modes on developing a small ball throwing skill in boys aged 8.

Materials and methods

Study participants

The study participants were 21 boys aged 8, who were randomly divided into three groups of 7 people. The children and their parents were fully informed about all the features of the study and gave their consent to participate in the experiment.

Study organization

The study examined the influence of the number of repetitions on the effectiveness of teaching boys aged 8 throwing a small ball at a target.

A pedagogical experiment examined the influence of 6, 12, and 18 repetitions with a 60-second rest interval on the increase in the level of proficiency in exercises of boys aged 8. In the first group, the boys repeated the task 6 times with a rest interval of 60 s, in the second group – 12 times with a rest interval of 60 s, in the third group 18 times with a rest interval of 60 s.

When teaching throwing exercises during the class, the study evaluated the level of proficiency by the alternative method ("performed", "failed") and calculated the probability of exercise performance ($p = n/m$, where n is the number of successful attempts, m is the total number of attempts).

In teaching boys aged 8, the method of algorithmic instructions was used. The next exercise started after three successful attempts. Throwing a ball at a vertical target was taught.

The study analyzed the impact of the number of sets on the level of proficiency in the following movements: 1. Throwing a ball against the floor; 2. Throwing a ball forward and up, feet shoulder width apart; 3. Throwing a ball forward and up, left leg forward; 4. Throwing a ball forward and up, left side to the throwing direction; 5. Throwing a ball at a 3 m distant target.

Statistical analysis

To determine the impact of the suggested modes of physical exercises for boys aged 8, discriminant analysis was conducted.

The study materials were processed by the IBM SPSS 20 statistical analysis software. During discriminant analysis, a prognostic model for group membership was created. This model builds a discriminant function (or, when there are more than two groups – a set of discriminant functions) in the form of a linear combination of predictor variables, which ensures the best division of groups. These functions are built according to a set of observations, for which their group membership is known. These functions can further be used for new observations with known values of predictor variables and unknown group membership.

For each canonical discriminant function, the study calculated: eigenvalue, dispersion percentage, canonical correlation, Wilks' Lambda, Chi-square.

The study protocol was approved by the Ethical Committee of the University. In addition, the children and their parents or legal guardians were fully informed about all the features of the study, and a signed informed-consent document was obtained from all the parents.

Results

Tables 1-3 show the results of a comparative analysis of the level of proficiency in a series of learning tasks of boys aged 8 depending on the number of repetitions.

The exercise mode of 6 repetitions with a 60-second rest interval has a statistically significantly better dynamics of the level of proficiency than the exercise mode of 12 repetitions with a 60-second rest interval for exercise 2 "Throwing a ball forward and up, feet shoulder width apart" ($p = 0.001$), the difference in proficiency in other exercises is not statistically significant ($p > 0.05$).

The exercise mode of 12 repetitions with a 60-second rest interval has a statistically significantly better dynamics of the level of proficiency than the exercise mode of 18 repetitions

Table 1. The results of a comparative analysis of the level of proficiency in a series of learning tasks of boys aged 8

No	Exercise	6 repetitions (n = 7)		12 repetitions (n = 7)		Δx	t	p	95% confidence interval of the difference of means	
		X	s	X	s				Lower limit	Upper limit
1	Throwing a ball against the floor	0.434	0.161	0.528	0.176	-0.094	-1.044	.317	-.291	.102
2	Throwing a ball forward and up, feet shoulder width apart	1	0	0.529	0.176	0.471	7.071	.000	.326	.617
3	Throwing a ball forward and up, left leg forward	0.433	0.162	0.529	0.176	-0.096	-1.057	.311	-.293	.102
4	Throwing a ball forward and up, left side to the throwing direction	0.48	0.263	0.67	0	-0.19	-1.914	.080	-.406	.026
5	Throwing a ball at a 3 m distant target	0.573	0.159	0.623	0.125	-0.05	.02632	.525	-.217	.117

Table 2. The results of a comparative analysis of the level of proficiency in a series of learning tasks of boys aged 8

No	Exercise	6 repetitions (n = 7)		18 repetitions (n = 7)		Δx	t	p	95% confidence interval of the difference of means	
		X	s	X	s				Lower limit	Upper limit
1	Throwing a ball against the floor	0.434	0.161	0.481	0.176	-0.047	-.522	.611	-.244	.149
2	Throwing a ball forward and up, feet shoulder width apart	1	0	0.811	0.176	0.189	2.828	.015	.043	.334
3	Throwing a ball forward and up, left leg forward	0.433	0.162	0.717	0.228	-0.284	-2.691	.020	-.514	-.054
4	Throwing a ball forward and up, left side to the throwing direction	0.48	0.263	0.67	0	-0.19	-1.914	.080	-.406	.026
5	Throwing a ball at a 3 m distant target	0.573	0.159	0.811	0.176	-0.238	-2.657	.021	-.434	-.043

Table 3. The results of a comparative analysis of the level of proficiency in a series of learning tasks of boys aged 8

No	Exercise	12 repetitions (n = 7)		18 repetitions (n = 7)		Δx	t	p	95% confidence interval of the difference of means	
		X	s	X	s				Lower limit	Upper limit
1	Throwing a ball against the floor	0.528	0.176	0.481	0.176	0.047	.500	.626	-.158	.253
2	Throwing a ball forward and up, feet shoulder width apart	0.529	0.176	0.811	0.176	-0.282	-3.000	.011	-.488	-.077
3	Throwing a ball forward and up, left leg forward	0.529	0.176	0.717	0.228	-0.188	-1.732	.109	-.426	.049
4	Throwing a ball forward and up, left side to the throwing direction	0.67	0	0.67	0	0	–	–		
5	Throwing a ball at a 3 m distant target	0.623	0.125	0.811	0.176	-0.188	-2.309	.040	-.366	-.011

with a 60-second rest interval for the first exercise ($p = 0.049$). For other exercises, the dynamics of the level of proficiency is not statistically significant ($p > 0.05$).

The exercise mode of 18 repetitions with a 60-second rest interval has a statistically significantly better dynamics of the level of proficiency than the exercise mode of 6 repetitions with a 60-second rest interval for the third and fifth exercises, and a worse dynamics for exercise 2 "Throwing a ball forward and up, feet shoulder width apart" ($p = 0.015$).

Thus, when developing a small ball throwing skill, the modes of physical exercises significantly influence the effectiveness of teaching.

To determine the impact of different modes of physical exercises on the level of proficiency, discriminant analysis was conducted (see Tables 4–6).

The first canonical function explains 75.3% ($r = 0.856$) of the results variation, the second canonical function explains 24.7% ($r = 0.688$) of the results variation, which indicates

their high informativeness (see Table 4). The materials of analysis of the canonical functions show a statistical significance of the first and second canonical functions ($\lambda_1 = 0.141$; $p_1 = 0.001$; $\lambda_2 = 0.526$; $p_2 = 0.036$). The first and second functions have a high discriminative ability and value in interpretation with respect to the general population (Table 5).

Table 6 shows the standardized canonical discriminant function coefficients, which make it possible to determine the ratio of the contribution of variables to the result of the function. The greatest contribution to the first canonical function is made by variable 2 "Throwing a ball forward and up, feet shoulder width apart", variable 3 "Throwing a ball forward and up, left leg forward"; to the second canonical function – exercise 5 "Throwing a ball at a 3 m distant target", exercise 3 "Throwing a ball forward and up, left leg forward": the greater the increase in proficiency in these exercises, the larger the value of the functions. The above indicates that exercises 2, 3, 5 are most sensitive to the number of repetitions in boys aged 8.

Table 6 shows the structure canonical discriminant function coefficients, which are the coefficients of correlation between the variables and the function. Thus, the first function is most closely connected with the results of the increase in proficiency in exercise 2 "Throwing a ball forward and up, feet shoulder width apart", exercise 4 "Throwing a ball forward and up, left side to the throwing direction": hence, a significant difference between the teaching modes is observed in exercises 2 and 4.

The second function is most closely connected with the results of the increase in proficiency in exercise 5 "Throwing a ball at a 3 m distant target", exercise 3 "Throwing a ball forward and up, left leg forward": hence, a significant difference between the teaching modes is observed in exercises 5 and 3. The first function makes it possible to differentiate three exercise repetition modes, the second function enables determining which exercises are most influenced by 12 and 18 repetitions.

Table 7 shows the coordinates of centroids for two groups. They make it possible to interpret the canonical function in relation to the role in classification. At the positive pole is a centroid for the exercise mode of 6 repetitions with a 60-second rest interval, at the negative — a centroid for the exercise mode of 12 repetitions with a 60-second rest interval (see Fig. 1). This indicates a significant difference of the impact of the number of repetitions on the increase in the level of proficiency in exercises during physical education lessons. The exercise mode of 6 repetitions with a 60-second rest interval is most effective in terms of the total impact. The results of group classification show that 85.7% of the original grouped observations were classified correctly.

Discussion

The study assumed the possibility of using a discriminant function to assess the effectiveness of different modes of physical exercises when teaching a series of throwing exercises, as the verification of canonical functions indicates their statistical significance.

The analysis determined the total impact of each teaching mode on the level of proficiency in five exercises, as well

Table 4. Canonical discriminant function. Eigenvalues. Boys aged 8

Function	Eigenvalues	% Dispersion Explained	Cumulative %	Canonical Correlation
1	2.744[a]	75.3	75.3	.856
2	.900[a]	24.7	100.0	.688

Table 5. Canonical discriminant function. Wilks' Lambda. Boys aged 8

Verification of Functions	Wilks' Lambda	Chi-Square	Degrees of Freedom	p
from 1 to 2	.141	31.394	10	.001
2	.526	10.270	4	.036

Table 6. Canonical discriminant function coefficients. Wilks' Lambda. Boys aged 8

N	Exercise	Standardized Coefficients		Structure Coefficients	
		1	2	1	2
1	Throwing a ball against the floor	.024	.253	-.146*	-.008
2	Throwing a ball forward and up, feet shoulder width apart	1.014	.298	.868*	.221
3	Throwing a ball forward and up, left leg forward	-.398	.404	-.145	.658*
4	Throwing a ball forward and up, left side to the throwing direction	-.239	.247	-.339*	.319
5	Throwing a ball at a 3 m distant target	.156	.805	-.098	.735*

Table 7. Functions at group centroids. Boys aged 8

Variants of Modes	Function	
	1	2
6 repetitions, rest interval of 60 s	1.910	-.589
12 repetitions, rest interval of 60 s	-1.846	-.653
18 repetitions, rest interval of 60 s	-.064	1.242

85.7% of original grouped observations are classified correctly

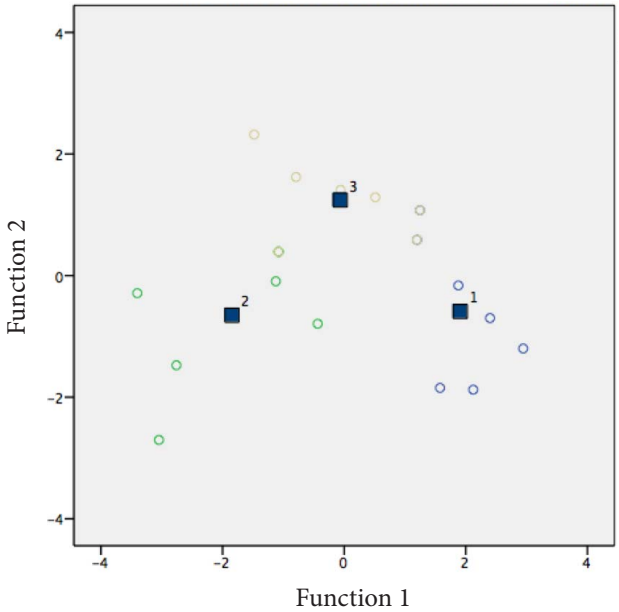

Fig. 1. Canonical discriminant functions. Graphic representation of classification results of the level of proficiency in exercises of boys aged 8: ▪ – centroids for data groups after 1 – 6 repetitions, 2 – 12 repetitions, 3 – 18 repetitions

as a detailed impact of the teaching modes on the level of proficiency in each exercise.

The data obtained supplement the information on the factors that influence the effectiveness of motor skills development (Afrouzeh et al., 2020; Khudolii, 2019; Hastie et al., 2019); confirm the information that the conditions for motor skills development are one of the factors that determine the effectiveness of schoolchildren's learning (Ivashchenko, 2020; Ivashchenko et al., 2019; Kapkan et al., 2019a). In addition, the study supplemented the data on the use of a discriminant function in the classification of schoolchildren by motor activity (Milić et al., 2011; Gert-Jan de Bruijn, & Benjamin Gardner, 2011; Lulzim, 2013). As in the papers by Geoffrey D. Broadhead and Gabie E. Church (1982), Kapkan et al. (2019a), Ivashchenko (2020), Ivashchenko et al. (2019), the study observed a high discriminative and prognostic ability of the obtained functions in assessing motor skills development in children and adolescents.

Discriminant analysis makes it possible to obtain new data to monitor the process of motor skills development in primary schoolchildren and supplements the information on the methods of assessing motor skills in children (Klingberg et al., 2019; Lovric et al., 2019; Nobre et al., 2020).

Based on discriminant analysis, it can be argued that to teach the five exercises, the mode of 6 repetitions (3 sets two times) with a 60-second rest interval may be recommended; for more difficult exercises — the mode of 18 repetitions (9 sets two times) with a 60-second rest interval. Based on the analysis of structure coefficients and centroids of functions, the mode of 18 repetitions (9 sets two times) with a 60-second rest interval may be recommended for the exercise "Throwing a ball at a 3 m distant target".

Conclusions

Discriminant analysis made it possible to determine the impact of the number of repetitions on the effectiveness of developing the skills of throwing a small ball at a target; answer the question as to how significantly the modes of repetitions differ by the effectiveness of motor skills development, what class the object belongs to based on the values of discriminant variables.

Based on the analysis of group centroids, it was found that in boys aged 8, six repetitions of the exercise (6 sets one time with a rest interval of 60 s) have the greatest total impact on the increase in the level of proficiency in exercises during physical education lessons. The results of group classification show that 85.7% of the original grouped observations were classified correctly.

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Conflict of interests

The authors state that there is no conflict of interest.

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РОЗПІЗНАННЯ ОБРАЗІВ: ВПЛИВ РЕЖИМІВ ВИКОНАННЯ ВПРАВ НА ФОРМУВАННЯ НАВИЧКИ МЕТАННЯ МАЛОГО М'ЯЧА ХЛОПЧИКІВ 8 РОКІВ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 8 с., 1 рис., 7 табл., 32 джерела.

Мета дослідження – визначити вплив режимів виконання вправ на формування навички метання малого м'яча хлопчиків 8 років.

Матеріали і методи. У дослідженні прийняли участь 21 хлопчик 8 років, які були розділені на три групи по 7 осіб у випадковому порядку. Діти та їхні батьки були інформовані про всі особливості дослідження і дали згоду на участь в експерименті.

Досліджувався вплив кількості повторень на ефективність процесу навчання метанню малого м'яча в ціль у хлопчиків 8 років. У педагогічному експерименті вивчався вплив 6, 12 і 18 повторень з інтервалом відпочинку 60 с на приріст рівня навченості вправ хлопчиків 8 років. У першій групі хлопчики повторювали завдання 6 разів з інтервалом відпочинку 60 с, у другій групі – 12 разів з інтервалом відпочинку 60 с, у третій групі 18 раз з інтервалом відпочинку 60 с. У процесі навчання кидкових вправ у занятті оцінювався альтернативним методом рівень навчености («виконав», «не виконав»), розраховувалася вірогідність виконання вправи ($p = n/m$, де n – кількість успішно виконаних спроб, m – загальна кількість спроб). У навчанні хлопчиків 8 років використовувався метод алгоритмічних розпоряджень. Перехід до наступної вправи здійснювався після трьох успішних спроб. Вивчалися метання м'яча у вертикальну ціль.

Матеріали дослідження опрацьовані в програмі статистичного аналізу – IBM SPSS 20. У процесі дискримінантного аналізу була створена прогностична модель для належності до групи.

Результати. Дискримінантний аналіз дозволив визначити вплив кількості повторень на ефективність формування навичок метання малого м'яча в ціль; дати відповідь на питання наскільки достовірно різняться режими повторення за результативністю формування рухових навичок, до якого класу належить об'єкт на основі значень дискримінантних змінних.

Висновки. На основі аналізу центроїдів груп визначено, що у хлопчиків 8 років 6 повторень вправи (6 підходів по 1 разу з інтервалом відпочинку 60 с) мають суттєвий вплив на приріст рівня навченості на уроках фізичної культури. Результати класифікації груп показують, що 85,7% вихідних згрупованих спостережень класифіковано вірно.

Ключові слова: хлопчики 8 років, метання м'яча, дискримінантна функція.

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ORIGINAL SCIENTIFIC ARTICLE

EFFECTIVENESS OF USING ACTIVE GAMES FOR STRENGTH DEVELOPMENT IN 10-YEAR-OLD BOYS AT THE INITIAL TRAINING STAGE IN KYOKUSHIN KARATE

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Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

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Abstract

The objective of the study was to examine the level of strength fitness indicators of 10-year-old boys who do Kyokushin Karate, and experimentally test the effectiveness of the impact of play techniques on the dynamics of strength development.

Materials and methods. The study involved 40 10-year-old boys. The children and their parents were informed about all the features of the study and gave their consent to participate in the experiment. To achieve the objective set, the following research methods were used: analysis of scientific and methodological literature, pedagogical testing, and methods of mathematical statistics for processing research results.

Results. There were the biggest changes in the results of the tests "Standing long jump" by 15.9% ($p < 0.001$), "Sit-ups in 30 s" by 16.0% ($p < 0.001$), "Pull-ups" by 18.3% ($p < 0.001$), and "Bent arm hang" by 15.6% ($p < 0.001$). The experimental group boys' result of the "Standing long jump" changed from low to above average. The lowest increase in results was observed in the "Right hand grip test" by 7.2% ($p < 0.001$), "Left hand grip test" by 6.9% ($p < 0.001$), and "Push-ups" by 11.8% ($p < 0.001$).

Conclusions. The initial level of the boys' strength fitness is sufficient and conforms to age norms. Most of them had an average – 30.36%, an above average – 19.64%, and a high – 23.21% level of strength abilities development. The data obtained give reason to recommend that teachers and coaches use active games aimed at developing strength. As a result of using play load (5 games, 3 repetitions with rest intervals of 40 s), there was a statistically significant increase in strength indicators ($p < 0.001$).

Keywords: boys, strength abilities, active games, play load, Kyokushin Karate.

Introduction

Martial arts have a special educational potential in developing positive models of behavior and moral values that can help reduce aggression in society (Augustovicova, Argajova, Rupcik, & Thomson, 2020; Cynarski, 2019; Cynarski & Niewczas, 2019). Kotarska, Nowak, Szark-Eckardt and Nowak (2019), Greco, Fischetti, Cataldi, and Latino (2019) found a positive correlation between martial arts, especially if they are practiced at a competition level, and healthy behaviors and a higher level of quality of life self-assessment.

Researchers have long proven the great potential of using a play-based approach in physical education (Khudolii & Marchenko, 2007; Marchenko, 2008, 2010; Nikitenkova & Marchenko 2017) and sport training (Korotkov, 1971; Alabin, Strashinskiy, Solovtsov, & Gavrilov, 1992; Slastina, Kravchuk, & Bybel, 2019). Active games and play-based exercises are increasingly used as some of the effective tools in the training process for comprehensive improvement of motor abilities in various sports.

Since active games are a mixed (cyclic and acyclic) activity, it is mainly dynamic, speed and strength in nature. Such actions as moving on the tatami, performing various kicks, defensive actions against an opponent's attack require a significant development of such a physical quality as strength.

The content of practical material during training depends on the tasks to be solved. When the task is to develop strength, it is useful to include in classes additional and preliminary games associated with short-term speed and strength efforts and various forms of overcoming an opponent's muscular resistance in a direct combat. The main content components of such games include various kinds of pulling, pressing, holding, pushing, elements of wrestling, etc. Motor operations with weights appro-

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priate for players, bending, squatting, arm bending and extending, rotating, turning, running, or jumping are very effective for solving this task (Meshcheryakov & Tashnichenko, 2010).

A sufficient level of strength fitness is the foundation for mastering a technique, and the means of its development occupy a central place in programs of teaching motor actions (Di Palma & Cusano, 2020; Marchenko & Kovalenko, 2020). Strength training is also seen as a basis for developing other motor abilities (Khudolii, Ivashchenko, Iermakov, Veremeenko, & Lopatiev, 2020; Khudolii, Kapkan, Harkusha, Marchenko, & Veremeenko, 2020; Khudolii, Ivashchenko, Iermakov, Nosko & Marchenko, 2019). Strength abilities development is most effective with an overall development of all muscle groups, so games should be diverse (Marchenko & Ishchenko, 2016; Nikitenkova & Marchenko, 2017; Do Kim & Pieter, 2020). According to Marchenko and Ishchenko (2016), significant increases in strength indicators of primary-school-age boys can be observed with a rational organization of strength training. Nikitenkova and Marchenko (2017) recommend the use of small weights and play-based exercises using one's body weight. Games should be performed at a fast and moderate pace. The number of games may vary from 4 to 8 depending on age, gender, level of physical development and physical fitness of pupils.

Unfortunately, today there is not enough literature to cover the issues described above regarding the use of active games and play-based exercises at the initial training stage in Kyokushin Karate. Most studies address issues related to high performance sport. Therefore, the issue of search and effective use of play techniques for strength development in 10-year-old boys who do Kyokushin Karate is relevant.

The objective of the study was to examine the level of strength fitness indicators of 10-year-old boys who do Kyokushin Karate, and experimentally test the effectiveness of the impact of play techniques on the dynamics of strength development.

Materials and methods

Study participants

The study involved 40 10-year-old boys who do Kyokushin Karate. The boys were randomly divided into two groups, an experimental group (n = 20) and a control group (n = 20). The children and their parents were informed about all the features of the study and gave their consent to participate in the experiment.

Study organization

To achieve the objective set, the following research methods were used: analysis of scientific and methodological literature, pedagogical testing, and methods of mathematical statistics for processing research results.

The testing program included well-known tests: Standing long jump, Right and left hand grip test, Push-ups, Sit-ups in 30 s, Pull-ups, Bent arm hang (Khudolii, 2019; Ivashchenko, 2020).

In the experimental group, during classes, the play material and loads proposed by Marchenko (2003, 2008) were used. Games for strength abilities development were conducted primarily at the beginning of the main part of the class. At the end of the main part, collective games with a predominant focus on developing strength endurance (Table 1) were used. Play load during the class included 5 games, number of repetitions – 3, rest intervals – 40 s.

Table 1. Organizational and methodological distribution of play means for strength abilities development in boys

No	Game	Participation in games		Predominant movements in the game				Physiological load					Place of the game during classes		
		Without division into teams	With division into teams	Running	Jumping	Throwing	Integrated actions	Low	Average	High	High	Maximal	Preparatory	Main	Closing
1	Carrying balls		+		+		+					+		+	
2	Move the bench		+				+				+			+	
3	Urgent cargo		+	+		+	+			+			+	+	
4	Who is stronger		+				+			+			+	+	
5	Wheelbarrow relay		+				+			+			+	+	
6	Relay with flags						+			+					
7	Wrestling in squares	+					+			+			+	+	
8	Forbidden circle	+					+			+			+	+	
9	Roll the ball		+				+			+			+	+	
10	Ball racing in rows	+			+		+			+			+	+	
11	Ball passing with feet	+		+			+			+			+	+	
12	Three's a crowd with resistance	+					+		+					+	+
13	Ball in the basket		+				+		+				+	+	
14	Flock of ducks	+					+		+				+	+	
15	Fight of roosters	+					+		+				+	+	
16	Break the circle	+					+		+				+	+	+

The subjects of the control group continued to attend traditional karate classes.

Statistical analysis

Data were collected and organized with EXCEL. Statistical analysis was performed using the IBM SPSS Statistics 26 statistical software package. The following parameters were calculated: arithmetic mean, standard deviation, arithmetic means were compared using the Student's t-test for dependent samples, Student's t-test for independent samples. The hypothesis about the normality of data distribution was determined using the Kolmogorov-Smirnov test.

Results

The ascertaining stage of the study (Table 2) revealed no statistically significant difference in any of the studied indicators of strength development between the experimental and control groups ($p > 0.05$). This meets the experiment requirements and indicates that the selected study sample fully meets the requirements of representativeness. It reproduces the characteristics of the general population and ensures the objectivity of conclusions of the performed pedagogical experiment.

The analysis of the obtained results at the beginning of the pedagogical experiment showed that the 10-year-old boys' strength abilities were sufficiently developed. Most of them had an average – 30.36%, an above average – 19.64%, and a high – 23.21% level of strength abilities development. 11.43% of the boys performed the set of tests at a low level, 15.36% – at a below average level. The best results were observed in the tests "Push-ups" (60%), "Pull-ups" (50%), and "Bent arm hang" (25%). The boys showed average and above average results in the tests "Right hand grip test" (42.5%, 27.5%), "Left hand grip test" (47.5%, 20%), and "Sit-ups in 30 s" (60%, 35%). Most children performed the test "Standing long jump", which characterizes speed and strength abilities, at low and below average levels (37.5%, 30%).

Thus, in general, the level of the boys' strength fitness conforms to age norms, and a considerable lag was found only in speed and strength fitness indicators.

The Kolmogorov-Smirnov test determined that the measurements for all characteristics in all the tests were nor-

Table 2. Statistical description of strength fitness indicators of the groups at the beginning of the experiment

Indicators under study	EG (n = 20)			CG (n = 20)			p
	Mean	Standard deviation	Standard error of mean	Mean	Standard deviation	Standard error of mean	
Standing long jump, cm	141.4	14.36	3.21	141.7	13.88	3.1	.947
Right hand grip test, kg	17.45	1.98	.44	17.4	1.98	.44	.937
Left hand grip test, kg	16.05	2.52	.56	15.95	2.23	.50	.895
Push-ups, times	26.35	7.60	1.7	26.55	7.67	1.71	.934
Sit-ups in 30 s, times	16.85	4.19	.94	16.65	4.18	.93	.881
Pull-ups, times	6.3	2.75	.61	6.25	2.63	.59	.954
Bent arm hang, s	18.68	10.11	2.26	18.73	10.12	2.26	.988

Table 3. Description of the impact of active games on strength development in 10-year-old boys

Indicators under study	Groups	Paired differences					t	Value (two-sided)	%
		Mean	Standard deviation	Standard error of mean	95% confidence interval for difference				
					Lower	Upper			
Standing long jump, cm	EG	22.5	6.848	1.531	25.705	19.295	14.69	.000	15.9
	CG	13.4	3.455	.773	15.017	11.783	17.34	.000	9.5
Right hand grip test, kg	EG	1.25	1.02	.228	1.727	.773	5.48	.000	7.2
	CG	.45	.887	.198	.865	.035	2.27	.035	2.6
Left hand grip test, kg	EG	1.1	.912	.204	1.527	.673	5.39	.000	6.9
	CG	.5	.761	.170	.856	.144	2.94	.008	3.1
Push-ups, times	EG	3.1	1.971	.441	4.022	2.178	7.03	.000	11.8
	CG	2.3	1.559	.349	3.03	1.57	6.59	.000	8.7
Sit-ups in 30 s, times	EG	2.7	.923	.206	3.132	2.268	13.07	.000	16.0
	CG	1.7	.865	.193	2.105	1.295	8.79	.000	10.2
Pull-ups, times	EG	1.15	.813	.182	-1.53	-.77	6.33	.000	18.3
	CG	.90	.641	.143	-1.20	-.60	6.28	.000	14.4
Bent arm hang, s	EG	2.92	1.619	.362	-3.678	-2.16	8.06	.000	15.6
	CG	1.83	.945	.2113	-2.275	-1.39	8.67	.000	9.8

mally distributed. So in this case, the use of the Student's t-test to compare paired samples is correct.

The results of a formative experiment investigating the effectiveness of using active games for strength abilities development in 10-year-old boys who do Kyokushin Karate are shown in Table 3.

A comprehensive control of the 10-year-old boys' strength fitness revealed statistically significant changes in all indicators in both groups ($p < 0.05$). There is a tendency for greater improvement of the results towards the experimental group.

There were the biggest changes in the results of the tests "Standing long jump" by 15.9% ($p < 0.001$), "Sit-ups in 30 s" by 16.0% ($p < 0.001$), "Pull-ups" by 18.3% ($p<0.001$), and "Bent arm hang" by 15.6% ($p < 0.001$). The experimental group boys' result of the "Standing long jump" changed from low to above average. The lowest increase in results was observed in the "Right hand grip test" by 7.2% ($p < 0.001$), "Left hand grip test" by 6.9% ($p < 0.001$), and "Push-ups" by 11.8% ($p < 0.001$).

Discussion

The study assumed that the use of specially selected active games could facilitate strength abilities development in 10-year-old boys who do Kyokushin Karate at the initial training stage. In the experimental group, the comparison of indicators showed a greater relative increase in all indicators than in the control group. The dynamics of results in all the exercises was statistically significant ($p < 0.001$).

The results obtained expand and supplement the data of Khudolii (2009), Ivashchenko and Yermakova (2015), Marchenko and Kovalenko (2020), Marchenko and Taranenko (2020) on the need for a sufficient level of children's strength fitness to improve the learning process and its importance for developing other motor abilities (Khudolii & Ivashchenko, 2014; Ivashchenko & Cieślicka, 2017; Khudolii, Ivashchenko, Iermakov, Nosko & Marchenko, 2019).

The study confirmed and verified the information on the effectiveness of using the load proposed by Marchenko (2008, 2010), Ivashchenko, Cieślicka, Khudolii and Iermakov (2014), Khudolii, Ivashchenko, Iermakov, Nosko and Marchenko (2019). It was found that for strength abilities development in 10-year-old boys it is optimal to perform 5 games, from 1 to 3 repetitions with rest intervals of 40 s.

Conclusions

Thus, active games are an important part of the training process in Kyokushin Karate. They contribute to an effective overall development of various muscle groups. The competitive nature of the game encourages all its participants to a greater manifestation of their abilities.

The initial level of the boys' strength fitness is sufficient and conforms to age norms. Most of them had an average – 30.36%, an above average – 19.64%, and a high – 23.21% level of strength abilities development.

The data obtained give reason to recommend that teachers and coaches use active games aimed at developing strength. As a result of using play load (5 games, 3 repetitions with rest intervals of 40 s), there was a statistically significant increase in strength indicators ($p < 0.001$).

Conflict of interest

The authors declare no conflict of interest.

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ЕФЕКТИВНІСТЬ ВИКОРИСТАННЯ РУХЛИВИХ ІГОР ДЛЯ РОЗВИТКУ СИЛИ У ХЛОПЦІВ 10 РОКІВ НА ЕТАПІ ПОЧАТКОВОЇ ПІДГОТОВКИ В КІОКУШИНКАЙ КАРАТЕ

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Авторський вклад: A – дизайн дослідження; B – збір даних; C – статаналіз; D – підготовка рукопису; E – збір коштів

Реферат. Стаття: 6 с., 3 табл., 28 джерела.

Мета дослідження – вивчити рівень показників силової підготовленості хлопців 10 років, які займаються кіокушинкай карате, та експериментально перевірити ефективність впливу ігрових засобів на динаміку розвитку сили.

Матеріали і методи. У дослідженні взяли участь 40 хлопців 10 років. Діти та їхні батьки були інформовані про всі особливості дослідження і дали згоду на участь в експерименті. Для вирішення поставлених завдань були

застосовані такі методи дослідження: аналіз науково-методичної літератури, педагогічне тестування та методи математичної статистики обробки результатів дослідження.

Результати. Найбільші зміни відбулися за показниками тестів «Стрибок у довжину з місця» на 15,9% ($p < 0,001$), «З положення лежачи на спині піднімання в сід за 30 с» на 16,0% ($p < 0,001$), «Згинання і розгинання рук у висі» на 18,3% ($p < 0,001$) та «Вис на зігнутих руках» на 15,6% ($p < 0,001$). У хлопців експериментальної групи результат «Стрибка у довжину з місця» змінився з низького рівня до вище середнього. Найнижчий приріст результатів спостерігався у тестах «Кистьова динамометрія правої руки» на 7,2% ($p < 0,001$), «Кистьова динамометрія лівої руки» на 6,9% ($p < 0,001$) та «Згинання і розгинання рук в упорі лежачи» на 11,8% ($p < 0,001$).

Висновки. Початковий рівень силової підготовленості хлопців достатній та відповідає віковим нормам. Більшість із них мали середній – 30,36%, вище середнього – 19,64% та високий – 23,21% рівні розвитку силових здібностей. Отримані дані дають підставу рекомендувати вчителям і тренерам використовувати рухливі ігри спрямовані на розвиток сили. У результаті застосування ігрового навантаження (5 ігор, 3 повторення з інтервалами відпочинку 40 с) відбулося статистично достовірне зростання силових показників ($p < 0,001$).

Ключові слова: хлопці, силові здібності, рухливі ігри, ігрове навантаження, кіокушинкай карате.

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ORIGINAL SCIENTIFIC ARTICLE

SHARE OF STRENGTH PARAMETERS OF BENCH PRESS AND BARBELL BENCH PULL ON A HORIZONTAL BENCH IN SPORTS PERFORMANCE IN KAYAK DISCIPLINES

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Abstract

The objective of the study was to deal with the ratio of the parameters of maximum muscle power and power endurance and explain their contribution to the sports performance in kayak disciplines of Slovakia National Team members.

Material and methods. Strength parameters were monitored by Tendo Power Analyser in the barbell bench press and pull on a horizontal bench. A diagnostic series of maximum power and effective repetition test for power endurance was performed at both, barbell bench press and bench pull exercises. Determining the factors limiting sports performance in kayak disciplines 200 meters, 500 meters, 1,000 meters, 5,000 meters, and marathon 21,500 meters, the evaluation of dependence between all power variables were used. The stepwise regression was used to reduce the indicators.

Results. It was found out that in kayak sprint disciplines (200 meters, 500 meters) the sports performance in the kayak is influenced by the barbell bench pull more than bench press on the horizontal bench when speaking about the strength parameters. In the middle-distance disciplines (1,000 meters), the ratio of strength parameters is balanced. As the length of kayak disciplines increases (5,000 meters and 21,500 meters), the ratio of strength parameters has changed in favor of the barbell bench press.

From the parameters of maximum muscle performance and muscle endurance measured in the barbell bench press and pull on a horizontal bench, the average power of power endurance was demonstrated to explain the sports performance in kayak disciplines.

Conclusion. From the parameters of maximum power and power endurance in the bench press and bench pull in all kayak disciplines, the parameter of average power in power endurance was proved to explain sports performance. Knowledge of these factors will allow optimizing the content of sports training of kayakers, the process of developing their strength skills, and their transformation process into a structure of sports performance and kayaking paddling technique.

Keywords: sports performance, kayak disciplines, stepwise regression, National Sports Center

Introduction

Sports disciplines in kayaking and canoeing are gaining more and more popularity (Akca & Muniruglu, 2008). Canoe Sprint is a traditional Olympic sport (Bielik et al., 2019) that belongs to one of the most successful sports in Slovakia and the Czech Republic, as evidenced by many gold, silver, and bronze medals from international competitions, Olympic Games, World Championships and Europe (McKean & Burkett, 2014). It is a water sport performed on calm stagnant or slightly flowing waters, whether they are natural or artificial (Plagenhoef, 1979). The goal is to overcome with the boat the distance in the shortest possible time. Races can be on two types of boats, first is canoe which is divided to C1, C2, C4 (depending on the number of competitors on the boat), and the second is the kayak which is divided to K1, K2, K4 (Schmidt, 1992; Doktor, 2001; Barton, 2002). In a canoe, the paddler kneels and uses a single-bladed paddle to propel the boat forward and in the kayak, the paddler is seated and uses a double-bladed paddle pulling the blade through the water on alternate sides to move forward (Baker, Rath, Sanders, Kelly, 1999; Sendelbeck & Schmid, 2016). Sprint canoe is the strength-endurance type of sport; however, this does not mean that it depends only on the strength and endurance abilities of the individual which fall into conditioning factors affecting sports performance (Lopata, 2014). In modern elite sports nowadays identification of the best training methods

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is used, which is useful for improving strategies during competitions. Such a strategy requires accurate measurements of biomechanical and physiological parameters affecting sports performance (Kendal, Sanders, 1992). Due to constant paddling, kayaking is considered demanding muscular activity consisting of cyclic and acyclic uneven movements (Stecenko, 1982, Vieira et al., 2015). Paddling requires proper technique and coordination of movement and muscles so that movement is economical and only the muscles necessary during paddling are involved (Bauer, 1988; Gagin, 1981). When paddling, the strength of the upper limbs is used, but the lower part of the body also contributes. Paddling itself can be further characterized as forward-pressure movements and backward-pulling movements (Borkovcová, 2005; Janura, Kratochvíl, Lehnert & Veverka, 2005). In kayaking, we distinguish disciplines of 200 m, 500 m, 1000 m, 5000 m, and marathon 21500 m (Grigorijev, Krasnopecev, 1972). Seating and support of the boat differ according to the discipline.

The objective of the study was to find the rate of the proportion of strength parameters measured in bench press and bench pull on the horizontal bench on explaining the sports performance in the kayak disciplines at 200 meters, 500 meters, 1000 meters, 5000 meters, and in the marathon 21500 meters. It was assumed, based on the previous studies, that the indicator of the average power of power endurance in the bench press will contribute the most to the explanation of sports performance in the kayak disciplines.

Material and methods

Study participants

The research sample consisted of representatives of the Slovak republic in kayaking N= 17, with average age M = 16.82 years SD = 0.89. The average body height of sample was M = 175.44 cm, SD = 23.19 and average body weight M = 84.62 kg, SD = 27.57 kg.

Study organization

The level of physical development, strength parameters, and sports performance is characterized by mean (M), standard deviation (SD), minimum (Min), maximum (Max) in Tables 1 and 2. The measurement of strength parameters took place in the Slovak National Sports Center. The best results in the kayak disciplines of 2019 were obtained from the documents of the Slovak Canoe Association.

Bench press and bench pull strength parameters were measured by the Tendo power analyzer. Tendo power analyzer measures average power and velocity, partial average power, peak power, velocity and force, eccentric average velocity, and rest time between reps or sets. In bench press and bench pull were performed diagnostic series of maximum power (weight of the barbell and average power) and test of effective repetitions for the power endurance (weight of the barbell, average power, number of repetitions). The weight of the barbell was the same in the bench press and bench pull.

Table 2 Sports performance of the monitored group in kayak disciplines

Kayak disciplines	M	SD	Max	Min
200 m [s]	41.12	1.74	43.87	38.16
500 m [min]	1:55.28	0:03.57	2:01.84	1:48.96
1000 m [min]	4:04.93	0:04.88	4:12.55	3:58.00
5000 m [min]	23:04.15	0:58.52	25:39.30	21:50.03
21500 m [h]	1:47:28	0:05:19	1:55:01	1:40:48

Statistical analysis

When defining the limiting factors of sports performance in kayak discipline, the base is on the evaluation of dependence between every strength parameter. Step regression analysis was used for the reduction of indicators and the elimination of multicollinearity. This technique has used the method Backward, which is characterized by the gradual separation of variables from the total set in the regression function. These are back-tested to see if they statistically affect the quality of the regression model. Dependency (Pearson correlation coefficient r) and share (βeta*r) of individual factors were determined by the correlation and regression analysis. From the regression parameters, we present the determinant of multiple correlation (R2) and the significance of the model (F). Effect size is measured by Cohen´s d and f2 (Cohen, 1998). Statistical significance is assessed on two significance levels $p<0.05$ and $p<0.01$ and effect size on 0.02 = small; 0.15 = medium; 0.35 = large effect. Empirical data were processed and evaluated in MS Excel and SPSS.

Results

When verifying the hypothesis, it was assumed that the indicator of the average power on the bench will contribute most to the explanation of sports performance in kayak discipline on 200 meters, 500 meters, 1000 meters 5000 meters and in marathon 21500 meters. To verify this hypothesis, technique of correlation, regression, and step analysis were used.

By the correlation analysis between parameters of strength in bench press and bench pull on the horizontal bench with the sports performance, the interactions were proven to a minimal extent. The strength parameters of the

Table 1 Comparison of the level of strength parameters in bench press and bench pull on the horizontal bench

Tendo Power Analyzer		Bench press		Bench pull		t-test	p	d
		M	SD	M	SD			
Maximum power	Barbell weight [kg]	58.235	5.847	61.471	6.063	2.184	0.044	0.543
	Average power [W]	538.647	55.913	654.118	76.587	9.608	0.000	1.722
Power endurance	Barbell weight [kg]	58.235	5.847	61.176	6.002	2.184	0.044	0.543
	Average power [W]	486.294	39.352	571.873	57.952	7.491	0.000	1.728
	Repetitions [n]	8.176	2.378	6.941	3.132	1.558	0.139	0.444

Table 3. Correlations of strength parameters in bench press and bench pull on horizontal bench with the sports performance in kayak disciplines ($p < 0.05$*; $p < 0.01$**)

Indicator			200 m	500 m	1000 m	5000 m	21500 m
Bench press	Maximum power	Barbell weight [kg]	-0.166	-0.345	-0.200	-0.011	-0.374
		Average power [W]	-0.141	-0.250	-0.043	0.143	-0.351
	Power endurance	Barbell weight [kg]	-0.166	-0.345	-0.200	-0.011	-0.374
		Average power [W]	-0.301	-0.401	-0.160	0.255	-0.218
		Repetitions [n]	-0.220	-0.021	-0.223	0.110	-0.117
Bench pull	Maximum power	Barbell weight [kg]	-0.034	-0.188	0.142	-0.029	-0.023
		Average power [W]	-0.211	-0.186	-0.059	-0.038	-0.234
	Power endurance	Barbell weight [kg]	-0.106	-0.230	0.118	-0.164	-0.067
		Average power [W]	-0.505*	-0.493*	-0.196	-0.059	-0.231
		Repetitions [n]	0.229	0.313	-0.212	0.160	-0.022

bench press did not show any statistically significant relations with sports performance in ani kayak discipline. From the bench pull parameters on the horizontal bench were statistically significant interactions of the average power of power endurance (W) to the sprint disciplines on 200 m $r(17) = -0.505$; $p < 0.05$ and to 500 m $r(17) = -0.493$, $p < 0.05$. Other remaining interactions between the strength parameters and sports performance were not statistically significant (Tab. 3).

Another technique used to determine the proportions of factors limiting sports performance was the multiple regression analysis of all strength parameters individually in bench press and bench pull on the horizontal bench. The multiples of the βeta correlation coefficients and the correlation coefficients "r" were calculated the partial shares (Tab. 4) to the sports performance. The highest contribution to the explanation of sports performance in the discipline of kayaking at 200 meters has the bench pull (38%) before the bench press (10.1%). From the parameters of power endurance in bench pull are important parameters of the average power 25.3%, the number of repetitions 7.7%, and maximum power 5.2%.

Same in 500 meters kayaking, the bench pull (30.9%) is over that bench press (25.0%). From the bench pull parameters, it is represented by power endurance (19.4%) and by numbers of repetitions (11.1%). In the bench press, key parameters are the weight of the barbell (11.5%), maximum power (6.4%), and average power (6.8%). The share of strength parameters in 1000 meters kayaking is similar (12.0% and 11.8%). In both cases "press vs. pull" are key parameters of the weight of the barbell (7.1% and 5.0%), numbers of repetitions (3.9% and 3.3%), and average power in the power endurance (1.1% and 3.1%). As the length of the kayak disciplines increases, the proportion of strength parameters changes in favor of the strength parameters at the bench press over the bench pull (5000 meters: 17.9% <> 5.5%; 21500 m: 36.6% <> 1.3%). In the discipline of 5000 meters kayaking, key parameters are the average power endurance (11.3%) and maximum power performance (5.9%). In marathon discipline (21500 meters) are important parameters of barbell weight (17.6%) and average maximum power (14.5%). It shows that in the sprint disciplines of kayaking (200 meters and 500 meters) the highest share on the sports performance has the strength parameters in bench pull before the bench press on the horizontal bench. In the medium distances (1000 meters) is the share of bench press and bench pull parameters equal. As the length of the kayak disciplines increases (5000 meters and 21500 meters), the proportion of strength parameters changes in favor of parameters of strength in the bench press.

When identification of limiting factors of sports performance in kayak disciplines, the reduction of indicators of all strength parameters individually in bench press and bench pull on a horizontal bench are used. For the reduction of indicators, the stepwise regression analysis was used. Mostly in all kayak disciplines, the parameter of average power in power endurance (Tab. 5) in the bench press and bench pull has the greatest information power.

In the complex reduction of strength parameters in the bench press and bench pull, the previous findings have been confirmed. In sprint disciplines, the parameters of bench pull

Table 4. Partial shares of strength parameters in bench press and bench pull on horizontal bench on the sports performance in kayak disciplines (βeta*r)

Indicator		Maximum power		Power endurance		
		Barbell weight[kg]	Average power [W]	Average power[W]	Repetitions [n]	R^2
200 m	Bench Press	0.033	-0.007	0.002	0.072	0.101
	Bench Pull	-0.002	0.052	0.253	0.077	0.308
500 m	Bench Press	0.115	0.064	0.068	0.003	0.250
	Bench Pull	0.005	-0.002	0.194	0.111	0.309
1000 m	Bench Press	0.071	0.000	0.011	0.039	0.120
	Bench Pull	0.050	0.004	0.031	0.033	0.118
5000 m	Bench Press	0.000	0.059	0.113	0.007	0.179
	Bench Pull	0.001	0.013	0.019	0.022	0.055
21500 m	Bench Press	0.176	0.145	0.027	0.014	0.363
	Bench Pull	-0.004	-0.019	0.036	0.000	0.013

Table 5. Step regression of strength parameters in bench press and bench pull to sports performance in kayak disciplines (βeta*r)

Indicator		Maximum power		Power endurance			F	sig	R^2	f^2
		Barbell weigth	Average power	Barbell weight	Average power	Repetitions				
200 m	Bench Press	-	-	-	0.090	-	1.499	0.240	0.091	0.100
	Bench Pull	-0.028	-	-	0.405	0.141	4.792	0.018	0.065	0.070
500 m	Bench Press	-	-	-	0.209	-	2.871	0.111	0.161	0.191
	Bench Pull	-	-	-	-0.154	-	4.827	0.044	0.287	0.402
1000 m	Bench Press	-	-	-	0.065	-	0.785	0.390	0.050	0.052
	Bench Pull	-	-	-	0.039	-	0.601	0.450	0.039	0.040
5000 m	Bench Press	-	-	-	0.065	-	1.043	0.323	0.065	0.070
	Bench Pull	-0.116	-0.017	0.712	-	-	6.274	0.007	0.598	1.486
21500 m	Bench Press	-	-	0.147	-	-	2.444	0.139	0.140	0.163
	Bench Pull	-	-	-	0.053	-	0.843	0.373	0.053	0.056

Table 6. Step regression of all strength parameters to sports performance in kayak disciplines (βeta*r)

Indicator		Maximum power		Power endurance			F	Sig	R^2	f^2
		Barbell weight	Average power	Barbell weigth	Average power	Repetitions				
200 m	Bench Pull	-	-	-0.020	0.405	0.141	4.789	0.018	0.525	1.105
500 m	Bench Pull	-	-	-	0.243	-	4.823	0.044	0.243	0.322
1000 m	Bench Pull	-	-	-	-	0.045	0.707	0.414	0.045	0.047
5000 m	Bench Press	-	-	-	0.065	-	1.043	0.323	0.065	0.070
21500 m	Bench Press	0.140	-	-	-	-	2.444	0.139	0.140	0.163

are statistically significant. In the endurance disciplines, the parameters of the bench press proved to be statistically significant.

In 200 meters, the greatest share on the sports performance has the average power (40.5%) and the numbers of repetitions in the power endurance (14.1%). A high share of average power in power endurance (24.3%) is recorded in 500 meters kayaking discipline. The significance of parameters to the sports performance was confirmed in both cases statistically ($p < 0.05$) with the effect size $f2 > 0.3$. In endurance kayak disciplines, the results are ambiguous according to their statistical significance. A factor of effective repetitions in power endurance in bench pull (4.5%) was measured in 1000 meters kayaking. The bench press is the limiting factor in the endurance kayak disciplines in 5000 meters (average power in power endurance 6.5%) and in 21500 meters (barbell weight 14.0%).

Discussion

This study aimed to compare the strength parameters measured in bench press and bench pull in the horizontal bench on the explanation of the sports performance in kayak disciplines in 200 meters, 500 meters, 1000 meters, 5000 meters, and in marathon 21500 meters (Endicott, 1995; Potočný, 1985). Data were recorded through the Tendo power analyzer. This study shows that the parameter of average power in power endurance (Strnadová, 2004) in the bench press and bench pull, has a great impact on the sports performance in kayak disciplines. Interactions of sports performance and strength parameters in the bench press did not prove to be statistically significant. Interactions of sports performance and strength parameters in bench pull were significant in the average power of power endurance in 200 meters and 500 meters. Sports performance partial shares in kayak disciplines determine limiting factors. In the discipline of 200 meters, have the highest share on the sports performance the bench pull parameters (power endurance in average power, numbers of repetitions, and maximum power). Similarly, in the 500 meters discipline the bench pull was a key determinant in parameters of power endurance and numbers of repetitions. In the bench press, the important determinants were the barbell weight, maximum power, and average power (Bílý et al., 2000). In the 1000 meters discipline, the parameters of barbell weight, numbers of repetitions, and average power in power endurance prevailed. The share of strength parameters in the bench press and bench pull is equal (Joachimsthaler, 1967; Rodano, Squadrone, Sacchi, & Marzegan, 2001). The average power endurance and maximum power in the bench press were key determinants in 5000 meters long discipline. In kayaking marathon (21500 meters) prevailed parameters of barbell weight and average maximum power measured in the bench press (Janura, Kubu, Kratochvíl & Stromšík, 2000). According to continuous measurements, performance in the kayak discipline is greatly influenced by the technique (Bauer, 1988; Fučíková, 2003). According to Janura et al. (2000), an effective technique can be described as a symmetrical range of movement of both hands, minimal torso movement in the anteroposterior direction, and greater arm rotation, which author calls mechanical skill. Doktor (2001) and Schmidt analyze in their work the paddling techniques. Strnadová (2004) discussed the importance of muscle involvement. On the sports performance in sprint kayak disciplines (200 meters and 500 meters) the strength parameters in bench pull on the horizontal bench are statistically important (Szanto, 1991, 2004; Šebesta & Podlucký, 2002). The proportion of power in the bench press and bench power is balanced in the medium distance discipline (1000 meters). With the increasing length of kayak disciplines (5000 meters

and 21500 meters), the proportion of strength parameters varies in favor of power in the bench pull (Sanders, 1998).

Conclusion

The used approach allowed pay attention to the strength parameters, which provide the essential information to an explanation of sports performance in kayak disciplines. It shows that in the sprint disciplines (200 meters and 500 meters) has a greater impact on the sports performance strength parameters measured in bench pull than in the bench press. In middle distance discipline (1000 meters) the share of power in bench press and bench pull is balanced. With the increasing length of kayak discipline (5000 meters and 21500 meters), the proportion of strength parameters varies in favor of power in the bench press. From the parameters of maximum power and power endurance in bench press and bench pull in all kayak disciplines the parameter of average power in power endurance was proved to explain sports performance. Knowledge of these factors will allow optimizing the content of sports training of kayakers, the process of developing their strength skills, and their transformation process into a structure of sports performance and kayaking paddling technique.

Conflict of Interest

The authors declare that there is no conflict of interest.

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ЧАСТКА СИЛОВИХ ПАРАМЕТРІВ ЖИМУ ЛЕЖАЧИ ТА ТЯГИ ШТАНГИ НА ГОРИЗОНТАЛЬНІЙ ЛАВІ У СПОРТИВНИХ ПОКАЗНИКАХ У ДИСЦИПЛІНАХ ВЕСЛУВАННЯ НА БАЙДАРКАХ

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Метою дослідження було розглянути співвідношення параметрів максимальної м'язової сили та силової витривалості та пояснити їхній внесок у спортивні показники у дисциплінах веслування на байдарках членів національної збірної Словаччини.

Матеріал і методи. Силові параметри контролювали за допомогою Tendo Power Analyzer у жимі штанги та тяги на горизонтальній лаві. Діагностична серія тестів максимальної потужності і ефективних повторень на силову витривалість була проведена як у вправах на жим штанги лежачи, так і у вправах на тягу лежачи. Для визначення факторів, що обмежують спортивні показники в дисциплінах веслування на байдарках 200 метрів, 500 метрів, 1000 метрів, 5000 метрів та марафоні 21 500 метрів, використовували оцінку залежності між усіма силовими змінними. Для зменшення показників використовувалася покрокова регресія.

Результати. Було виявлено, що у дисциплінах спринтерського веслування на байдарках (200 метрів, 500 метрів) на спортивні показники впливає тяга штанги більше, ніж жим штанги на горизонтальній лаві. У дисциплінах на середні дистанції (1000 метрів) співвідношення параметрів сили виважене. Зі збільшенням довжини дисциплін у веслуванні на байдарках (5000 метрів та 21 500 метрів) співвідношення параметрів сили змінилося на користь жиму штанги.

На основі параметрів максимальної м'язової продуктивності та м'язової витривалості, виміряних у жимі штанги та тязі на горизонтальній лаві, була використана середня потужність силової витривалості для пояснення спортивних результатів у дисциплінах веслування на байдарках.

Висновки. Аналіз показників максимальної потужності та силової витривалості в жимі лежачи та тязі лежачи доводить, що у всіх дисциплінах веслування на байдарках параметр середньої потужності в силовій витривалості пояснює спортивні результати. Знання цих чинників дозволить оптимізувати зміст спортивної підготовки байдарочників, процес розвитку їх силових здібностей та процес їх трансформації в структуру спортивної діяльності та техніку веслування на байдарках.

Ключові слова: спортивні показники, дисципліни веслування на байдарках, покрокова регресія, Національний спортивний центр

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