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Anthropometrical, physiological and psychological characteristics among competitive rowers

Doctoral (Ph.D.) Thesis

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CHAPTER 1: INTRODUCTION

1.1. Introduction of the research topic

Rowing is a unique strength-endurance sport, which differs from other form of sport activities in many aspects. Firstly, rowers sit on a seat, facing opposite to the moving direction. Secondly, during rowing almost all muscle groups have to work, as the power produced by both the rowers' two limbs, trunk and arms (Shephard, 1998; Steinacker, 1993). Thus, in rowing complex coordination of movements is highly demanded. In contrast to other sports, such as running or cycling, the rower's two legs work in a synchronous way (Volianitis, Yoshiga & Secher, 2020). Furthermore, both static and dynamic exercise are important in the different phases of a rowing stroke (Penichet-Tomas et al., 2021; Secher, 1993). The metabolic cost to perform 2000m distance on a rowing ergometer was estimated to consist of 60-84% aerobic and 14-30% anaerobic contribution (Hagerman, 1984; Mäestu, Jürimäe & Jürimäe, 2005; Martin & Tomescu, 2017; Secher, 1983) and the energy needs from aerobic and anaerobic metabolism for a 2000 m on-water race was also reported (De Campos Mello et al., 2009). Biomechanics of rowing has already been widely studied (Baudouin & Hawkins, 2002; Kleshnev, 2002a; Yusof et al., 2020; Zatsiorsky & Yakunin, 1991). Because of the several peculiarities of this sport successful rowers have to possess specific features and aptitude to acquire outstanding rowing performance.

Nowadays it is getting even harder both for athletes and coaches to reach the best results in sport competitions. As several factors affect rowing performance, it is important to identify the most important ones. Knowing these parameters, talent identification can be enhanced and more specific selection assessments can be utilized (Akça, 2014). Furthermore, it is difficult to develop effective training programs, as athletes respond differently to the same training load, which can cause overtraining and staleness. By monitoring those parameters that influence rowing performance, more effective training plans could be concocted, with regard to each rower's physical and mental state (Mäestu, Jürimäe & Jürimäe, 2005).

The overall aim of the present study is to enhance the Hungarian rowing sport. Thus, the investigations presented in this study have searched those parameters that affect rowing performance and also have examined the extent of these factors' influence on performance utilizing statistical analysis. According to the results derived from these studies, development of talent identification methods for competitive rowing and construction of more effective training plans could be achieved.

1.2. Background and personal motivation

First of all, I consider it important to ascertain my strong personal motivation to search this topic. I have been devoted to rowing for many years and former in the junior category I took part both in national and international rowing competitions and reached quite good results. Unfortunately, I had to give up this sport at my young ages because of a serious illness. Recognizing that I can not complement to the success of Hungarian rowing as a rower I dedicated myself as a coach to bring Hungarian rowing into international level. Although a few Hungarian rowers took part successfully in international competitions (such as European or World Championships), the popularity of this sport discipline lags behind other sports in Hungary. As I am the head coach at the Rowing Division of Győri Athletic Club, I try to popularize this sport and develop talent identification method to select the most promising children at earlier ages, who may each even better results in the future. One of my colleagues, László Ficsor called my attention to the lack of information about Hungarian rowers' physical and psychological state. To fill this gap, Hungarian rowers had to be more thoroughly observed. Thus, various measurements were conducted and the collected data were analyzed to gain useful conclusions.

1.3. Objective of the Ph.D. study

The overall purpose of the present Ph.D. dissertation is to advance Hungarian rowing. In order to achieve this goal useful performance prediction model should be established, which may help the talent identification for rowing at early ages. For this reason, the physical and psychological parameters that influence rowing performance must be examined. Thus, extensive data acquisition and the analysis of the collected information are required. The differences in the anthropometric and physiological as well as psychological profiles of Hungarian rowers in various ages, rankings and different genders were widely examined, aiming to find the answer for the following questions listed below, which could contribute to the development of a rowing performance prediction model. The following hypotheses were investigated in the dissertation:

H1 We assume that the anthropometric characteristics are indeed dominant elements of the sport selection process.

H2 It is hypothesized that the estimated relative maximal aerobic capacity (e.r. VO2max) is the strongest predictor of rowing performance.

H3 It is assumed that strong relationship is obtainable between estimated relative maximal aerobic capacity (e.r. VO2max) and calculated relative power output (rW×kg-1).

H4 Psychological profile contributes significantly to better rowing performance.

1.4. Feasibility and significance of the study

In the literature, several studies can be found in connection with those factors that influence rowing performance, aiming to find the most important ones. As detailed below, it is challenging to predict on-water rowing performance, because it depends not only on the rower's abilities and features but also on external circumstances. Data from samples of both male and female rowers from different nationalities of various ages and rankings were collected and evaluated using statistical methods aiming to establish rowing performance prediction models. However, such investigation on Hungarian rowers is absent from the literature until this study, although these measurements could help Hungarian coaches to improve training plans and the selection process of successful rowers. It is clear, that such a study is highly required, which emphasizes the importance of the present study.

1.5. Study overview

After the Introduction part, in Chapter 2 a brief summary of the knowledge on rowing is presented. Firstly, it is important to clarify the general information about rowing, aiming to reach not only the attention of rowing professionals (like coaches and athletes), but also those, who may know less about this sport. Then, a short historical overview is followed by the presentation of the International Rowing Federation and the types of rowing races. As the main purpose of the present study is to move forward Hungarian rowing sport, thus the most outstanding domestic rowing results are also discussed. Furthermore, the anthropometric and physiological measurements and the relation of these factors to rowing performance according to the former research are also summarized. Rowers have to possess specific psychological traits, thus this aspect of rowing has to be investigated. Hence, without aiming completeness, the knowledge of sport psychology and psychological aspect of rowing is overviewed in a nutshell. Later, the importance and difficulties of sport selection as well as its significant role in the world of rowing are emphasized.

In Chapter 3 the methodology of this study is demonstrated, by showing the process of data collection and the short description of the utilized tests and measurements as well as the statistical analysis used within the framework of the selected and presented examinations.

Keeping in mind the goals of the Ph.D. study, own articles – obtained together with my colleagues from our research group – that were published in prestigious national or international journals and deal with the above-listed hypotheses were chosen to be presented in this doctoral thesis.

Chapter 4 includes an extensive investigation (Study 1) of young Hungarian elite male and female rowers. Anthropometric data of 245 rowers were collected, relative maximal oxygen uptake was calculated, the rowing ergometer performance on different distances was examined and the correlations were evaluated using stepwise multiple regression.

Study 2 on Hungarian male rowers in Chapter 5 presents the differences between three age categories and elite or non-elite rankings while emphasizing the importance and difficulty of the selection for rowing. Among several anthropometric and physiological characteristics, relative body fat content was also estimated with the procedure by Pařízková, based on the measurement of skinfolds. Furthermore, the participants were asked to perform countermovement jump on a force plate as well as 2000 m all-out ergometer test. Dealing with question 3, Hungarian rowers characteristics were compared to the results of such measurements of Polish and Croatian rowers.

Further investigating those factors that can predict rowing performance the most effectively, anthropometric and physiological characteristics of 15 Hungarian male junior rowers were measured in Chapter 6 (Study 3) and the most significant predictors were selected in regression equations.

Chapter 7 (Study 4) focuses on the differences obtained between the anthropometric and physiological characteristics of Hungarian male and female rowers of different ages. Data from 130 men and 70 women were classified into three age categories (junior, older junior, senior). Several parameters were measured, and the differences between genders and age categories were analyzed.

Study 5 in Chapter 8 investigates the role of psychological profiles. Although former examinations and the above-mentioned studies also pointed out the importance of physical characteristics on rowing performance, in competitive sports the athlete’s mental state can also contribute to better results. Hence, different psychological tests were applied to investigate the effect of psychological traits on rowing performance.

Finally, Chapter 9 summed up the Ph.D. research by reconsidering the findings and conclusions of each study.

CHAPTER 2: LITERATURE REVIEW

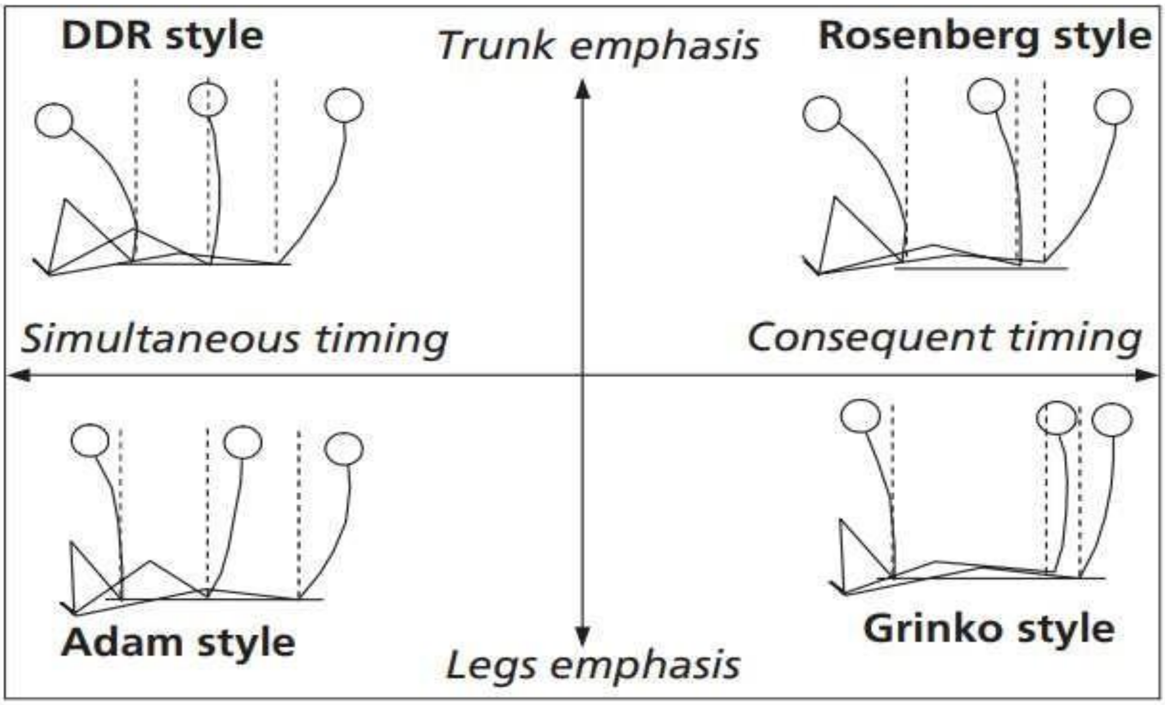
2.1. Rowing

In this section the means of competitive rowing, boat classes, the equipment, a short historical overview as well as the presentation of competitions and rowing organizations and the state of Hungarian rowing are all covered. This brief summary helps professionals and athletes receive knowledge about rowing, while introducing those, who are less familiar with this topic, but who are interested in, to the world of rowing.

2.1.1. Basic information about the sport

To clairvoyance, the term of ’rowing’ has two meanings; in one hand it refers to the movement of propulsion a boat by oars, on the other hand ’rowing’ is interpreted as an endurance sport. When it comes about ’rowing’ as a sport, there are two different means. ’Sweeping’ refers to the use of one oar, gripped with both hands, while in ’sculling’ the rower grasps two oars, one in each hand. Rowers sit in the opposite direction of forward moving. To carry out this sport, special equipment is required: a boat (commonly known as shells) and oars. Shells and oars were originally fabricated from wood, while nowadays mostly from composite material (fiberglass, carbon fiber and plastic) and the design of the boats improve continuously with technological innovations (Filter, 2019; Volianitis & Secher, 2009). The general parts of the shell are the following: a small fin at the bottom of the shell, which provides stability, furthermore may a rudder also attached to the fin (except on coxless sculling boats). The end of the shell is called the „stern”, while the opposite end (which reaches the finish first) is called the „bow”. For safety, a white ball is fixed on the bow. The rower sits on a seat (fitted with wheels), which rolls on slides, but rowing boats with fixed seat are also exist. The size of a boat depends on the boat class. A washboard hinders waves from splashing water into the boat. The oars are hollow in order to reduce their weight. There are different size and shapes of oars available (e.g. Macon, Cleaver, Square). Generally, the parts of an oar are the shaft, the sleeve, the button, the blade and the handle.

Figure 1. The four different rowing styles (N. H. Secher & Volianitis, 2009)



There are many different techniques to properly the boat effectively. Usually four rowing styles are distinguished: Adam, DDR, Grinko and Rosenberg style (Secher & Volianitis, 2009). The rowing stroke consists of four phases: (1) Catch: the blades are placed in water, (2) Drive: a forceful acceleration indicated by leg muscles, (3) Finish: the blades are taking out of the water and (4) Recovery: the preparation for the following stroke (Churbuck, 1988).

There are several boat classes in international rowing regattas, involving heavyweight and lightweight (L); male (M) and female (W); coxed (+) or coxless (-) categories in sculling (x) as well as in sweeping.

In lightweight categories the average body weight of the crew can not exceed 70 kg (for men) and 57 kg (for women).

Nowadays para-rowing gets increasing interest. This is a category for disabled rowers, which involves nine boat classes: PR3 - mixed coxed four, mixed double sculls, men's pair, women's pair; PR2 - mixed double sculls, men's single sculls, women's single sculls and PR1 - men's single sculls, women's single sculls.

Furthermore, the popularity of the extreme version of rowing – coastal rowing – is also growing. In coastal rowing wider hulls (called gigs) provide stability, which makes it easier to learn the technique of this type. Events usually take place in open water, basically in two formats: 4-to-6 kilometer races around multiple turning points (Coastal rowing), or short sprints (250-250 m) along the beach with a 180-degree turn, called Beach sprint. This type involves seven boat classes: single scull, double sculls, coxed quadruple sculls both for men and women and mixed double sculls (WorldRowing).

2.1.2. Historical overview

Water has always played an essential role in the lives of mankind, since there is no life without water. However, in many cases it set a barrier for people, as from time to time it was necessary to cross the rivers, lakes, seas and oceans. For this purpose, originally tree trunks were used, but later our ancestors fabricated special tools from wood: carved tree trunks were made to reach their destination across the water. Thus, rowing was initially a mean of transporting goods and people. The first trace of the appearance of a rowing boat dates back to 5800 BC in Finland, while larger boats were used by the Phoenicians around 3000 BC. Frescoes and inscriptions suggest that rowing was already present in Egypt in 2500 BC. Rowing appeared in the Greek, Roman, the Viking cultures. Roman emperors organized rowing races. The writer Virgil also mentioned rowing as a part of funeral games arranged by Aeneas. Later, in the Middle ages Italian carnivals in Venice often included rowing regattas. Records from the first rowing regatta comes from 1315, Venice, where gondoliers competed in their gondolas. Over time, the construction of the boats transformed, they became lighter and faster, and rowing has spread to other parts of the world. For example, rowing races have long-time traditions in Malta and Spain (Secher & Volianitis, 2009). Modern rowing sport developed in the 18th century as one of the oldest organized sport in England on the River Thames, where races were organized every year since 1714 (Doggett Coat and Badge boat race). One of the best-known race between Oxford and Cambridge Universities has been organized annually since 1829 (Dodd, Marks & Cleg, 2004; Ross, 1956). Another famous race, the Royal Henley Regatta has been held since 1839. In America the first recorded race was organized in 1756. However, organized rowing sport in the USA dates back to 1843, when Harvard and Yale Universities established their rowing clubs and from 1852 raced against each other. (Grinold, 1993; Lewis, 1970; Lewis, 1967). As rowing became more and more popular, many college teams formed and competed against each other, but amateur rowers in different ages also appeared. Further nations, among others Germany, Italy, Holland, Australia and Japan also contributed significantly to the improvement of race rowing (Secher & Volianitis, 2009). The world’s oldest public rowing club is Leander Rowing Club, founded in 1818 (Leander Club), and in the following years several clubs were established worldwide.

As rowing spread over the world, the need for regulations also appeared. Therefore, on June 25. 1892 delegates from France, Belgium, Switzerland, Italy and Austria – Hungary established the first amateur sport governing body, *Fédération Internationale des Sociétés d'Aviron* (World Rowing Federation, FISA) (Secher & Volianitis, 2009), and the race lengths, boat composition (Filter, 2019) and weight classes were controlled (WorldRowing).

2.1.3. Rowing as competitive sport

The distance of international rowing races are standardized at 2000 m (Secher, 1993), but short-distance (500 m, 1000m, 1500 m) competitions are also organized, as well as long-distance races (e. g. 4000m, 6000m, 10000m, 50 or 25 km). Depending on the number of the participants in a category, heat races, semifinals and finals are also organized.

Championships organized annually by FISA since 1893. World Rowing Championships started in 1962, then World Rowing Junior Championships for rowers under 18 in 1967. World Rowing Masters Regatta for rowers over 27 has been organized every year since 1973, while World Rowing Under 23 Championships since 1976. Later, World Rowing Cup started in 1997 and in the 2000s the palette has further broadened: World Rowing Sprints first took place in London in 2002. World Rowing Coastal Championships were introduced in 2006. Most recently the first World Rowing Beach Sprint Finals were held in 2019, in China. At the Summer Olympics rowing involved since 1900, as in 1896 the races were canceled because of bad weather conditions. Until the Olympic Games in 1976 only men were allowed to take part in rowing races, but then women’s events also appeared. Events in lightweight category were introduced in 1996, but this category will be organized at the Olympics probably only until 2024 and Coastal Rowing and Beach Sprint events will replace them in 2028.

Continental rowing confederations (African Rowing Federation, Americas Rowing Confederation, Oceania Rowing Confederation, European Rowing Confederation) are partners of World Rowing Federation and organize continental rowing competitions. The European national rowing federations are represented by the European Rowing Confederation, which organizes annually the European Rowing Championships, the European Rowing Under 23 Championships and the European Rowing Junior Championships (WorldRowing). Several further international and national competitions are held in many countries throughout the year, so it is in Hungary as well (Magyar Evezős Szövetség).

2.1.4. Rowing in Hungary

In Hungary many national races are organized annually under the supervision of the Hungarian Rowing Federation. One of the most important competitions is the Hungarian National Championship, usually organized in August. Although some quite excellent results have been reached, Hungarian rowing not as rich in success in international level as other nations. However, the greatest Hungarian successes are worth mentioning. Béla Szendey got the first gold medal in the European Championships in 1930, and then in every year at least one gold medal was awarded to us. In 1948 Antal Szendey, Béla Zsitnik and Rómert Zimonyi in coxed pair (M2+) reached the third place at the Olympics in Hungary, the Hungarian Rowing Federation is responsible for the organization of national competitions and participation in international races. In 1968 György Melis, György Sarlós, József Csermely, Antal Melis coxless four achieved the greatest result in the history of Hungarian rowing: silver medal at the Olympics. As women are concerned Jenő Papné must be mentioned, as she won the European Championships in single sculls four times in a row. Furthermore, many silver and bronze medal went to the Hungarians in these years. Mariann Ambrus is also a prominent person in Hungarian rowing, as she reached the second place in single sculls at the World Rowing Championship in 1975. Later, in 1989 Katalin Sarlós got the bronze medal in the World Rowing Championship. The 2000s brought further success, as in 2001 Ákos Haller and Tibor Pető became world champions in double sculls. In 2005 Zsolt Hirling and Tamás Varga also reached this title. Recently active rowers also accumulate success to success.

Figure 2. Bence Szabó, Kálmán Furkó LM2- ("Magyar Evezős Szövetség")

The two-time European champion, Péter Galambos has also won three bronze and two silver medals in the World Championships. Adrián Juhász and Béla Simon became world champions in coxed pair in 2017, while Bendegúz Pétervári-Molnár reached the 10th place in the Olympic Games in 2021. It is a great pride of mine that one of my rowers, Bence Szabó became European champion with his fellow, Kálmán Furkó. Moreover, Hungarian junior and U23 rowers achieve outstanding results in international events year after year, as well as para-rowers, for example Zsolt Pető (Magyar Evezős Szövetség).

2.2. Anthropometric and physiological aspects of rowing performance

Recently, rowing has become a much-loved sports activity both among amateur and elite level athletes in all age groups, regardless of gender, but its popularity still lags behind mass sports practiced by many people. Books, journal articles, reviews and other related literature is available in connection with rowing as many examinations have already been conducted on male and female, elite and amateur rowers from all age groups and several nationalities. This sport is defined as a cyclic, repetitive type of sport. The rower's movement consists of four phases, repeated continuously: the catch, drive, finishing and recovery phases (Secher, 1993). During a rowing stroke, $46.4 \pm 4.5\%$ of the power is generated from the legs, $30.9 \pm 5.2\%$ from the trunk and $22.7 \pm 5.2\%$ from the arms (Kleshnev, 2002b). This is a unique sport discipline, which requires both muscular strengths to achieve high power per each stroke, endurance to complete the whole 2000m distance, while sustaining this high power, as well as motoric (Sablic, Versic & Uljevic, 2021), technical (Buckeridge, Bull & Mcgregor, 2015; Holt et al., 2020; Sanderson & Martindale, 1986; Shaharudin & Agrawal, 2016; Soper & Hume, 2004) and tactical skills. Both preferential anthropometric (Adhikari, 2015; Akça, 2014; Barrett & Manning, 2004; Bourgois, 2000; Cerasola et al., 2020; Forjasz, 2011; Hebbelinck et al., 1980; Penichet-Tomas et al., 2021) and physiological (Hagerman, 1984; Messonnier et al., 1997; Mikulić, 2008; Secher & Volianitis, 2009; Steinacker, 1993; Steinacker et al., 1986; Volianitis & Secher, 2009) characteristics are important for successful rowers, thus it is reasonable to examine these parameters.

In the following, conclusions of previous studies on the physical – both anthropometric and physiological – traits of rowers are presented. First of all, the attention is drawn to the complexity of measuring rowing performance. After that a short summary of the anthropometric and physiological measurements and possible predictors of rowing performance is provided, emphasizing the unquestionably important performance-related role of these characteristics (Yusof et al., 2020). With regard to the enormous number of research available in the literature, this Ph.D. study did not aim to collect all of them, thus only selected references are mentioned.

2.2.1. Measuring rowing performance

As mentioned above, rowing performance depends on many different factors, such as anthropometric, physiological characteristics, technique and tactics. Due to these many requirements, it is quite difficult to determine what makes someone a good rower. Many researchers have tried to investigate the predictability of rowing performance and aimed to find those factors that influence rowing performance, and excrete the best predictors of performance, with the purpose of supporting sport selection and improving training planning (Smith & Hopkins, 2011).

Smith & Hopkins (2012) summarized the difficulties of measuring rowing performance, and reviewed the most commonly used measures for this purpose (Smith & Hopkins, 2011). As a good predictor of rowing performance must have acceptable validity and reliability, the appropriate measure should require a standard error of measurement less than 0,3%, which proves to be difficult to accomplish.

As the standardized rowing competition's distance is 2000m, it seems to be evident to choose the 2000m on-water time for the criterion measure of rowing performance, and may compose the larger units (such as fours or eights) based on individual times in single sculls. However, many aspects should be taken into consideration when searching for the best measures of rowing performance. In case of on-water measurements additionally to personal physiological variability from race to race, environmental perturbations (e. g. wind, water resistance) can also influence rowers differently. Furthermore, if rowers from a crewed boat are individually tested in single sculls, this could not reflect the performance, as technique may be enhanced by the faster movements in a team (Magee & Denys, 2005).

Nowadays, technical development makes it possible to conduct on-water rowing performance measurements by measuring boat speed. One way is to film the rowers during training or competitions. On the other hand, instrumenting the boats with different devices makes it also possible to conduct measurements. The two most commonly used speedometers are based on an impeller (and measure true speed) or GPS system (measuring relative speed). However, measuring boat speed proved not to be suitable for monitoring one's rowing performance. Furthermore, on-water ergometry utilizes sensors, but it is still unclear, how reliable is the information provided by this kind of measurement, while the equipment is expensive, complicated to install and often brittle (Baudouin & Hawkins, 2004; Smith & Hopkins, 2012). All in all, on-water measurements are found to be inappropriate for the purpose of measuring one's rowing performance.

Despite some differences have been found between on-water and off-water rowing, for example in arm motion (Lamb, 1989), handle force and acceleration profiles or consistency in stroke timing (Green & Dawson, 1993), the difficulties in connection with on-water measurements and the greater reliability (standard error is about 0.5%) provided by measures on rowing ergometers led to the widespread use of these devices to evaluate rowing performance. Moreover, it also has been shown that rowing ergometer time trial could reflect on-water performance much more effectively, if the rowing ergometer speed is divided by body mass (Nevill et al., 2010).

Since, rowing ergometers provide not only good equipment for training but the 2000m Concept II rowing ergometer time trials and other measures derived from this have become the most commonly utilized tools for coaches to predict rowing performance and thus to select successful rowers (Smith & Hopkins, 2012) as it is independent from environmental conditions. As rowing ergometer time trial can indicate rowing performance, many researchers aimed to define those factors that influence the 2000 m ergometer time, consequently the rowing performance. Numerous studies emphasize the importance of anthropometric or physiological characteristics and try to find the best predictor among these variables, establishing various prediction models. However, it is also suggested that variables from different categories would predict performance better together than variables from only one category (Russel, le Rossignol & Sparow, 1998).

2.2.2. Anthropometric parameters

Anthropometry refers to the systematic collection of measurements of the human individual, originated in the 19th century (Komlos, 2004, 2009). The generally measured anthropometric characteristics are age, sex, weight and height, but further measures are also in use (e. g. girths, breadths, skinfolds). Two types of anthropometric profile can be determined: restricted or full profile, from which the latter consists of more parameters (Norton & Olds, 1996). A combination of measurements, *indexes* can also provide important information. For example, body mass index (BMI, also known as Quetelet-index) estimates body fat from weight and height. Volume height index (VHI) can be an alternative to BMI (Tovée, 2012). Body surface area (BSA) is the calculated surface area of the human body (Ikeotuonye et al., 2020).

Moreover, several other anthropometric measurements and calculated indicators are used (e.g. symmetry measures, waist-to-hip ratio, arm span, sitting height, shoulder width etc.) (Fredriks, 2005; Tovée, 2012).

Many different techniques, consequently a plethora of measuring instruments (e.g. stadiometer, weighing scales, segmometer, calipers etc.) are available to conduct anthropometric measurements. Anthropometric studies are made for several reasons (Norton & Olds, 1996). This kind of scientific study is useful for several purposes, just to mention a few example: getting deeper insight into one's health condition (Komlos, 2009), evaluating the right development of children (Sandler, 2021) or predict birth weight (Ikeotuonye et al., 2020) etc. Importantly, sports anthropometry has developed a lot over the years. Initially, mainly its descriptive and comparative, but later its predictive functions have also become important. Knowledge of biological factors of the human body and the relationship between these characteristics and sports performance can sub serve talent detection, predicting outstanding sport performances and more purposeful training planning in different sports (Malina, Battista & Siegel, 2002; Mészáros, 2000; Ross, De Rose & Ward, 1988; Russo et al., 1992; Tittel & Wurtscherk, 1992).

Anthropometric data of rowers has been intensively examined. Both female and male amateur and elite level rowers of different ages were already subjected to such investigations. Several studies aim to search the relationship between rowing performance (most commonly measured by the performance on rowing ergometer in different distances or times) and these characteristics (Akça, 2014; Cerasola et al., 2020; Ross, De Rose & Ward, 1988).

Generally, former studies emphasize that greater lean body weight with high muscle percentage and low fat percentage affects rowing performance positively (Barrett & Manning, 2004; Bourdin et al., 2017; Izquierdo-Gabarren et al., 2010; Mikulić & Ružić, 2008; Yoshiga & Higuchi, 2003). In contrast to other endurance sports such as running, in rowing the athlete's body is supported by a seat, thus high body mass is not disadvantageous, except in case of lightweight rowers. As seated position is beneficial for tall persons (Tittel & Wurtscherk, 1992), height is also an important factor influencing beneficial rowing performance. (Bourgois, 2000; Forjasz, 2011; Huang, Nesser & Edwards, 2007; Shephard, 1998). A taller rower can reach a bigger catch angle and sweep the blade in long stroke to transfer the hydrodynamic force to the blade, allowing for an extended rowing drive phase (Winkert et al., 2019; Yusof et al., 2020).

In addition to body size, relative body proportions and absolute length dimensions of body parts (e.g. arm or leg length, sitting height) have also been examined (Carter et al., 1982; Claessens et al., 2005; Jürimäe et al., 2010; Rodriguez, 1986; Ross, De Rose & Ward, 1988), showing differences between sweep rowers and scullers. Most of the successful rowers have long extremities in absolute length as well as in proportion to their standing height. The taller rower with a shorter sitting posture relative to his/her stature, forms a relatively low center of gravity which is good for the boat stability (Yusof et al., 2020). Among world champions male rowers are typically 194±5 cm, female rowers are 181±5 cm tall, weighing 94±6 kg and 76±5 kg (Kerr et al., 2007; Winkert et al., 2019). Furthermore, rowers with better results have lower skinfold values than their less successful rivals. Elite and amateur, from junior to senior women and men rowers have already been subjected for this kind of measurements (Akça, 2014; Bourdin et al., 2017; Izquierdo-Gabarren et al., 2010; Mikulić, 2008; Yoshiga et al., 2000).

2.2.3. Physiological measurements

Besides the anthropometrical characteristics, physiological factors are also important and their connection with rowing performance is often studied. In contrast to descriptive disciplines, such as anatomy, physiology focuses on the mechanisms of living beings, integrating studies from cellular level through the interactions of organs and systems to the whole body function and the environmental effects. It purposes to get deeper insight into the details of the processes that control and regulate the living individuals. Physiology is a multidiscipline, covering several subdisciplines (e. g. cell, systems, evolutionary or exercise physiology etc.). Human physiology studies the functions of the organs and systems inside the human body. Sport physiology is a subdiscipline, which examines how the stress – caused by exercise – affects the human body, thus how can be sport performance enhanced. Many different physiological attributes can be measured, which provide useful information in connection with sport performance (Henige, 2021). Physiological aspects of rowing have been densely studied, thus the most often investigated physiological variables which have found to be in correlation with rowing performance are mentioned in this chapter.

2.2.3.1. Metabolic cost of rowing

Anaerobic capacity is ’the maximal amount of ATP resynthesized via anaerobic metabolism during a specific type of short-duration, maximal exercise’ (for detailed description see Green & Dawson, 1993). However, maximal aerobic power is of decisive importance, when large muscle groups are working at a high intensity for a longer period of time (astrand). On average, the duration of a 2000 m rowing race in an international competition is between 5.5 to 7.0 minutes, depending on weather conditions and boat category (Mäestu, Jürimäe & Jürimäe, 2005). Thus, for an all-out 2000m rowing race, rowers need both high aerobic and anaerobic capacity. During an all-out rowing race, the estimation of aerobic-anaerobic energy contribution differs according to earlier studies (Mäestu, Jürimäe & Jürimäe, 2005), however, they agree on that compared to other endurance sports, the anaerobic metabolism plays an important role during rowing competitions, especially in the initial spurt and the finishing phase of the race (Akça, 2014; Cerasola et al., 2020; Ingham et al., 2008; Izquierdo-Gabarren et al., 2010). The anaerobic contribution to an all-out 2000m rowing race is estimated to be between 21-30% (Droghetti, Jensen & Nilsen, 1991; Secher, 1993), but the aerobic capacity of rowers is also one of the largest among endurance athletes (Volianitis & Secher, 2009). Aerobic capacity is best indicated by maximal oxygen consumption, ($VO2_{max}$, in L/min) which describes the highest amount of oxygen that body can utilize during heavy exercise (Jürimäe et al., 2000). According to Jensen, Johansen & Secher (2001) during the initial phase of the rowing stroke, ventilation up to 270 L/min is developed. A large pulmonary capacity is required to provide for the $VO2_{max}$ of elite rowers that approaches 7 L/min (Volianitis, Yoshiga & Secher, 2020). Unlike the measurement of aerobic capacity with the measure of the maximal oxygen uptake ($VO2_{max}$), it is difficult to quantify the anaerobic capacity. Several methods have been tried to test one's anaerobic capacity including invasive measurements of muscle metabolite by magnetic resonance spectroscopy and peak blood lactate concentration after intense exercise and the oxygen debt. However, the most common means of assessing anaerobic performance are the ergometric assessments of mechanical work, such as measures of peak power, time to exhaustion etc., which are non-invasive procedures and provide an indirect method of assessment (Gastin, 1994; Volianitis, Yoshiga & Secher, 2020). The average blood lactate concentration after a rowing race has already been measured and found to be 12.5 ± 0.45 mmol/l (Secher & Volianitis, 2009). Other researchers have emphasized the role of maximal force (F_{max}) and muscle power output (W_{max}) for rowing success (Secher, 1993; Steinacker et al., 1986). According to Steinacker (1993) the power per stroke may reach as high as 1200 W, and the average power is measured to be 450-550 W.

2.2.3.2.Ventilation

According to Jensen, Johansen & Secher (2001) during the initial phase of the rowing stroke, ventilation up to 270 L/min is developed. A large pulmonary capacity is required to provide for the $VO2_{max}$ of elite rowers (Volianitis, Yoshiga & Secher, 2020). The ventilatory volumes observed during maximal rowing are the highest among competitive sports. The lungs of rowers reflect their body size, and vital capacity up to 9.1 L has been recorded. As the vital capacity is the only link of the oxygen transport chain that could not be improved with training, a correlation between rowing performance and vital capacity is often reported and rowers typically demonstrate vital capacity values of 7 L compared to 5.5 L as expected for their body size (Secher & Volianitis, 2009).

2.2.3.3.Circulation

In rowing there is a combined demand for a large VO_{2max}, cardiac output and stroke volume in addition to overcoming the high blood pressure at the beginning of each rowing stroke. The stroke volume of elite rowers is impressive (195 versus 110 mL for control subjects), but it is not limited by the capacity of the heart to encompass a large volume of blood. The cardiac output provides blood flow to tissues - including working skeletal muscles – and coupling between cardiac output and VO_{2max} in trained rowers is reported to be 6.5 or 5.8: 1, in contrast to untrained people with 7.5: 1. Thus, the largest reported VO_{2max} (7.4 L/min) would be expected to require a cardiac output of ≤ 49 L/min and accordingly values of 40 L/min are reported regularly (Secher & Volianitis, 2009; Volianitis, Yoshiga & Secher, 2020).

During rowing, blood pressure also varies with the rowing cycle, thus a "pulse pressure" of more than 100 mmHg is observed because of the Valsalva-like maneuver (which means a forceful attempt of exhalation against a closed airway) performed at the catch of each stroke. This means that the systolic pressure may approach 200 mmHg during maximal rowing (Secher & Volianitis, 2009).

The central blood volume is higher during rowing than during running which allows for lower heart rate and larger VO_{2max} (Yoshiga & Higuchi, 2003). Heart rate recorded to reach 190-200 beats/min during maximal rowing (De Campos Mello et al., 2009; Hagerman, 1984). Thus, the seated position may partially explain the extreme work capacity during rowing.

The heart adapts to the load it is exposed to by training, which is manifested in a heart size (left ventricular mass of 330 g and left ventricular wall thickness of 16 mm) comparable with the largest hearts among elite athletes (Volianitis & Secher, 2009).

2.2.4. Rowing performance predictors

The relevance of anthropometric factors for success in rowing races has already been indicated by several studies. As shown above, among anthropometric characteristics body mass, lean body mass and body height play an important role in successful rowing, consequently they are accepted determinants of rowing performance. Thus, it is not surprising that these parameters are often included in national talent identification for rowing (Kerr et al., 2007) Lawton, Cronin & McGuigan, 2012; Mikulić & Ružić, 2008). For more, these variables are relatively easy to be measured.

As anaerobic metabolism processes contribute significantly to the 2000m rowing ergometer performance, efficiency of these energy pathways can also be important predictors of rowing performance. Nowadays blood lactate concentration is a commonly used parameter for performance assessment (Mäestu, Jürimäe & Jürimäe, 2005). High blood lactate concentration of rowers also support that rowers have high anaerobic capacities. Different anaerobic threshold concepts and their relationship with rowing performance have also been reviewed (Jürimäe et al., 2000). Aerobic capacity is also important for competitive rowers. The majority of the studies conducted on physiological aspects defined the maximum oxygen consumption (VO2max, indicator of aerobic capacity) as the best predictor of rowing performance (Cosgrove et al., 1999; Kramer et al., 1994).

Power at VO2max, VO2 at the blood lactate threshold, power at 4 mmol/l blood lactate concentration and maximal power could be used to predict rowing performance (Ingham et al., 2002). According to the results of rowing Wingate test and one repetition maximal strength tests, anaerobic power and strength have also important predictive values. Mean power, maximum and minimum power, one repetition maximum leg press, one repetition maximum bench pull and biceps strength correlated with performance (Akça, 2014). The predictive role of leg press, inverted row and vertical jump has also been investigated (Huang, Nesser & Edwards, 2007). These studies emphasize the importance of strength and anaerobic power development.

2.3. Sport psychology

The history of sport psychology dates back nearly two centuries, but flourished in the 20th century (Lochbaum et al., 2022). Sport and exercise psychology as an academic pursuit was officially born in 1965 at the 1st World Congress in Sport Psychology, when the International Society of Sport Psychology was established. In 1970 the first specialized journal, the International Journal of Sport Psychology was published, and since then research and publication in this field have grown significantly and many further international journals have been established (Németh, Vega & Szabó, 2016). All in all, recently sport psychology has grown into an expanding field of psychology. Due to the increased number of studies and articles, a systematic review of the existing literature in sport psychology has already been made (Lochbaum et al., 2022). As sport psychology spreads across many other psychological subdisciplines, a useful knowledge map of sport psychology has also been presented (Latinjak & Hatzigeorgiadis, 2021).

However, it is difficult to determine, what sport psychology is. Although many researchers tried to describe exactly this discipline, the comprehensive and internationally accepted definition of sport psychology is still missing. For example, the American Psychological Association's Society for Sport, Exercise and Performance Psychology (APA Division 47), the Association of Applied Sport Psychology (AASP), the British Psychological Society (BPS) or the European Federation of Sport Psychology (FEPSAC) all define it differently (Eklud & Crocker, 2019). Generally, psychology is a subdiscipline of psychology applied to competitive sports, specified for organized physical (motor) activity. In contrast to other settings (physical education, leisure, rehabilitation), competitive sport is focused on high achievement and consistent excellence. Sport psychology studies and applies those psychological factors that enhance athletic performance and their impact of sport participation on a person's (or team's) development. Hence, the aim of this discipline is to help athletes to concentrate better, deal effectively with competitive stress and anxiety, and to prepare for competitions more efficiently. Furthermore, sport psychology also investigates the impact of long-term sport participation on personal development. The performance of the athletes can be evaluated and compared to others in sport competitions, according to the approved rules of that sport. The results allow ranking the participants. Thus, these events mean a great opportunity for the athletes to demonstrate their excellence in public, and get social recognition and prestige. However, to reach even better results athletes have to train regularly and develop their physical condition. In addition to physical aspects, mental health and skills are also play important role in successful sport careers. Sport psychology studies various performance-related situational experiences (self-confidence, attention, concentration, motivation and anxiety) that determine a state of readiness for competition.

In the following, the importance of sport-confidence and anxiety is discussed, based on the available literature.

2.3.1. Sport-confidence

The term 'confidence' is not restricted to confidence in sport, thus 'sport-confidence' has been conceptualized. It can be defined as the belief that an individual owns all internal resources and abilities to be successful in sport. Furthermore, the sport-confidence model has also been created. In this theory two components are examined: trait (SC-trait) and state (SC-state) confidence. The former is the dispositional feeling that one is able to perform an objective, while the latter means the instantaneous belief about the ability to perform the task. Consequently, two inventories have also been developed, namely Trait Sport Confidence Inventory and State Sport Confidence Inventory (TSCI & SSCI) (Vealey, 1986). By getting deeper understand into these two concepts can help determine where a person's confidence level is or how to build up higher level of confidence (Vealey, 1988). Sources of self-confidence in sport have been investigated, and nine sources have been identified (Hays et al., 2009; Vealey et al., 1998) by establishing the Sources of Sport Confidence Questionnaire (SSCQ).

2.3.2. Anxiety

Anxiety is an emotional response to stress characterized by worry about the possibility of physical and psychological threat. Thus it can be defined as a tendency to view competitive situations as harmful and to respond to these with apprehension (Martens, Vealey & Burton, 1990). Anxiety consists of both cognitive (e.g. nervousness, worry, fear, arousal) and physiological (e.g. tension, sweating, increased hearth rate) responses and its intensity varies over time and depends on the level of anxiety (Grossbard et al., 2009; Wang et al., 2004). State and trait anxiety can be distinguished (Spielberger, 1966). State anxiety appears in specific situations, hence it can be defined as transitory emotional response, while trait anxiety refers to stable individual differences in tendency to anxiety. The measures of sport specific state and trait anxiety have been reviewed (Smith & Smoll, 1990). State-Trait Anxiety Inventory (STAI) (Spielberger, Gorsuch & Lushene, 1970) is a general anxiety scale, proved to be moderately useful for assessing sport- performance anxiety, while Sport Competition Anxiety Test (SCAT (Martens, 1977)) is a reliable and valid measure of anxiety and has become an often used research tool in the field of sport psychology.

Anxiety in sport is not harmful by all means. It can be beneficial through concentrating on the task to be done, and may the negative emotions before competitions can lead to increased effort and motivation. However, if the athlete perceives anxiety as interpretation of the negative emotions which endangers performance, this can increase physical anxiety, resulting in further negative thoughts and affecting detrimentally the ability to perform well. (Eysenck et al., 2007; Lazarus & Folkman, 1984; Neil & Woodman, 2019).

2.3.3. Correlation between sport-confidence, anxiety and performance

Many types of research in connection with sport psychology investigate how stress affects sport performance, however resulted in different conclusions (Smith & Smoll, 1990). Some earlier theories in connection with the impact of anxiety on performance are the inverted-U hypothesis (Yerkes & Dodson, 1908), the drive theory (Hull, 1943) and reversal theory (Apter, 1982), which founded the way for the establishment of multidimensional models, for instance the Smith and Smoll conceptual model (Smith & Smoll, 1990), the multidimensional anxiety theory (Martens, Vealey & Burton, 1990), the catastrophe theory (Hardy & Parfitt, 1991) and the Individual Zones of Optimal Functioning (Hanin, 1997). Ford et al. (2017) shortly summarized the different concepts of these earlier and more developed models. In general, they agreed in the main points, that anxiety influences performance, which can be both positive and negative affect, and that the direction of such effect depends on the individual's responses to the stressful situation. Anxiety is also an important predictor of discontinuation of sport participation (Ford et al. 2017; Scanlan, Babkes & Scanlan, 2005).

High sport-confidence facilitate sport performance through its positive effect on athletes' thoughts, feelings, and behaviors (Hays et al., 2009). Research on self-confidence in sport has shown that athletes and coaches identify self-confidence as critical to performance and there is evidence that self-confidence has positively influenced athletes' performance in both experimental lab settings and also in the natural competitive settings (Neil & Woodman, 2019).

2.4. Sports selection

For decades, the selection of athletes has been a determinative topic in sport sciences. The aim of selection may be to reach short-term goals (e. g. when players are choosing to assemble the team for the next match), but could also focus on long-term outcomes. The latter means the selection of those athletes at young ages, who later may reach excellent results. However, it is difficult to predict, who can become a successful athlete in the future. In sports, performance prediction is critical for the selection of athletes. It is essential to know, that (1) What kind of performance do we want to predict? and (2) what methods can best be used to predict that performance? (Schmid, Conzelmann & Zuber, 2021) The literature in connection with searching sporting talents is extensive, including empirical articles, reviews, books, governing body documents, theses, anecdotal evidence etc. Several models and frameworks of talent development have already been established based on various opinions and aspects (Rees et al., 2016). In the following the features of an athlete, which should be taken into consideration when searching for talents are discussed, highlighting the most important factors in successful rowers' selection.

2.4.1. Difficulties of talent detection

There is evidence that genetics explains significantly the variations in a plethora of measures, such as explosive strength, speed of limb movement, reaction time, flexibility, balance, lean muscle mass, change in maximum voluntary force, isometric strength and VO_{2max}. Specific gene variants appear to influence participation in physical activity and determine the endurance (aerobic) and muscle strength (anaerobic) performance (Bray et al., 2009; De Moor et al., 2009; Guth & Roth, 2013; Rankinen et al., 2010). The potential impact of genetics could be significant, and thus additional research in this area is required.

There is a long history of anthropometric and physiological studies of athletes. These factors have already been identified across a number of sports at all levels of performance. Many variables are examined, for example height, weight and (lean) body mass, limb length and circumference; amount of adipose tissue; jumping ability, strength, blood lactate and VO2max. According to investigations in different sport disciplines, it is clear, that aerobic capacity, anaerobic endurance and anaerobic power are important for optimal sport performance. However, the issue of talent identification in sport in the way of predicting adult performance from adolescent anthropometric and physiological data is still problematic. Solving this question could have an enormous impact on talent identification procedures (Rees et al., 2016).

In addition to physical features, psychological skills and motivational orientations also must be investigated in the process of searching for successful athletes. Generally, more successful athletes display higher levels of motivation and perceived control, higher levels of mental toughness and resilience, better ability to cope with adversity, greater resistance to 'choking' (for references see Rees et al., 2016) in high-pressure situations, and employ a wide range of mental skills and psychological techniques. Confidence has been associated with positive affect, while in contrast, the lack of confidence has been associated with anxiety, depression, and dissatisfaction (Feltz, 2007; Martens, Vealey & Burton, 1990; Vealey, 1986, 1988; Vealey et al., 1998). Assessing whether and how psychological skills at young age influence long-term adult elite performance is highly demanded in talent identification procedures (Rees et al., 2016).

2.4.2. Selection of successful rowers

It can not be stressed enough, that rowing is a highly demanding sport both physically and mentally. Thus rowers must be prepared to cope with the pain and exhaustion during training and competition (Connolly & Janelle, 2003). Statistical analyses have shown, that world-class rowers began rowing at quite young age (15 ± 2 years) and won their first medal at the Olympic Games or the World Rowing Championships between the ages of 24 and 28 and spent 1100-1200 hours per year with training (Fiskerstrand & Seiler, 2004). The importance of specific anthropometric and physiological characteristics has been mentioned above, as well as the several psychological skills. Furthermore, rowers need specific motor skills in order to balance the boat and coordinate their movements with the other members of the crew. Similarly, to other sports, in the sport of rowing, talent identification programmers have also attempted to identify potential young athletes using various performance variables, including several anthropometric measurements, physiological examinations and psychological tests. Although many researchers came to corresponding conclusions and showed analogous variables to use for talent identification in rowing, the ultimate methods are still highly demanded.

CHAPTER 3: METHODOLOGY

3.1. Participants and data collection

The subjects of the cross-sectional studies presented in the following were groups of rowers from Hungarian rowing clubs of different sizes. The participants had a valid competition license and valid medical certificates, participated regularly in trainings and in national and/or international competitions. Furthermore, they did not limit their physical activity levels to the extent that could significantly affect their motor fitness. Data collection was conducted at several Hungarian rowing events 2020 in the Hungarian National Rowing Championships, the Hungarian National Rowing Ergometer Championships. Furthermore, tests were conducted in the Human Performance Laboratory in Gyor, Hungary.

3.2. Procedures

3.2.1. Anthropometric measurements and body composition estimations

For the anthropometric measurements Sieber-Hegner measuring instruments were used. Body height was measured with a calibrated Soehlne Electronic Height Rod 5003 (Soehlne Professional, Germany) according to standardized guidelines. Body mass (measured to the nearest 0.1 kg), BMI and body composition characteristics, such as body fat percentage (BFP) and skeletal muscle mass (SMM), were determined by bioelectrical impedance with an InBody 720 body composition analyzer. The remaining anthropometric characteristics, such as sitting height [cm], arm span [cm], limb length [cm] were measured with the use of the Weiner and Lourie methods (Weiner & Lourie, 1969) and the calculation of BSA [m^2] was conducted with the use of Mosteller's formula (Mosteller, 1987). Skin fold measurements (biceps, triceps, scapula, suprailiac, abdomen, thigh, lower leg) were obtained using a Harpenden caliper. Relative body fat content was calculated using the estimation by Pařízková (Pařízková, 1961).

3.2.2. Physiological measurements

The 2000 m rowing ergometer tests and different distances (3x100m, 60 sec, 500m, 2000m and 6000 m) were performed on certified rowing ergometer (Concept 2 D-model) and the power output in watts (W) was measured. The calculation of watts was performed as follows: First, the distance was defined: distance = (time / number of strokes) × 500. In the next step, the concept of a "split" was clarified: split = 500 × (time / distance). The watts were calculated as $2.8 / (\text{split} / 500)^3$. The estimated relative aerobic capacity (ErVO2) was calculated by using the formula of McArdle, Katch & Katch (2006) for men: ErVO2 = (Y × 1000) / BM, where BM is body mass, and Y = [BM <75kg; 15.1- (1.5 × time)]; BM => 75kg; 15.7- (1.5 × time)]. The power delivered over 2000 meters was divided by body weight to obtain the relative performance (rW2k).

The power output of the lower extremities and the height attained by the center of body mass during vertical jumps were measured with a PJS-4P60S force plate ("JBA" Zb. Staniak, Poland) with a 400 Hz sampling rate (Batra et al., 2021; Gajewski et al., 2018). The force plate was connected via an analog-to-digital converter to a PC with the MVJ v.3.4 software ("JBA" Zb. Staniak, Poland). The amplifier was connected to a PC via an A/D converter. For measurement, the MVJ v. 3.4. software package ("JBA" Zb. Staniak, Poland) was used.

3.2.3. Psychological tests

Sport Competition Anxiety Test (SCAT) is a scale with 10 items specific to sport competition, which has adequate test-retest reliability and good internal consistency (Martens 1977). Competitive State Anxiety Inventory-2 (CSAI-2) is a multidimensional state anxiety measure. The 27-item scale designed to measure cognitive and somatic state anxiety as well as self-confidence.

Athletic Coping Skills Inventory-28 (ACSI-28) contains seven sport-specific subscales. The scales can be summed to yield a score, which is assumed to reflect a multifaceted psychological skills construct.

Trait Sport Confidence Inventory (TSCI) consists of 13 items with no subscale components, utilizing a 9-point Likert scale anchored by 1 (low) and 9 (high) to assess how confident athletes generally feel when they compete in sport.

3.3. Statistical analysis

Measurements were statistically processed with Statistica PL, v. 13.5. Normality was verified with the Shapiro-Wilk test. It was checked that all tested features have normal distributions. Therefore, for comparisons of two arithmetic means, Student's *t*-test was used. To compare three arithmetic means, one-way analysis of variance (ANOVA) was used. If ANOVA indicated a significant difference, Tukey's Honestly Significant Difference (HSD) test was used for post-hoc analysis. Cohen's d was used as a measure of the effect size of differences between male and female rowers and interpreted according to modified thresholds (for sports sciences as trivial (0.2), small (0.21–0.6), moderate (0.61–1.2), large (1.2–1.99), and very large (<2.0). Statistical significance was set at $p \leq 0.05$. Additionally, the value of the Szopa dimorphism index was calculated. For detailed description of the utilized statistical analyses see the studies presented in Chapters 4, 5, 6, 7 and 8.

CHAPTER 4: Examination of selection criteria among young rowing male and female (Study 1)

Note: This article has been accepted for publication and the final published version is presented in this dissertation. The final published version is available and can be downloaded online from the publisher's website:

Alföldi, Zoltán – Katona, Zsolt – Suszter, László [et al.] (2020): Kiválasztási kritériumok vizsgálata utánpótláskorú evezős leányok és fiúk körében=Examination of selection criteria among male and female of junior rowing age. In: *Magyar Sporttudományi Szemle*, 21(6):3-10.

4.1. Abstract

This study aimed to examine the relationship between selected physiological variables of male and female rowers and rowing performance as determined by a 2000 m time- trial. The participants were 245 young rower's athletes: female (n=101) and male (144) club standard oarsmen. Their mean (17.24± 1.38) age female and (18.22± 1.33) male. Under the recommendations of the International Society for the Advancement of Kinanthropometry, the anthropometry was performed as follows: stature (BH), body mass (BM), arm span (AS), sitting height (SH), calculated body mass index (BMI), body surface area (BSA). The participants were tested on the rowing ergometer to estimate their relative maximal oxygen uptake (e.r. VO2max) based on (McArdle, Katch & Katch (2006) equation and calculated the relative performance (rW2k ×kg-1). A repeated-measures analysis of variance showed significant differences between estimated maximal oxygen uptake in each age group independent of gender. A stepwise multiple regression showed that (e.r. VO2max) was the best single predictor of the completed time for the 2000 m time trial. This study has contributed to the scientific understanding of rowing, limited information is available on the relationship between the physiological variables of rowers and rowing performance. Relating physiological variables to performance could be valuable for designing training programs and for team selection.

Keywords: anthropometry, performance components, circulatory system

4.2. Introduction

The importance of sport selection is indisputable. However, the focus is on the extent to which early specialization is necessary (allowed) and the extent and quality of general training. In addition to sport selection, however, there are general indicators whose measurement should be a fundamental requirement. These include conformation, motor learning traits, circulatory and respiratory system characteristics, the quality of physiological and psychological adaptation to exertion, motivation and social relationships.

Several prediction models predicted expected performance using anthropometric variables alone (height, sitting height, arm span) (r=0.82) and aerobic capacity (VO2max), which (r=0.93) showed a significant relationship with performance (Russel, le Rossignol & Sparow, 1998). Successful selection for rowing is a highly complex process. Its complexity is due, on the one hand, to the fact that the success of the task is influenced by the optimal use of a device and, on the other hand, by the fact that this activity must be performed in a sitting position (Mäestu, Jürimäe & Jürimäe, 2005).

For tool use, appropriate physiological traits and for extreme work in the seated position, an excellent oxygen delivery system is required, especially with regard to quality venous return and, thus, to enhance cardiovascular function. Thus, measurements of the metabolic and circulatory systems, as well as of the effort, show that training should simulate rowing in a boat as much as possible (Secher, 1983). This fact is confirmed by the work of Amy L. Woods and colleagues (Woods et. al., 2017), where they identify rowing as a unique challenge by pushing human capabilities to extreme limits. Among other things, she also stressed that it is very difficult to select talented candidates (rowers) because of their interdependence with (the boat) and also because it is a team sport and therefore very difficult to monitor an individual's work and objectively assess their progress.

This study aims to analyze the constitutional and circulatory characteristics that may qualify the selection of successful rowing trainees. Favorable anthropometric profiles, such as body height (BH), sitting height (SH), and arm spam (AS), should be considered as important criteria for sport selection.

- So the question arises, can these characteristics be indeed dominant elements in sport selection?
- Are predictive values of anthropometric and cardio-respiratory characteristics an important complement to the talent identification goals of rowing?
- In this study, do anthropometric characteristics or estimated relative maximal aerobic capacity (e.r. VO2max) emerge as a stronger predictor of performance?
- Is there a relationship between the estimated relative maximal aerobic capacity (e.r. VO2max) and the calculated relative power output (rW×kg-1) for both sexes and both distances?

Our work aims to answer these questions by studying the physiological and circulatory characteristics.

4.3. Materials and methods

Two hundred and forty-five (n= 245), (n= 101); (17.24±1.38), female and (n= 144); (18.22±1.33), male of age was recruited from 16 rowing clubs in 10 Hungarian cities. In the study, sample selection was done to ensure that all subjects had an equal chance of being included in the sample. The requirements of the Declaration of Helsinki on Voluntariness and Parental Consent, as well as the willingness of the associations to cooperate, were taken into account and were met in all the required details. The minimum requirement for inclusion was the completion of planned, general and sport-specific exercises (at least three times a week, for at least 50 minutes, at 80-90% of maximum performance, outside compulsory PE lessons). Three age groups were created based on the considerations of Baxter-Jones & Mirwald (2004). Anthropometric data were recorded using certified Sieber-Hegner instruments. In our work, the International Society for Kinanthropometry (Krüger, De Ridder & Grobbelaar, 2006) procedural recommendations were used as a guideline in our work. Body mass (BM) and height (BH) were measured. Sitting height (SH) was determined as the distance between the vertex and the seat. It was specified as a requirement that the subject should be seated on a rigid, horizontal seat with the thigh and leg at right angles and the knee bend touching the seat. The posture should be straight, with the spinal column straightened as much as possible. The head position shall be the Frankfurt horizontal described in the height measurement. When measuring the arm spam (AS), the arm is in lateral mid-stance (palm facing forward) and the maximum distance between the tips of the two middle fingers is the determining factor. The examiner holds the anthropometer at the level of the subject's clavicle, in a horizontal plane. Body mass index (BMI) was calculated by dividing the body weight in kilograms by the square of the body height in meters (BM (kg)/ BH^2). Body surface area (BSA) was calculated using Mosteller's formula (Mosteller, 1987) BSA (m^2) = $[BH\ (cm)\ x\ BM\ (kg)/3600]^{½}$. Using a verified rowing ergometer (Concept 2 D-model), the power output in watts (W) was measured at 3x100m, 60mp, 500m, 2000m and 6000 m. The calculation of W can be described as follows. First, the definition of distance was defined: distance=(time/number of strokes)×500. In the next step, the concept of "split" was clarified: split=500×(time/distance). With these, the watt=$2.8/(split/500)^3$.

There were slight variations in intensity due to individual variations in stroke rate and the ability to keep the 500 m split time constant. Before each test, all participants performed a 6 min warm-up for a 500 m section for 2 min 30 s. Participants then rested for 6 minutes, during which time they performed stretching exercises.

Estimated relative aerobic capacity (e.r.VO_2) was determined using the empirical formula (McArdle, Katch & Katch, 2006) of watt power delivered at 2000m, age, sex, body weight and fitness level: b.r.VO_2 = (Y×1000)/TS. Where Y= for females [BM<61.36kg; 14.6-(1.5×time)] and [BM>61.3kg; 14.9-(1.5×time)] for males [BM<75kg;15.1-(1.5×time)]; BM=>75kg; 15.7-(1.5×time)].

The data were analyzed using the "Statistica for Windows" 13.2 software package. Gender differences in anthropometric and circulatory characteristics of the three groups were analyzed by repeated measures ANOVA Post hoc, Tukey (HSD) with random error $p<0.05$. Relationships between calculated relative power at 2000 ($rW_{2k} \times kg^{-1}$) and 6000 ($rW_{2k} \times kg^{-1}$) m and arm load and estimated aerobic capacity were analyzed by correlation, while individual and combined variables and times on the 2000 m rowing ergometer were analyzed by linear regression.

4.4. Results

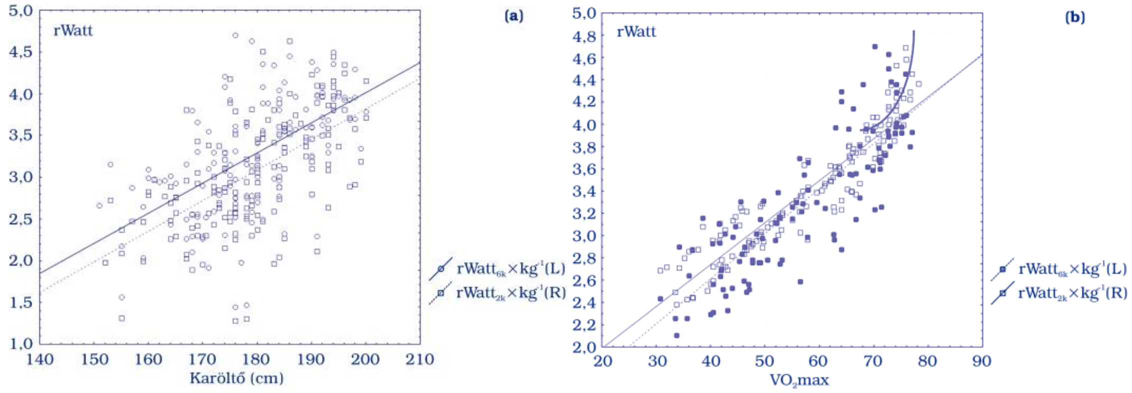
The difference in mean height (BH) between age groups BH (group I) =166.87±7.73-TM (group II) =171.27±5.68; ($p<0.05$) is significant in the female group (**Table 1**). There was no real difference between the means of body mass (BM), body mass index (BMI) and body surface area (BSA). The means of the means of the arm spam (AS) are significant between groups 1 and 3 AS (group I)=167.13±9.50-AS. (GroupIII.)=173.42±4.62; ($p<0.05$), while for sitting height (SH), a real difference was found between groups one and two S(group I)=86.52±3.51-S(group II)=89.23±4.73, ($p<0.05$). Estimated relative aerobic capacity (e.r. VO_{2max}) was significantly different in all age groups. Differences in means between age groups are Group I- Group II ~5; Group II- Group III ~9 ($ml \times kg^{-1} \times min^{-1}$). Power per body weight (rWatt) for all six and two- kilometer rowing ergometer tasks showed a true difference between groups one and three and between groups two and three. As for the results of the same characteristics of the boys by age group, their differences, measured (BH, BM, AS, SH) and calculated (BMI, BSA), are real differences in all cases between groups one and two and between groups one and three. The difference between the means of the estimated relative aerobic capacity (e.r. VO_{2max}) is significant between groups one and two and between groups one and three ~9 ($ml \times kg^{-1} \times min^{-1}$). The power per body mass (rWatt) does not show a real difference between groups one and two and between groups one and two and between groups two and three for the six-kilometer rowing ergometer exercise, but does show a real difference for the two-kilometer distance. As for the comparison between sexes, there the difference between the means of the aerobic capacities estimated at the peak of the exercise (e.r.VO_{2max}), is almost double for 16 year olds, in favor of male; Group I female e.r.VO_{2max} $=37.54\pm9.27$; Group I male e.r.VO_{2max} $=60.43\pm6.91$ ($ml \times kg^{-1} \times min^{-1}$); ($p<0.000$).

1. **Table** Anthropometric and exercise physiological characteristics

Female										
Variables	**mean± SD. (Group I) (n=31)**	**min.**	**max.**	**mean± SD. (Group II) (n=41)**	**min.**	**max.**	**mean± SD. (Group III) (n=29)**	**min.**	**max.**	p
age (years)	15.65(0.49)	15.00	16.00	17.39(0.49)	17.00	18.00	19.89(0.81)	19.00	21.00	1<2; 2<3; 1<3
BH (cm)	166.87(7.73)	155.00	186.00	171.27(5.68)	160.00	188.00	171.16(4.39)	163.00	180.00	1<2; 2<3;1<3
BM (kg)	61.36(9.36)	48.00	81.80	64.18(8.18)	52.00	92.50	65.95(6.74)	54.00	83.70	1<2
BMI	21.92(1.95)	18.22	26.41	21.88(2.60)	17.59	30.55	22.49(1.79)	18.25	25.83	NS
BSA(m^2)	1.68(0.16)	1.44	2.00	1.74(0.12)	1.55	43872	1.77(0.11)	1.61	2.05	NS
AS (cm)	167.13(9.50)	153.00	191.00	170.87(7.48)	152.00	185.00	173.42(4.62)	165.00	184.00	NS
SH (cm)	86.52 (3.51)	81.00	93.50	89.23(4.73)	68.00	96.00	88.31(2.98)	81.00	92.00	1<3
e.rVO2max	37.54(9.27)	30.46	47.42	42.57(8.63)	31.18	57.83	51.35(6.22)	39.38	61.96	1<2
rWatt6k	2.41(0.49)	1.47	3.16	2.69(0.40)	1.45	3.41	3.12(0.28)	2.75	3.66	1<2; 2<3;
rWatt2k	2.95(0.49)	1.85	3.63	3.17(0.43)	1.82	3.91	3.57(0.40)	2.68	4.24	2<3; 1<3
Male	**(n=34)**			**(n=54)**			**(n=56)**			2<3; 1<3
age(years)	16.00(0.17)	16.00	16.00	17.57(0.50)	17.00	18.00	19.39(0.71)	19.00	21.00	1<2, 2<3, 1<3
BH (cm)	176.17(7.63)	164.00	186.00	183.44(6.31)	164.00	196.00	184.61(5.74)	165.00	196.00	1<2;2<3;1<3
BM (kg)	61.75(11.34)	46.00	82.00	72.37(8.20)	57.00	94.00	75.79(7.74)	63.50	97.00	1<2;1<3
BMI	19.75(2.25)	17.10	24.22	21.51(2.33)	17.40	29.34	22.25(2.25)	18.59	32.79	1<2;1<3
BSA(m^2)	1.73(0.19)	1.45	2.05	1.92(0.13)	1.65	2.16	1.97(0.11)	1.71	2.22	1<2;1<3
AS (cm)	178.75(8.56)	164.00	193.00	186.20(7.57)	168.00	200.00	186.34(6.94)	167.00	200.00	1<2;1<3
SH (cm)	89.75(4.16)	83.00	96.00	94.91(3.09)	85.00	101.00	94.74(3.21)	85.00	101.00	1<2;1<3
e.rVO2max	60.43(6.91)	49.66	67.98	67.49(5.64)	52.98	75.50	68.79(6.67)	49.52	78.26	1<2;1<3
rWatt6k	3.71(0.49)	2.96	4.36	3.76(0.42)	2.98	4.63	3.74(0.46)	2.59	4.70	1<2;1<3
rWatt2k	3.77(0.39)	3.26	4.34	4.32(0.45)	3.29	5.37	4.44(0.57)	3.19	5.59	NS

Legend: (BH)=stature (cm),(BM)= body mass (kg), (AS)= arm span (cm), (SH)= siting height (cm), BMI= body mass index, (BSA)= body surface area, relative maximal oxygen uptake (e.r.VO2max) (ml×kg-1×min-1), rWatt6k = relative power performance a six-kilometer rowing ergometer (Watt), rWatt2k = relative power performance a two-kilometer rowing ergometer, NS = not significant, (p> 0.05). .

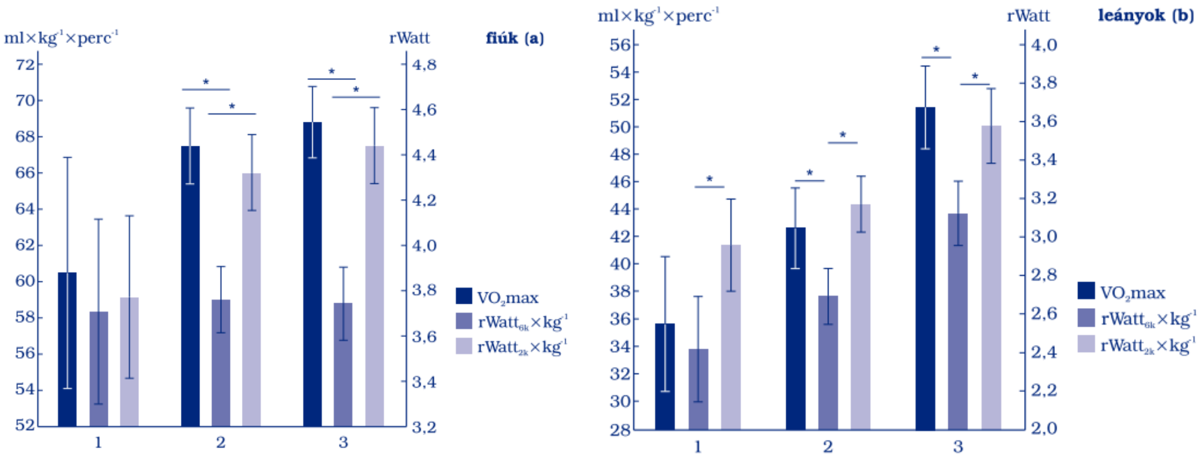
Figures 1.a/b Relationship of arm spam (AS) and estimated relative aerobic capacity (e.r. VO_{2max}) to power output in the six-kilometer (rWatt 6k ×kg -1) and two-kilometer (rWatt 2k ×kg -1) rowing ergometer trials (unisex sample)



Legend: The horizontal axis (x_j) in figure (a) is the arm spam (AS), (140-210cm) in figure (b) the horizontal axis (x_b) [(0-90); (ml×kg -1 ×min -1)] is the relative aerobic capacity (e.r. VO_{2max}) with power, on the left (y_b) axis rWatt 6k×kg -1 , on the right (y_j) axis rWatt 2k ×kg -1 [arm spam (cm): rWatt 6k ×kg -1 : r=0,5831; (p=0,0000)]; [arm spam (cm): rWatt 2k ×kg -1 : r=0,6012; (p=0,0000) [e.r.VO_{2max} : rWatt 6k ×kg-1 : r=0,8531; p=0,0000; e.r.VO_{2max} : rWatt 2k ×kg -1 : r=0,9306; p=0,0000]

In the full sample, the relationship between the two variables (arm spam and the two ergometric performances) is significant. The point set displaying the results shows a significant scatter between the two trend lines (**Figure 1/a**). The two trend lines run parallel to each other, equidistant from each other. The cointegration of the two averages (r_{6k} =0.5831, (p=0.000); r_{2k}=0.6012, (p=0.000), is rather moderate. The calculated common variance is only 35% which is not statistically or human-biologically significant. **Figure** (**1/b**) shows the relationship between aerobic capacity and the performances of the two tests. The two trend lines run parallel, with a significant slope, with the same distance up to 40 (ml×kg-1×min-1) and then a steadily decreasing distance up to 70 (ml×kg^{-1} ×min^{-1}). From the 70-80 (ml×kg^{-1} ×min^{-1}) point, they continue to overlap. From the middle to the last third of the trendline, the points are located below the trendline rather than above it. Between 70 and 80 (ml×kg^{-1} ×min^{-1}) the points deviate from the linear and continue to increase almost exponentially, without exception above the trend line. The cointegration of the two means [(r_{6k} =0.8531, (p=0.000); r_{2k} =0.9306, (p=0.000)] is significant. The calculated joint variance is significant only for human biological content of ~80%.

Figure 2.a/b Age group differences in aerobic capacity (e.r. VO2max) and power (rWatt) between male and female



Legend: the left chart (a) shows the results for male, while the right chart (b) shows the results for female presents. The horizontal axis of both graphs shows the three age groups (1=15-16 year olds), (2=17-18 year olds), (3=19-22 year olds). On the left (y_b) axis, the scaling of relative aerobic capacity (e.r. VO2max) is plotted, and on the right (y_j) axis, the results of the performance are plotted. And the columns by age group represent the three variables presented in pairs in the right-hand corner ($p < 0.05$*)

Figure **(2a)** shows the male (fiúk) results. In all three groups the aerobic capacity is greater than the performance in the two trials. Except of the first group, aerobic capacity is significantly greater for all but two performances. The power delivered at two kilometres is significantly greater than the power delivered at six kilometers for the second and third groups. The pattern of relative power output (rWatt) differences between the three age groups is similar to the estimated relative aerobic capacity (e.r. VO2max) for the two-kilometer distance. While for the six-kilometer rowing ergometer exercise, relative power (rWatt) shows a consistent pattern despite the significantly higher estimated relative aerobic capacity of the second and third age groups. The within-group pattern for female (leányok) in Figure **(2b)** is identical to that of male except for the first and second groups. In the first and second groups, the power delivered over two kilometers is greater than the aerobic capacity. In the first group, the difference is real in favor of the two-kilometer power output. The pattern of relative power output (rWatt) differences between the three age groups is similar to the estimated relative aerobic capacity (e.r. VO2max) for both the six and two kilometer distances.

Table 2 Results of linear regression analysis of individual and combined anthropometric and cardiorespiratory variables measured during the 2000m ergometer survey

	R	**adjusted R^2**	**Standard error of estimate (SEE)**
Anthropometric characteristics			
1	,773[a]	0.598	6.4238
2	,664[b]	0.436	8.064
3	,745[c]	0.551	5.119
4	,683[d]	0.466	3.941
Cardiorespiratory characteristics			
1	,947[e]	0.466	3.942
2	,886[f]	0.785	9.978

Legend: a= (BH) stature, b= (BM) body mass, c=(BSA) body surface area, d=(AS) arm span, e=relative maximal oxygen uptake (e.r. VO2max), f=W2k×kg-1, R=coefficient of determination, R2=adjusted, SEE=Standard error of estimate

In Table 2, the two strongest predictors of anthropometric characteristics among the 2000 m time and the four variables are body height (BH), [(adjusted R^2 =.598; standard error of estimate (SEE)=6.423] and body surface area (BSA), [(adjusted R^2 =.551; standard error of estimate (SEE)=5.119]. While for the cardiorespiratory elements, the estimated relative aerobic capacity [(e.r. VO2 max); adjusted R^2 =,466; standard error of estimate (SEE)=3,942], is the strongest predictor.

4.5. Discussion and conclusions

In our study, we found a relationship between anthropometric variables (body height, sitting height, arm span) and performance. For the three groups of female, significantly increasing values of sitting height and arm span were the most significant predictors of parallel increasing performance. Previous studies have also found similar results (Akça, 2014; Barrett & Manning, 2004; Mikulić, 2009; Mikulić & Ružić, 2008). The same could be said for the male groups, but between the second and third groups the measured stature characteristics were almost identical, which was also associated with similar performance. There is no real difference in body weight, nutritional index or body surface area averages between the female groups. As for the differences between age groups for the same characteristics in male, in all cases the differences were significantly larger for groups one and two and for group three, a difference that was also reflected in higher performance. In contrast, among body composition characteristics, several studies identified lean body mass as a factor associated with performance (Cosgrove et al., 1999; Mikulić, 2009; Yoshiga et al., 2000). Of the characteristics examined, body height (BH) and body surface area average (BSA) were the strongest predictors in our work. In other words, it can be said that the anthropometric profiles formulated as questions in our study sample are indeed dominant elements of sport selection. A similar conclusion had been reached previously, that larger body size is advantageous for rowing performance (Mikulić & Ružić, 2008).

However, regression analyses of previous research have identified different anthropometric variables as stronger predictors (Huang, Nesser & Edwards, 2007; Majumdar, Das & Mandal, 2017; Russel, le Rossignol & Sparow, 1998). According to Battista et al. (2007) although an athlete may have favourable morphological characteristics, his or her performance is significantly influenced by the time spent in the sport, the experience gained (Battista et al., 2007).

The difference in the means of the estimated relative aerobic capacity (e.r. VO2max) between age groups showed an increasing significant difference for the girl groups. For the male age groups, as with the anthropometric variables, only the mean of the first group results showed an increase, with the means of the second and third male age groups being almost identical.in the means of the estimated relative aerobic capacity (e.r. VO2max) between age groups showed an increasing significant difference for the girl groups.

For the male age groups, as with the anthropometric variables, only the mean of the first group's results showed an increase, with the means of the second and third male age groups being almost identical.

Our regression analyses suggest that cardiorespiratory characteristics are stronger predictors than anthropometric variables. For power per body mass, our analyses showed that estimated relative aerobic capacity was a stronger predictor. That is, in our study, estimated relative aerobic capacity (e. VO2max) was the strongest predictor. This is in line with the results of previous studies where relative aerobic capacity was also identified as the strongest predictor (Cosgrove et al., 1999; Kendall et al., 2011; Mikulić & Ružić, 2008). Power per body mass (rWatt) was strongly correlated with estimated relative aerobic capacity (e.r. VO2max) in our sample. Previous studies have reached a similar conclusion that there is a strong relationship between maximum relative aerobic capacity and rowing performance (Cosgrove et al., 1999; Gillies & Bell, 2000; Mikulić, 2009; Mikulić & Ružić, 2008; Yoshiga et al., 2000). In the two-kilometer rowing ergometer exercise, estimated relative aerobic capacity (e.r. VO2max) increases significantly over the whole sample. This is accompanied by significantly higher relative power (rWatt), except for the female age groups one and two. While a similar correlation was found only between the female age groups for the six-kilometer distance, the male groups performed consistently despite significantly higher estimated relative aerobic capacity in age groups two and three. In any case, several researchers have suggested that the maximum aerobic power in watts is an important parameter in predicting rowing times in 2000m tests. (Ingham et al., 2002; Jürimäe et al., 2000; Riechman et al., 2002; Womack et al., 1996) In our opinion, it is important to pay due attention to the anthropometric characteristics under study when selecting successful junior rowing athletes. This is all the more important since the cardio-respiratory system of a junior athlete with optimal abilities, which shows a significant relationship with performance and thus with results, can be developed through appropriate training.

The predictive values of the variables presented in this study can be considered an important complement to the rowing talent identification objectives. Considering the relationships between body height, body mass, arm load, seat height and performance in the present study, the use of the variables discussed above may be logical in the initial stages of the talent identification process. In rowing, therefore, these results can be used in the later stages of the talent identification process, as these tests can be performed through movement technique and athletic experience. Strong correlations were observed between certain anthropometric and circulatory indicators and performance. Therefore, the physical effects of these indicators on rowing performance should not be underestimated.

CHAPTER 5: Differences in the anthropometric and physiological profiles of Hungarian male rowers of various age categories, rankings and career lengths: selection problems (Study 2)

Note: This article has been accepted for publication and the final published version is presented in this dissertation. The final published version is available and can be downloaded online from the publisher's website:

Alföldi, Zoltan – Borysławski, Krzysztof – Ihasz, Ferenc [et al.] (2021): Differences in the Anthropometric and Physiological Profiles of Hungarian Male Rowers of Various Age Categories, Rankings and Career Lengths: Selection Problems. In: *Front Psychol*, 12:747781.

5.1. Abstract

Background: Little is known about the anthropometric and physiological profiles of lower-ranking athletes who aspire to rise to the pinnacle of their profession.

Aim: The aim of this study was to create anthropometric and physiological profiles of Hungarian male rowers of different age categories (15-16, 17-18, and over 18 years), sports rankings and career lengths.

Materials and methods: Anthropometric and physiological profiles were created for 55 juniors, 52 older juniors and 23 seniors representing seven of the largest Hungarian rowing clubs. One-way independent analysis of variance (ANOVA) was used to compare arithmetic means.

Results: Rowers in older age categories were significantly taller (185.0±5.0 cm vs 183.0±7.3 cm vs 178.7±7.2 cm) and heavier (81.1±8.8 kg vs 73.7±8.4 kg vs 66.8±12.3 kg) than their younger peers, with significantly higher BMI values and larger body dimensions. Compared to younger athletes, rowers in older age categories also covered 2000 m significantly faster (6.6 ±0.3 min vs 6.9 ± 0.4 min vs 7.5 ± 0.5 min) while developing significantly more power (372.2 ± 53.0 W vs 326.8 ± 54.5 W vs 250.6 ± 44.6 W). Similarly, seniors and older juniors had higher values of maximal oxygen uptake and force max (by 6.2 and 7.0 ml/kg/min, and by 263.4 and 169.8 N). Within the older juniors, internationally ranked rowers had significantly greater body height (+5.9 cm), body mass (+6.1 kg), sitting height (+2.7 cm), arm span (+7.9 cm), limb length (+3.73 cm) and body surface area (+0.21 m^2). They also rowed 2000 m significantly faster (– 0.43 min, $p < .001$) and had significantly higher values of power (+58.3 W), relative power (+0.41 W/kg), jump height (+4.5 cm), speed max (+0.18 m/s) and force max (+163.22 N).

Conclusions: The study demonstrated that potential differences in anthropometric and physiological profiles are more difficult to capture in non-elite rowers, and that the final outcome may be determined by external factors. Therefore, athletes with superior aptitude for rowing are more difficult to select from among lower-ranking rowers, and further research is needed to determine specific training requirements to achieve the maximum rowing performance.
Keywords: rowing, age categories, ranking, seniority, anthropometric and physiological characteristics.

5.2. Introduction

Rowing is a sport discipline that has been extensively studied (Shephard, 1998). Penichet-Tomás, Pueo & Jiménez-Olmedo (2019) defines it as a cyclic sport with a strength endurance nature in which successful performance depends on technical (Baudouin & Hawkins, 2004; Shaharudin & Agrawal, 2016), anthropometric/biomechanical (Alacid et al., 2011; Almeida-Neto et al., 2020; Battista et al., 2007; Bourgois, 2000; Forjasz, 2011) and physiological characteristics (Jürimäe et al., 2010; Maciejewski et al., 2019; Majumdar, Das & Mandal, 2017; Messonnier et al., 1997; Mikulić & Ružić, 2008; Slater, 2005).

Performing simulations of official competitions can be of great value for evaluating and advancing athletes' performance (Keenan, Senefeld & Hunter, 2018; Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019). To improve rowing training methods and the selection of athletes with superior aptitude for the sport, it is useful to conduct both studies that assess the motor development of rowers and those that examine the relationship between rowers' anthropometric and physiological characteristics and the results that they obtain (Koutedakis, 1989; Lawton, Cronin & Mcguigan, 2011). The anthropometric characteristics of athletes often reflect the physiological, functional, and biomechanical demands of their specific sport as well as modifications associated with training and diet (Battista et al., 2007). However, as Mikulić (2008) points out, some characteristics (e.g., anthropometric length and breadth measurements) are almost exclusively genetically determined and can be difficult to change via training (Mikulić & Ružić, 2008). Therefore, precise information regarding the anthropometric and physiological status of rowers is a fundamental issue in contemporary rowing.

In sports demanding high force production, muscle mass may be closely associated with performance outcomes (Kavvoura et al., 2018; Peterson, Alvar & Rhea, 2006). In these sports in general and in Olympic rowing in particular, greater fat-free body mass may favor increased performance in competition (Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019; Schranz et al., 2010). In addition, given the importance of force production, anthropometric variables (i.e., body mass, body height, length of legs and body span) and muscular strength endurance of the trunk and upper and lower limbs are also associated with rowing performance (Maciejewski et al., 2019; Majumdar, Das & Mandal, 2017).

Reports on the anthropometric characteristics of adult rowers (females and males) stress the importance of body mass (Bourgois, 2000; Forjasz, 2011; Giroux et al., 2017; Maciejewski et al., 2019; Secher & Vaage, 1983) and body size and proportions (Hebbelinck et al., 1980; Majumdar, Das & Mandal, 2017; Mikulić & Ružić, 2008; Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019; Schranz et al., 2010) as determinants of success in rowing at the international level. A comparative study of male and female fixed-seat rowers revealed that body height was the best predictor of performance in male rowers, and muscle mass – in female rowers (Penichet-Tomas et al., 2021). This observation could suggest that high lean body mass and a favorable power-to-body mass ratio are better predictors of success than high body mass because increased body mass and BMI negatively impacted on career attainment (Winkert et al., 2019).

More detailed analyses have also taken other factors into account in relation to anthropometric and physiological characteristics and performances in motor tests and sport competitions. These factors include different rowing modalities, such as sliding seat or fixed seat rowing (Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019); different boat types, i.e., sweeping or sculling (Claessens et al., 2005); events, e.g., single scull, skiff, or coxless pair (De Larochelambert et al., 2020); position occupied in the boat (Lawton, Cronin & Mcguigan, 2011); weight category, i.e., heavyweight or lightweight (Steinacker, 1993); ranking, e.g., world and Olympic champions vs club members and college/university rowers (Mikulić & Ružić, 2008); and age, e.g., juniors vs older juniors vs seniors (Mikulić, 2008). These analyses have shown that, in general, more successful rowers are typically taller and heavier than less successful ones (Bourgois, 2000). Junior rowers are generally similar to adult heavyweight rowers in stature, except that the juniors tend to be lighter (Mikulić, 2008). Physiologically speaking, elite rowers differ from their less successful peers in terms of a higher average VO2max, and they typically have better technique, with a more efficient recovery phase (particularly with regard to the timing of forces at the catch), a faster stroke rate and a stronger, more consistent and effective propulsive stroke (Hagerman, 1984; Hofmijster et al., 2007; Lawton, Cronin & Mcguigan, 2011; Smith & Spinks, 1995). If all other factors are equal, rowers who can maintain greater net propulsive forces will achieve faster boat speeds (Lawton, Cronin & Mcguigan, 2011; Smith & Spinks, 1995).

In addition to size and physique, relative body proportions are important in rowing, in particular relative arm length and leg length (Claessens et al., 2005). A report comparing medalists and non-medalists at world championships indicated that the more successful lightweight rowers were more mesomorphic and less endomorphic and tended to have a shorter sitting height and longer upper and lower extremities (Rodriguez, 1986), which increase biomechanical efficiency. These findings are consistent with those of reports on heavyweight rowers (Kleshnev & Kleshnev, 1998; Shephard, 1998). Proportionally longer arms and legs not only correspond to a larger size but also give sweep rowers a biomechanical advantage due to the increased length of the levers (Claessens et al., 2005; Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019; Piotrowski et al., 1992; Skład, Krawczyk & Majle, 1993; Skład, Krawczyk & Majle, 1994). The best younger oarsmen also tend to be taller and heavier and have greater length, breadth and girth than their less successful peers (Bourgois, 2000; Forjasz, 2011; Mikulić, 2008).

A 2000 m Olympic rowing competition requires a mixture of aerobic and anaerobic power (Wolf, 2021). These events require maximum exertion for a duration of five to seven minutes (Steinacker et al., 1986). During this time, the relative anaerobic contribution ranges from 21 to 30% (Secher, 1993), which means that, in addition to a large aerobic capacity, a highly developed anaerobic capacity is also essential for successful international performance (Hagerman, 1984; Mäestu, Jürimäe & Jürimäe, 2005).

In general, rowing imposes heavy physiological demands, requiring a high degree of power and endurance, and a successful performance also requires a high level of technical proficiency (Keenan, Senefeld & Hunter, 2018). According to Jurišić et al. (2014), aerobic metabolism provides 75–80% of the energetic demands during a rowing competition. Thus, as would be expected, elite rowers display impressive aerobic capacities: the VO2max of internationally successful rowers regularly exceeds 5 l/min, it exceeds 6.0 l/min fairly often, and it sometimes reaches or exceeds 6.5–7.0 l/min at ventilation values above 240 l/min (Jurišić et al., 2014; Secher, 1993; Steinacker, 1993). In sliding-seat Olympic rowing, around 75–80% of the power produced by successful elite rowers during a rowing stroke comes from their legs, and around 20–25% from their arms (Cosgrove et al., 1999). Various researchers have mentioned the ability of rowers to tolerate relatively high lactic acid (LA) concentrations during both rowing (Jürimäe et al., 2000; Steinacker, Kellmann & Böhh, 1999) and leg press exercises that were conducted at individual physical working capacity (PWC) (calculated as heart rate (HR) 205–1/2 age) (Jürimäe et al., 2010). During the leg press exercise test, the subjects achieved a mean of 113.4 ± 38.5 repetitions with a mean duration of 450.2 ± 99.1 s, a mean HR of 137.4 ±

14.2 beats min^{-1}, and a mean LA concentration of 7.62 ± 2.83 mmol l^{-1}. The practical significance of these findings is that rowing exercise should stimulate increased oxygen uptake and raise the threshold (in terms of percentage of maximum oxygen uptake) at which blood LA concentration begins to increase substantially (Jurišić et al., 2014).

A review of the literature indicates that most published studies described the profiles of highly successful athletes and/or compared them with the profiles of lower-ranking rowers. Meanwhile, variables such as age category, ranking and length of the sports career have been explored by very few researchers. Moreover, there is a general scarcity of studies that approach the subject in a comprehensive manner and analyze intermediate rowers who have not yet achieved international success. Therefore, it remains unknown whether endogenous factors (anthropometric and physiological characteristics) determine the success of intermediate level athletes, or whether other external factors (such as organizational factors) also play a role. Trainers working with intermediate rowers could find it more difficult to capture minor differences in the anthropometric and physiological profiles of athletes that differ in ranking and career length. As a result, the elements of the training program may not be adapted to specific training goals, which can undermine the program's effectiveness. It should also be noted that the number of athletes characterized by lower rowing performance is much higher than the number of elite athletes who win the most prestigious rowing championships. Hungarian rowers belong to the latter group. Only one Hungarian rower qualified for the Tokyo 2021 Olympic Games in Tokyo, and he ultimately came tenth in the men's single scull category. Therefore, this study had two objectives: a) to develop anthropometric and physiological profiles of Hungarian male rowers belonging to different age categories, (15-16, 17-18, and over 18 years), had different sports rankings (international vs club) and different career lengths (seniority levels); b) to identify and explain potential differences between the analyzed groups of athletes who do not represent the highest level of rowing performance.

5.3. Materials and methods

Participants

The study was conducted in Gyor Rowing Club, and the sample consisted of 130 male rowers from the seven largest Hungarian rowing clubs. The study lasted for three consecutive days in the middle of the racing season (8 days after one rowing regatta and 7 days before the next rowing regatta). The participants were selected by targeted sampling (based on the researchers' arbitrary decision), and all rowers from the seven clubs were analyzed in the sampling process. The participants differed in ranking and length of sports career. Each rower was assigned to one of the three age categories: juniors (N=55, range: 15 – 16 years), older juniors (N=52, range 17 – 18 years), and seniors (N=23; over 18 years). The senior group was relatively young, and the oldest senior rower was only 22. The following inclusion criteria were applied in the targeted sampling procedure: rowers in all age groups had to hold a valid competition license and participate in national and/or international competitions for minimum one year. All rowers had valid medical certificates; they participated regularly in training, and they did not limit their physical activity levels (for whatever reason) to the extent that could significantly affect their motor fitness. The training program was consistent with the guidelines of the Hungarian Rowing Federation Training Plan: 12-13 hours/week for 15- to 16-year-olds, 14-15 hours/week for 17- to 18-year-olds, and 16-17 hours/week for 19- to 22-year-olds. The aerobic-to-anaerobic training ratio in the above groups was 80:20%, 75:25 and 70:30%, respectively. Athletes with an international ranking participated in training camps organized by the Hungarian Rowing Federation two to three times a year (depending on age group). It was hypothesized that the anthropometric and physiological characteristics of the rowers, as well their performance while rowing a 2000 m distance and on motor tests would differ depending on their age, ranking, and length of sports career.

This research was conducted in line with the guidelines and policies of the Health Science Council, Scientific and Research Ethics Committee (IV / 3067-3 / 2021 / EKU), Hungary, and in accordance with the Declaration of Helsinki. Each participant was provided with detailed information about the purpose of the study, potential risks, measurement methods, and the techniques in motor tests that could be practiced during training sessions held directly before the study. All rowers gave voluntary informed consent to participate in the study by signing consent forms.

Procedures, data collection and equipment

Each rower was subjected to anthropometric and physiological tests in the middle of the 2020 racing season. On day one, anthropometric features were measured, on day two, the athletes performed motor tests, and on day three, they covered a distance of 2000 m.

The coaches in charge of the rowers in the sports clubs helped us with the measurements. At all times, the coaches were instructed not to engage the subjects in any strenuous training the day before the testing took place. Each subject was always tested in the morning and the participants were instructed to eat a light meal (800-1200 kcals) containing mainly carbohydrates (60-70%) not later than 3-4 hours before the study (Williams, 1999). Body height was measured to the nearest 1 mm with a calibrated Soehlne Electronic Height Rod

5003 (Soehlne Professional, Germany) according to standardized guidelines. Body mass (measured to the nearest 0.1 kg), BMI and body composition characteristics, such as body fat percentage (BFP) and skeletal muscle mass (SMM), were determined by bioelectrical impedance with an InBody 720 body composition analyzer. The remaining anthropometric characteristics, such as sitting height [cm], arm span [cm], limb length [cm] and BSA [m^2], were measured with the use of the Weiner and Lourie methods (1969). Skin fold measurements (biceps, triceps, scapula, suprailiac, abdomen, thigh, lower leg) were obtained using a Harpenden caliper.

Estimation of relative body fat content

The calipermetric estimation of relative body fat content that was developed by Pařízková (1961) was used. This procedure requires the measurement of 5 skinfold thicknesses: over the biceps and triceps, subscapular, suprailiac and medial calf. The sum of the 5 skinfold values is multiplied by 2; the product is then used to look up the estimated relative body fat content in a table.

Countermovement jumping

The power output of the lower extremities and the height attained by the center of body mass during vertical jumps were measured with a PJS-4P60S force plate ("JBA" Zb. Staniak, Poland) with a 400 Hz sampling rate (Batra et al., 2021; Gajewski et al., 2018). The force plate was connected via an analog-to-digital converter to a PC with the MVJ v.3.4 software ("JBA" Zb. Staniak, Poland). The amplifier was connected to a PC via an A/D converter. For measurement, the MVJ v. 3.4. software package ("JBA" Zb. Staniak, Poland) was used. In the physical model that was used for calculations, the subject's body mass was treated as a point affected by the vertical components of external forces: the force of gravity acting on the body and the vertical component of the platform's reactive force. Each subject performed three counter-movement jumps (CMJ) with maximal force. A CMJ is a vertical jump from a standing erect position, preceded by a counter- movement of the upper limbs and lowering of the body mass center before take-off. Each subject was asked to perform a countermovement jump from the force plate to determine maximal force [N] and the rate of displacement [m/s]. From these measurements, jump height (by integrating ground reaction forces) [cm] and peak power [W] were determined. Using the body mass of the subject, the relative peak power [W/kg] was calculated.

2000 m. Maximal Rowing Ergometer Test

The participants were asked to perform an all-out 2000 m test a certified rowing ergometer (Concept 2 D-model). The screen of the ergometer was set to display the number of meters remaining, the average 500 m time and the accumulated time.

The power output in watts (W) was measured over 2000 m. The calculation of watts was performed as follows: First, the distance was defined: distance = (time / number of strokes) ×500. In the next step, the concept of a "split" was clarified: split = 500 × (time / distance). The watts were calculated as 2.8 / (split / 500). There were slight differences in intensity due to individual changes in stroke value and ability to keep the 500 m split time constant. Prior to all tests, each participant warmed up for 6 minutes on a 500 m distance. Participants then rested for 6 minutes, during which time they performed stretching exercises. The estimated relative aerobic capacity (ErVO2) was calculated by using the formula of McArdle, Katch & Katch (2006) for men: ErVO2 = (Y × 1000) / BM, where BM is body mass, and Y = [BM <75kg; 15.1- (1.5 × time)]; BM => 75kg; 15.7- (1.5 × time)]. The power delivered over 2000 meters was divided by body weight to obtain the relative performance (rW 2k).

Due to time and logistical constraints, including the need to perform a relatively high number of separate measurements within three consecutive days in a specific club to minimize disturbances to the athletes' training and changes in their condition, this study did not examine heart rates (HR) and all indicators of acid-base balance, such as the concentration of lactic acid in the blood, alkaline deficiency or excess, blood pH and current molecular pressure of CO_2.

Statistical analysis

Measurements were statistically processed with Statistica PL, v. 13.5. Based on the median length of participation in rowing competitions (juniors, 3 years; older juniors, 5 years; seniors, 7 years), the athletes in each age category were further divided into two subcategories: greater and lesser seniority. The rowers were ranked as international (participants in international competitions) or club (participants in inter-club competitions at the national level) level. Normality was verified with the Shapiro-Wilk test. It was checked that all tested features have normal distributions. Therefore, for comparisons of two arithmetic means, Student's *t*-test was used. To compare three arithmetic means, one-way analysis of variance (ANOVA) was used. If ANOVA indicated a significant difference, Tukey's Honestly Significant Difference (HSD) test was used for post-hoc analysis. Cohen's d was used as a measure of the effect size of differences between male and female rowers and interpreted according to modified thresholds for sports sciences as trivial (0.2), small (0.21–0.6), moderate (0.61–1.2), large (1.2–1.99), and very large (>2.0). Statistical significance was set at $p \leq 0.05$.

5.4. Results

Analysis 1: Anthropometric and physiological characteristics

Table 1 presents the anthropometric characteristics, body composition, motor performance and physiological characteristics of the male rowers in the following age categories: juniors (15-16 years), older juniors (17-18 years) and seniors (18-22 years). Senior and older junior rowers were significantly larger than junior rowers in terms of height and body mass (height: +6.25 and 4.32 cm, respectively; body mass: 14.32 and 6.88 kg; p-values for all comparisons are given in Table 1). Seniors were also significantly heavier than older juniors (+7.44 kg; p =.011). Regarding BFP, seniors had a significantly higher value than juniors and older juniors (+4.28 and +3.83%, respectively; p = .006 and p = .014, respectively). FFM did not differ significantly between these groups. Although older groups had significantly higher BMI than younger groups, the values of all groups were within the norms (20.8 - 23.72 kg/m^2). Sitting height and arm span were significantly less in the youngest group than in the other two groups (for both comparisons, p < .001), but these measurements did not differ significantly between the older juniors and the seniors. Body surface area was also significantly larger in older groups than in younger groups (p-values ranged from p = .017 to p <.001), but the groups did not differ significantly in terms of limb length, skin fold thickness and body fat estimated by Pařízková`s formula. The seniors covered the 2000 m distance in a significantly shorter time than the older juniors and juniors (respective differences: 0.31 min and 0.95 min; p = .019 and p < .001), and older juniors covered this distance 0.64 min faster than juniors (p <.001). The peak power that was generated also differed significantly between these groups: seniors generated 45.4 W more than older juniors and 121.7 W more than juniors (p = .002 and p < .001, respectively); older juniors surpassed juniors by 76.3 W (p <.001). Senior and older junior rowers also had significantly higher maximal oxygen uptake than juniors (by 6.2 and 7.0 ml/kg/min; p = .002 and p < .001, respectively) and force max (by 263.4 and 169.8 N; p < .001 and p = .009, respectively). In terms of jump height, speed max and relative peak power (RPM), seniors and older juniors did not differ significantly, but these values were significantly lower in the juniors than in the older juniors (by 4.57 cm, 0.15 m/s, 3.98 W/kg; p < .001, p = .003 and p = .006, respectively).

Table 1. Comparison of arithmetic means of **men's** anthropometric, physiological and motoric parameters depending on the age categories [ns- non significant differences].

Characteristics		Age category [years] (1) 15-16 (N=55)			(2) 17-18 (N=52)			(3) 19-22 (N=23)			Difference		HSD (*post-hoc*)			Cohen's *d*		
		Mean	**SD**	**min-max**	**Mean**	**SD**	**min-max**	**Mean**	**SD**	**min-max**	***F***	***p***	**1-2**	**2-3**	**1-3**	**1-2**	**2-3**	**1-3**
Body height [cm]		178.70	7.22	162.1-	183.02	7.27	167.7-	184.96	4.98	174.4-	8.66	<0.001	0.004	*ns*	<0.001	0.66	016	1.11
Body mass [kg]		66.82	12.27	39.6-	73.70	8.43	56.6-89.7	81.14	8.80	62.1-	16.72	<0.001	0.002	0.011	<0.001	0.66	0.86	1.34
Body fat [%]		12.39	5.54	4.0-28.9	12.84	5.39	5.3-33.0	16.67	4.33	9.4-22.9	5.38	0.006	*ns*	0.014	0.006	0.07	0.84	0.79
Skeletal muscle mass		41.90	5.04	14.1-52.6	43.30	3.47	27.2-49.2	41.12	3.83	29.9-46.6	2.50	*ns*	*ns*	*ns*	*ns*	0.32	0.60	0.42
BMI [kg/m^2]		20.82	2.97	15.02-	21.98	2.10	18.28-	23.72	2.43	18.28-	10.63	<0.001	0.049	0.018	<0.001	0.42	0.64	0.90
Sitting height [cm]		92.50	4.60	79.4-	95.33	3.56	87.5-	96.56	2.04	93.9-	11.87	<0.001	<0.001	*ns*	<0.001	0.67	0.40	1.00
Arm span [cm]		181.13	13.00	104.3-	188.43	8.56	168.5-	189.29	5.53	179.7-	8.58	<0.001	<0.001	*ns*	0.004	0.66	0.12	0.71
Limb lenght [cm]		101.01	4.07	92.1-	102.40	4.98	90.3-	103.02	3.98	96.5-	2.14	*ns*	*ns*	*ns*	*ns*	0.29	0.13	0.20
BSA [m^2]		1.67	0.36	0.89-3.08	1.88	0.26	1.32-2.31	2.09	0.25	1.50-2.63	16.87	<0.001	<0.001	0.017	<0.001	0.69	0.80	1.25
Skin fold thickness [mm]	Biceps	7.04	3.57	2-20	5.69	3.13	3-21	5.96	2.69	3-12	2.44	*ns*	*ns*	*ns*	*ns*	0.39	0.08	0.32
	Triceps	14.16	5.66	5-29	12.08	4.50	5-26	12.65	4.57	5-20	2.36	*ns*	*ns*	*ns*	*ns*	0.39	0.12	0.28
	Scapula	10.96	4.57	4-31	9.96	3.16	6-23	10.70	3.48	3-18	0.91	*ns*	*ns*	*ns*	*ns*	0.37	0.11	0.35
	Suprailiac	9.95	5.66	4-33	8.26	3.76	4-21	8.52	2.29	5-13	2.04	*ns*	*ns*	*ns*	*ns*	0.40	0.20	0.26
	Abdomen	14.06	6.89	5-42	12.29	4.81	5-26	12.48	3.82	7-22	1.44	*ns*	*ns*	*ns*	*ns*	0.28	1.12	0.30
	Thigh	20.36	7.84	6-46	18.45	7.54	7-39	18.48	6.01	4-29	1.04	*ns*	*ns*	*ns*	*ns*	0.31	0.14	0.27
	Lower	14.07	6.27	4-30	12.31	5.99	5-30	13.39	4.46	4-22	1.18	*ns*	*ns*	*ns*	*ns*	0.29	0.18	0.31
Body fat [%] *)		23.03	4.04	13.8-31.5	21.86	4.14	14.5-30.9	22.43	3.62	12.2-26.6	1.13	*ns*	*ns*	*ns*	*ns*	0.22	0.14	0.15
Peak power [W]		250.55	44.60	138-322	326.80	54.48	210-435	372.22	52.96	292-461	54.99	<0.001	<0.001	0.002	<0.001	0.47	0.84	2.56
RPP [W/kg]		3.76	0.53	2.11-4.71	4.42	0.51	3.10-5.31	4.59	0.45	3.57-5.35	30.74	<0.001	<0.001	*ns*	<0.001	1.26	0.34	1.62
Time 2000 m [min]		7.51	0.51	6.85-9.09	6.87	0.41	6.20-7.90	6.56	0.32	6.08-7.08	46.61	<0.001	<0.001	0.019	<0.001	1.35	0.79	2.02
ErVO_2 max [mL/kg/min]		66.43	9.49	38.32-	73.44	6.31	56.69-	72.61	5.59	60.76-	11.59	<0.001	<0.001	*ns*	0.005	0.87	0.75	0.54
Jump height [cm]		36.02	4.97	23.5-44.4	40.59	7.62	24.7-58.9	38.44	6.31	22.9-51.0	6.86	0.001	<0.001	*ns*	*ns*	0.71	0.30	0.54
Speed max [m/s]		2.59	0.19	2.06-2.91	2.74	0.29	1.97-3.33	2.66	0.24	2.08-3.09	5.43	0.005	0.003	*ns*	*ns*	0.40	0.14	0.34
Force max [N]		1551.35	323.58	899-2317	1721.19	283.77	1180-	1814.74	272.22	1328-	7.75	<0.001	0.009	*ns*	0.001	0.55	0.33	0.84
RPM [W/kg]		48.43	5.69	34.8-60.9	52.41	7.88	30.2-63.4	49.39	6.04	36.3-63.2	4.90	0.009	0.006	*ns*	*ns*	0.58	0.40	0.17

(*) Pařízková`s formula; *ns* – not statistically significant, RPP – relative peak power, RPM – relative maximal power, ErVO_2 – estimated relative maximal aerobic capacity, Cohen's *d* – effect size

Analysis 2: Ranking of rowers

In the groups of older juniors and juniors, significant differences in the studied characteristics were associated with differences in ranking (club vs international). The older juniors had the larger number of significant differences between these ranking categories (tab. 2). In this age group, the internationally ranked rowers were significantly taller (+5.88 cm, p =.0027) and heavier (+6.1 kg, p = .0078), and they had a longer sitting height (+2.67 cm, p =.0058), arm span (+7.90 cm, p = .0051), limb length (+3.73 cm, p = .0058), and BSA (+0.21 m^2, p=.0028). Rowers in the older junior category with an international ranking were significantly taller (+5.88 cm, p=.0027) and heavier (+6.1 kg, p=.0078) than their club level peers, and they had a longer sitting height (+2.67 cm, p=.0058), arm span (+7.90 cm, p=.0051), and limb length (+3.73 cm, p=.0058), as well as a larger BSA (+0.21 m^2, p=.0028). In addition, they covered the 2000 m distance in significantly less time (-0.429 min, p<.0001) and developed greater peak power (+58.3 W, p<.0001) and relative peak power (+0.41 W/kg, p=.0037). In motor tests, they obtained higher jump height (+4.5 cm, p=.0325), speed max (+0.178 m/s, p=.0255), and force max (+163.22 N, p=.0373).

Regarding the juniors, two of their characteristics differed significantly between the ranking categories: international level juniors achieved higher power (+29.91 W, p=.0274) and covered 2000 m in a shorter time (-0.342 min, p=.0271). These groups also differed in terms of some other characteristics, although the differences were not statistically significant.

Analysis 3: Length of rowers' sports careers

In all age categories, the length of the athletes' sports career was not associated with significant differences in anthropometric characteristics, body components, results of motor performance tests, and time to complete a 2000 m distance (p>.05). The only exception was the level of adipose tissue in lower leg skin, which was significantly higher (difference: +3.48 mm, p = .044) in the group of rowers that had competed for a shorter time, which is probably due to chance. Interestingly, however, even though the differences were not statistically significant, senior and older junior rowers tended to have higher body mass (+1.40 kg and +2.68 kg, respectively), fat percentage (+1.86 % and +0.71%, respectively), and BMI (+0.61 kg/m^2 and 1.45 kg/m^2, respectively).

Table 2. Comparison of arithmetic means of **older junior male rowers** anthropometric, physiological and motoric parameters depending on the ranking categories.

Characteristics	**Ranking category**				**Difference**		**Cohen's *d***
	International		**Club** (N=28)				
	Mean	**SD**	**Mean**	**SD**	***t***	***p***	
Body height [cm]	186.18	5.23	180.30	7.74	3.15	0.003	0.97
Body mass [kg]	76.98	6.23	70.88	9.13	2.77	0.008	0.79
Sitting height ([cm]	96.77	3.24	94.10	3.40	2.88	0.006	0.83
Arm span [cm]	192.68	6.04	184.78	8.79	3.71	0.001	1.19
Limb length [cm]	104.41	3.96	100.68	5.18	2.88	0.006	0.80
BSA [m^2]	1.99	0.19	1.78	0.28	3.14	0.003	0.88
Peak power [W]	356.54	41.38	298.24	50.60	4.40	<0.001	1.26
RPP [W/kg]	4.63	0.42	4.22	0.52	3.05	0.004	0.87
Time 2000 m [min]	6.65	0.27	7.08	0.41	-4.30	<0.001	1.24
Jump height [cm]	43.01	6.04	38.51	8.31	2.20	0.033	0.62
Speed max [m/s]	2.84	0.21	2.66	0.32	2.30	0.026	0.67
Force max [N]	1809.08	249.97	1645.86	293.47	2.14	0.037	0.61

Legend: BSA- Body Surface Area, RPP- Relative Peak Power (watt/kg), Body height [cm], Body mass [kg], Sitting height (cm), Arm span [cm], Limb length [cm], Peak power [W], Time 2000 m, Jump height [cm], Speed max [m/s], Force max [N], p- significant, s d- Cohen.

5.5. Discussion

Anthropometric and body composition profiles

Rowers in specific age categories were assessed in terms of skeletal structure (body height, body mass, sitting height, arm span, limb length, BMI, BSA), body composition (BFP, SMM) and thickness of skin folds (biceps, triceps, scapula, suprailiac, abdomen, thigh, lower leg). It was found that rowers in older age categories had higher body mass, BMI, and BSA than their younger peers. Compared to the juniors, seniors and older juniors had greater body height, sitting height, and arm span. These results are similar to those of a study of Croatian rowers by Mikulić (2008). In that study, Croatian champions and members of the Croatian national team were classified into elite seniors (28.1±3.0 years), sub-elite juniors (22.16±2.8 years), and elite juniors (17.6±0.4 years). They found that the elite seniors were taller and heavier than the sub-elite juniors (+5.4 cm, 4.3 kg) and the juniors (+5.1 cm, + 11.1 kg).

Rowers with larger body dimensions (body mass, body height, length of lower and upper extremities) achieve proportionally better rowing performances (Cosgrove et al., 1999; Mikulić, 2008; Yoshiga & Higuchi, 2003). This is probably the reason why, in the present study, the seniors and older juniors, who had larger body dimensions than the juniors, covered 2000 m faster and developed more peak power, RPP and force max over this distance, while achieving a higher $ErVO_{2max}$. However, with regard to jump height, speed max, and RPM, only the older juniors differed significantly from the juniors.

Hungarian rowers in the senior age group had significantly higher values of BFP than older juniors and juniors. A similar phenomenon was observed in Croatian elite rowers, where BFP was lower in the juniors than in the elite and sub-elite seniors, although no difference was observed between the two groups of seniors (Mikulić, 2008). Similar differences were found in Belgian rowers: compared to non-finalists, finalists were heavier and taller with greater length, breadth (expect for the bicrystal diameter), and girth (Bourgois, 2000).

In the present study, many of the differences in anthropometric characteristics between the international and club level rowers were not statistically significant. These results are properly interpreted as inconclusive, as explained by the guidelines of the American Statistical Association (Wasserstein & Lazar, 2016) and many other experts (Amrhein et al., 2017; Greenland et al., 2016). Therefore, the present results are not necessarily in disagreement with the findings of Secher (1975), who found that the body mass of internationally competitive rowers was greater than that of club rowers, or the results of Penichet-Tomás, Pueo & Jiménez-Olmedo (2019), who reported that higher-performing rowers had significantly larger anthropomorphic measurements than lower-performing ones. Our assumptions were confirmed by the fact that all of the examined rowers were only aspiring to become elite performers, and none of them was a finalist of prestigious rowing regattas. In addition, the senior group was relatively young (19-22 years), whereas the average age of male and female single scullers in the Olympic finals has risen by roughly seven years, from around 24 to 31. The above can be attributed to the fact that elite rowers' efficiency remained stable because their oxygen uptake at 300 W was similar at the ages of 25 and 31. Some elite rowers, such as Steven Redgrave and Eskild Ebbesen, won their last Olympic titles at the age of 38 and 40, respectively (Nybo et al. 2014). Thus, it would be interesting to perform another study with a different sample of Hungarian rowers or measure the same individuals in the following years to see if the differences between the groups being compared would continue to be statistically non-significant when taking rankings and length of sporting career into account. The only exception was the group of older juniors, where significant differences in anthropometric and physiological characteristics were noted between rowers with international and club rankings, and where the studied parameters were more favorable in the former category of athletes. There are several reasons why older juniors with an international ranking had an advantage over their peers with a club ranking. Firstly, these athletes had participated in the highest number of training camps (qualification rounds) during the selection of the Hungarian national team. Secondly, they were most successful in rowing events, both in terms of the scored results and the rank of rowing regattas.

The mean body mass of the senior rowers in this study (81.14 kg) is similar to that of the elite Olympic rowers measured by Forjasz (2011), which ranged from 80 to 85 kg. The Hungarian senior rowers in the present study had a mean height of 184.96±4.98 cm, which is also very similar to what Forjasz (2011) measured.

In the present study, the differences in FFM between age categories were not statistically conclusive. However, Mikulić (2008) found that FFM was greater in elite seniors than in elite juniors (+ 6.1 kg). Moreover, rowing performance has generally been found to correspond closely to FFM values (Cosgrove et al., 1999; Yoshiga et al., 2000), and FFM is considered one of the best predictors of performance (Ingham et al., 2002; Riechman et al., 2002). Thus, it would be interesting to investigate the FFM of Hungarian rowers with a different sample, and perhaps combine those results with the results of this study via statistical meta-analysis.

For rowers, BMI values of approx. 24 kg/m^2 are considered optimal Olympic rowing (Barrett & Manning, 2004; Claessens et al., 2005; Sanada et al., 2009), but the BMI of traditional rowers is sometimes higher (Penichet-Tomas et al., 2021). The mean BMI value of the elite seniors in the present study (23.72 kg/m^2) was very close to this benchmark, while those of all the other rowers were within normal limits (range: 20.82 – 23.72 kg/m^2). However, when considering these results, it is important to remember that the BMI does not give reliable information about the body composition of sports athletes and does not allow an important distinction to be made between the distribution of fat and muscle tissue in the lower and upper half of the body (Garrido-Chamorro et al., 2009; Mazic et al., 2009).

Physiological and motor performance profile

The results of the study presented here support the conclusion of Jurisić et al. (2014) that aerobic metabolism predominantly determines success in a 2000 m rowing race on a simulator. Although lactate anaerobic threshold was not assessed in this study, older rowers finished the 2000m simulation in significantly less time than their younger counterparts while attaining higher values of ErVO2max and RPP. In addition, the older rowers developed significantly more power than their younger peers, and the seniors and older juniors developed significantly higher force max values than the juniors although the difference between the seniors and older juniors was not statistically significant.

The mean VO2max values of the junior, older junior and senior Hungarian rowers examined in the present study were higher than those reported for Croatian rowers (Mikulić, 2008) (66.43, 73.44, and 72.61 $mLmin^{-1}kg^{-1}$ vs. 62.5, 55.3, and 58.4 $mLmin^{-1}kg^{-1}$, respectively). When combining all these results with those of a study of Croatian 12–13-year-old rowers ($VO2_{max}$:48.8 $mLmin^{-1}kg^{-1}$) (Mikulić & Ružić, 2008), it appears that there is a general trend of $VO2_{max}$ values increasing during the early years of training when rowers are at younger ages. This increase could be due in part to the fact that the growth processes of men continue up to 21 years of age, and these processes contribute substantially to rowing performance (Almeida-Neto et al., 2020). However, an analysis of changes in the maximal oxygen uptake at certain ages of Polish male rowers showed substantial improvement at 19-19.9 and 21-22 years (Klusiewicz et al., 2014). Maximal oxygen uptake, which is the gold standard for cardiorespiratory fitness, is a multifactorial trait influenced by environmental factors (e.g., exercise training) and genetic factors (Mann, Lamberts & Lambert, 2014; Rankinen, 2011; Williams et al., 2017). However, improvements in cardiorespiratory fitness in response to exercise training vary greatly between individuals, with some people responding well or very well (‘responders’ or ‘high-responders’) to exercise training, whereas others do not respond so well following similar exercise training (Bouchard et al., 2015; Mori et al., 2009; Williams et al., 2017).

Finally, it should be remembered that the differences in performance between these Hungarian, Croatian and Polish rowers may also be due to variations in the conditions in which they were tested. Visual and verbal feedback may be factors that can substantially improve rowing performance over 2000 m (Stine et al., 2019).

In conclusion, these results for Hungarian rowers are in line with those of the previous studies cited in the introduction of this paper that suggest that a rower's height and length are proportional to his/her level of rowing performance (Mikulić, 2008; Yoshiga & Higuchi, 2003). In the future, different age categories should be compared to optimize training outcomes in rowers. On the one hand, a clear improvement in the performance of Hungarian male rowers transitioning to an older age category could indicate that the selected training methods are adequate. However, minor differences in the anthropometric and physiological profiles of rowers with a different ranking and different career length could imply that the selection of training approaches is not optimal, which suggests that other measures are needed to fully tap the performers’ potential in this stage of the training process. For example, to achieve high-level rowing performance, the training program of rowers should include the development of strength and endurance capacity with the aim of increasing muscle mass, aerobic capacity and metabolic efficiency, and decreasing percent body fat (Durkalec-Michalski et al., 2019;

Lakomy & Lakomy, 1993; Warmenhoven et al., 2018). Such activities are an indispensable part of the selection process, and they could be lacking among Hungarian rowers in the preparation process. The lack of significant differences in individual age categories when variables such as ranking and competition seniority were taken into account stands in contrast to numerous studies conducted by other authors. However, these authors compared the finalists of major rowing events with intermediate rowers. Meanwhile, the examined group of Hungarian rowers had both club and international ranking, but the latter had not scored spectacular success in the international arena. As a result, the analyzed population was less diverse in terms of anthropometric and physiological profiles, and potential differences were much more difficult to capture. From the practical point of view, trainers may find it difficult to select the most promising rowers because the final result can be influenced by external factors (organizational, financial or motivational) that are not directly linked with endogenous factors (anthropometric and physiological characteristics).

In our opinion, this is one of the first studies to address this issue, but definitive conclusions cannot be drawn at this stage of research, which is why further studies of Hungarian rowers spanning a longer period of time are needed

Strengths and Limitations

This paper makes a novel contribution to the literature by providing information about the anthropometric and physiological characteristics of Hungarian rowers who are relatively young and are only aspiring to become elite athletes. This study makes the first ever attempt to capture differences in the anthropometric and physiological characteristics of intermediate rowers. In our opinion, the above fact is a definite strength of the study because the number of non-elite athletes significantly exceeds the number of rowing champions who constitute a relatively small group. This approach contributes to the novelty of our study, but our findings are difficult to compare with those reported by other authors due to the general lack of research addressing intermediate athletes. The size of the analyzed sample was relatively large in comparison with similar studies (Klusiewicz et al., 2014; Mikulić, 2008); therefore, the formulated conclusions can be viewed with a relatively high degree of confidence.

The fact that HR values (minimum, average and maximum) and lactate anaerobic threshold values could not be included in the study because measurements were performed within a timeframe of 3 consecutive days is a limitation of this study. Despite the above, the study generated valuable insights about differences between age categories, including measurements of VO2max values which are considered the gold standard for cardiorespiratory fitness. To complement our findings, acid-base balance indicators, including blood pH, partial pressure of CO2 in arterial blood (pCO2), HCO3- ion concentration, and alkaline deficiency or excess (BE), should be examined in the future. Repeated measurements involving the same athletes during different training periods could also generate interesting results.

5.6. Conclusions

Hungarian rowers in older age categories have higher values of anthropometric and physiological characteristics than younger ones. Within the older juniors but not in the other age categories, these characteristics are significantly better in rowers with an international ranking than in those with a club ranking. Within these age categories, length of sports career was not associated with significant differences between rowers.

The study revealed that potential differences in anthropometric and physiological characteristics are more difficult to identify in rowers who are not elite athletes and differ in age, ranking and length of the sport career than when rowing champions are compared with the remaining, lower-ranking rowers. As demonstrated on the example of Hungarian rowers, the ultimate success of intermediate rowers is determined not only by endogenous factors associated with training and anthropometric and physiological characteristics, but also by external factors (organizational, financial and motivational). Further research is needed to confirm the present findings. For instance, it would be interesting to investigate whether athletes with optimal training conditions are more successful than those with less favorable training conditions. Future studies should also involve advanced statistical analyses, such as partial correlation analysis, to identify variables that exert the greatest influence on rowers' performance. It would be interesting to perform a longitudinal study that examines how these characteristics change or remain the same as the season progresses, or even over several years of the athletes' sports careers. These repeated examinations could provide an opportunity to assess more accurately whether the relationships between anthropometric and physiological characteristics and the results obtained in motor tests should play an important role in the process of sports selection.

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Data Availability: The Excel data used to support the findings of this study are restricted by the Ethics Committee of the University of Warmia and Mazury in Olsztyn (UWM), Poland in order to protect participants' privacy. Data are available from Robert Podstawski, E-mail:

podstawskirobert@gmail.com for researchers who meet the criteria for access to confidential data.

Author Contributions: R. P. designed this study; Z. A., I. F., I. S., and R. P. contributed to data collection; K.B., and R.P. analyzed and interpreted the data; R.P., and I. F. drafted the primary manuscript and with the assistance of Z. A., K. B. drafted the final version. All authors critically reviewed and approved the manuscript prior to submission.

Conflict of interest: All Authors declare that there is no conflict of interests regarding the paper and its publication.

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CHAPTER 6: Anthropometric and physiologic characteristics of elite male female junior rowers (Study 3)

Note: The manuscript has already been submitted to potential journals and currently is under review. For this reason, the latest version of the article is presented in this dissertation.

6.1. Summary

The purpose of this study was to identify the factors that explained the 2000-m rowing performance in adolescent rowers. Fifteen rowers (six males and nine females) ages 15-18 years who competed in the Hungarian Junior Rowing Championships performed a 2000-m rowing ergometer test in the laboratory. Prior to this task, these subjects completed a measure of body size, composition and vertical jump on a force platform. Oxygen consumption was measured along with power output during the rowing ergometer trial. The time in the competition and time on the rowing ergometer were strongly related ($r = 0.721$). Excluding power in the regression analyses, oxygen consumption (VO2) and percentage lean body mass (%Lean) were identified as the significant (($F=50.63$, $df=2,12$, $p < 0.001$) predictors of performance time. No other variables were selected in the regression equations. The rate of oxygen consumption and lean mass in adolescent rowers need to be considered in explaining performance.
Keywords: elite youth athletes, anthropometric variables, VO_{2max}, rowing performance

6.2. Introduction

Rowing is a competitive sport where both males and females of all ages compete. Rowing can involve a single individual or a crew of people consisting of 2-8 members all of which are known as oarsmen. Across various countries, rowing is widely known allowing it to become an Olympic sport where two separate disciplines of rowing are used: ‘sweep’ rowing and sculling. In ‘sweep’ rowing, the oarsmen will handle one oar whereas in sculling they will use two oars (Secher, 1993). Regardless of the discipline, the objective of rowing is to move a boat across a body of water for 2000 m which last approximately 6-8 min (Drarnitsyn, Ivanova & Sazonov, 2009). In rowing, static and dynamic work of approximately 70% of the body's muscle mass is involved for 5.5 to 8 min at an average power of 450 to 550 W (Steinacker, 1993). The movement of an oarsmen consists of a large movement of the legs followed by a more significant movement of the trunk and a minor contribution of the arms. During a race, the use of both the anaerobic and aerobic energy pathways is expected; approximately 20-35% and 60-85% respectively (Martin & Tomescu, 2017; Secher, 1993; Smith & Hopkins, 2012).

Along with the physical demands of rowing, environmental conditions will influence the outcome of a race. For studies examining physiological parameters of rowing these environmental factors can affect the validity of the studies. Over the years, the use of a rowing ergometer has become the most widely used method to help combat this problem (De Campos Mello et al., 2009). A rowing ergometer is used indoors allowing for a controlled environment with the intentions of mimicking the same movements one would use during water rowing.

The aerobic power ($VO2_{max}$) during a rowing ergometer can be measured in a similar way as a researcher would examine metabolism during cycling. Higher capacities of $VO2_{max}$ result in faster rowing times as to the body using oxygen more efficiently. Rowing boat velocity correlate to maximal oxygen uptake ($VO2_{max}$) which reaches 6.0-6.61.min-1 (65-70 ml.min-1. kg-1) and to the $VO2_{max}$ during a race (Steinacker, 1993). Cerasola et al. (2020), Riechman et al. (2002), Cosgrove et al. (1999), Yoshiga & Higuchi (2003) and Russel, le Rossignol & Sparow (1998) indicated $VO2_{max}$ as one of the best predictors in rowing performance when evaluating male rowers. Other variables influencing rowing performance include the anthropometrics of lean body mass, height, and long limbs.

When examining female rowers, Battista et al. (2007) found that vertical jump ($P < 0.05$) and years of experience before college ($P < 0.05$, ≈ 0.5 years) were the most significant indicator between novices and varsity athletes; supported by Huang, Nesser & Edwards (2007) and Ingham et al. (2002). The winning time and World record holder for women's rowing is in fact 16% slower than the men's record. Researchers determined this outcome to be due to women having a smaller body frame ($P < 0.001$) and lower lean body mass ($P < 0.001$). The large body frame indicates a longer stroke length which results in a larger amount of ground covered. A higher lean body mass indicates an individual having more muscle than fat, and the sport of rowing requires almost all muscles of the body to be used (Yoshiga & Higuchi, 2003).

Most of the studies reported in rowing is performed on young adult rowers. As rowing experience before a "senior age classification" is important, the study of adolescent or "junior age" athletes are needed. Mikulić and Ružić (2008) studied the rowing performance of 12-13-year-olds in order to detect factors in young rowers for talent identification purposes.

Anthropometric characteristics at junior age affect long-term career attainment even within elite U19 National Team rowers, underlining the relevance of anthropometric assessments and their consideration for talent identification and development programmers in rowing (Winkert et al., 2019). Both anthropometric and physiological variables were included in the regression model for 1000-m rowing performance. The higher aerobic power and larger body size in these rowers explained 85% of the difference in rowing performance on ergometers. More specific in the body size, the biacromial (shoulder) width, thigh girth, and height were the variables used in the regression model. Thus, the morphological growth in youth might explain the rowing performances for this study population. Also, as youth reach sexual maturation, these factors might explain changes in performance over time. As the study population in this study were boys, it is important to identify the role of sexual maturation on physical performances that are based upon improvements in lean body mass and energy associated with aerobic power.

The purpose of this study is to identify factors which influence 2000 m rowing performance for male and female elite rowers aged 13-17 years old. We hypothesize that athletes with higher lean body mass and longer limbs will have higher power per stroke which contribute to faster performance in this event. The efficiency of movement will provide an explanation for differences between developmental aged rowers. This descriptive study will test relationships between various physical and physiological variables in order to suggest factors which explain the rowing performance of a group of Hungarian rowers who competed in the Hungarian Junior National Championships.

6.3. Materials and methods

Subject Characteristics. Fifteen rowers (six males and nine females) who participated in the Hungarian National Rowing Championships 2020 (July) conducted a 2000m rowing performance test on a rowing ergometer in the Human Performance Laboratory in Gyor, Hungary. The males were ages 15-17 years with on average six years of training. The females were ages 15-18 years with three years of training. All subjects were highly ranked in the Hungarian Rowing Federation with top finishes the national rowing competitions. The 2000-meter rowing times from the Hungarian Junior Rowing Championship were reported.

Anthropometric and Body Composition Measures. Each subject was measured for stature and body mass with a stadiometer (model 214, Seca-Bodymorph, UK) to the nearest 0.1 cm and calibrated scale (model 707, Seca Corporation, Columbia, Maryland) to the nearest 0.1 kg. From these measures, body mass index (BMI) and body surface area (BSA) were calculated. In addition, sitting height, arm span, limb length using standard anthropometric procedures were taken by the same technician and reported in centimeters (cm). The body composition was measured using an InBody 720 Bioelectrical Impedance Analyzer (BIA) to obtain percentage fat and lean (non-fat, non-bone). The Athletic Club of Győr allowed the research team to access data and informed consent was provided.

Ethics: The study was conducted ethically according to Declaration of Helsinki and it was approved by the Bioethics Committee at the University of Pécs.

Countermovement jumping. Each subject was asked to perform a countermovement jump from a force plate PJS-4P60S (Poland) to determine maximal force (in newton's) and the rate of displacement (in meters per second). From these measures, Jump Height (cm) and Peak power

(W) was determined. Using the body mass of the subject, the relative peak power (Watts per kilogram body mass) was calculated.

2000-meter rowing ergometer performance. Each subject was asked to perform a 2000-meter rowing task as fast as possible. All rowing in the lab were performed using a rowing ergometer (which reports power, cadence, and time to complete the 2000 meters. From the rowing ergometer, average power (watts) was determined and time to complete 2000-meters was (Concept 2 D-model rower, USA) recorded. During the task, a measure of oxygen consumption (VO_2) and carbon dioxide (VCO_2) production were taken using indirect calorimetry (JAEGER® Vyntus CPX.) In addition, heart rate was monitored using Polar heart rate monitoring (H7) with Bluetooth smart technology. Peak Heart rate, VO_2 (mL/min) and VCO_2 (mL/min) were recorded. From these measures Oxygen Pulse was calculated.

Statistical Analyses. All data from each subject were organized by sex and entered into a SPSSX (Version 25) spreadsheet. Descriptive analyses were used to report mean and standard deviations (sd) of all variables. The relationship between laboratory performance and field rowing performance were tested using a Pearson correlational analyses. Since field performances (in the water) were potential affected by temperature, water conditions, and race strategy, the laboratory rowing performance time was used as the outcome (dependent variable) which other variables were entered in a stepwise regression analyses to identify predictors of the outcome.

6.4. Results

The mean (sd) anthropometric measures and body composition for all study participants and separated by sex are reported in Table 1 while Jump variables are reported in Table 2.

Table 1. Mean (sd) anthropometric measures and body composition

Measure	Group (n = 15)	Males (n= 6)	Females (n=9)
Body Mass (kg)	68.8 (7.7)	72.3 (5.8)	65.9 (7.6)
Stature (cm)	176.6 (9.2)	183.4 (6.6)	172.1 (7.9)
BMI (kg/m^2)	22.1 (1.1)	21.7 (1.0)	22.3 (1.2)
BSA (m^2)	1.7 (0.3)	1.9 (0.2)	1.6 (0.2)
Fat %	19.5 (7.3)	11.8 (2.3)	24.6 (4.1)
Lean %	37.3 (5.0)	42.9 (1.7)	33.5 (1.6)
Sitting height (cm)	93.3 (4.9)	97.4 (4.3)	90.6 (3.2)
Arm Span (cm)	179.3 (10.0)	186.1 (8.5)	174.8 (8.6)
Limb length (cm)	102.3 (5.7)	103.0 (2.8)	101.9 (7.2)

Legend: Body Mass (kg), Stature-Body height (cm), BMI-Body Mass Index (kg/m^2), BSA-Body Surface Area (m^2), Fat %- Body fat (%), Lean (%), Sitting height (cm), Arm Span (cm), Limb length (cm)

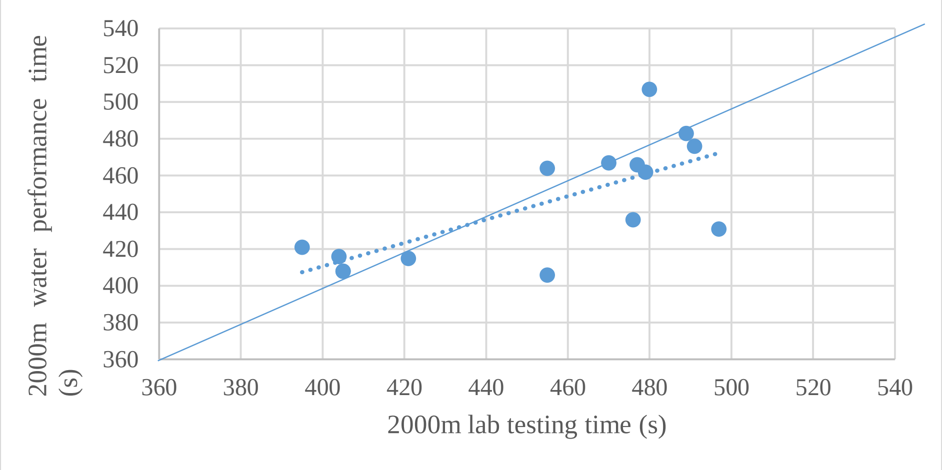
Table 2. Mean (sd) of Countermovement Jump Variables

Measure	Group (n=15)	Males (n=6)	Females (n=9)
Peak Force (N)	1569.9 (248.7)	1713.8 (208.6)	1474.0 (234.8)
Rate of Displacement (m/sec)	2.5 (0.3)	2.8 (0.2)	2.4 (0.2)
Relative Power (W/kg)	47.8 (9.2)	52.9 (6.3)	44.4 (9.6)

Legend: Peak Force (N), Rate of Displacement (m/sec), Relative Power (W/kg)

The time to complete the 2000-meters on the water (during competition) was on average 444.4 seconds (sd = 3.24 s) while the time to complete the 2000-meters on the rowing ergometer was 453.3 seconds (sd = 36.7 s). The relationship between these two performance times were strong based upon a Pearson correlation coefficient = 0.721. Figure 1 illustrates this relationship for the group including the trendline and line of identify. The physiological variables measured during the rowing ergometer test are reported in Table 3.

Figure 1. Relationship between competition performance and laboratory performance



Legend: 2000m water performance time in boat (sec), 2000m lab testing ergometer time (sec).

Table 3. 2000-meter rowing performance and physiological variable.

Measure	Group (n=15)	Males (n=6)	Females (n=9)
Time to Complete (s)	453.3 (36.7)	414.2 (21.7)	479.3 (12.4)
Average Power (W)	250 (65.7)	319.8 (44.9)	204.0 (16.4)
Average Cadence (cpm)	39.0 (3.1)	40.4 (2.0)	38.0 (3.4)
Peak Heart Rate (bpm)	190.9 (8.8)	195.0 (4.7)	188.1 (10.0)
Peak VO2 (mL/min)	3768.3 (783.4)	4495.2 (683.1)	3283.7 (349.2)
Peak VCO2 (mL/min)	4301.8 (1000.6)	5223.5 (919.1)	3687.3 (402.9)
Oxygen Pulse (mL/beat)	19.8 (4.0)	23.1 (3.7)	17.5 (2.4)

Legend: Average Cadence- Cadence per minute (cpm), Time to Complete (sec), Average Power (Watt), Peak VO2 (mL/min), Peak VCO2 (mL/min), Oxygen Pulse (mL/beat).

The percentage lean tissue (Lean%), Arm Span, fat percentage (Fat%), sitting height, Peak VO2, and Peak Force (while jumping) were chosen for regression analyses due to the strength of their relationships with 2000-meter rowing performance ($r > 0.70$). The stepwise regression indicated that peak VO2 and Lean% were identified as significant ($F=50.63$, $df=2,12$, $p < 0.001$) predictors of time to complete 2000-meter rowing distance accounting for 89% of the shared variance. Peak VO2 only was identified as a significant predictor ($F=63.34$, $df=1,13$, $p<0.001$) of time to complete the 2000-meter rowing distance accounting for 83% of the shared variance. The linear regression equations are:

1) Time (s) to complete 2000-meter rowing = 670.97 - 0.554(VO2 mL/min) – 0.438(Lean%)
2) Time (s) to complete 2000-meter rowing = 614.16 - 0.911(VO2 mL/min)

All other variables entered into the stepwise regression were excluded. As average power directly influences the rowing performance, this variable was excluded from this analyses so as to identify other factors.

6.5. Discussion

This descriptive study of Junior Rowers (ages 15-18 years) identify the importance of aerobic power (rate of oxygen consumption) as a predictor of rowing performance. Since the mean Power was highly related ($r = 0.99$) with the time to complete the rowing distance, factors that reflect power might also be evaluated to confirm these findings. The average cadence for each subject was not related to average power ($r = 0.18$) and therefore not considered a factor. The ability to generate force in the legs has been suggested as a factor for rowing (both sculling and sweep rowing), although the relationship between these variables (average power and peak force while jumping) was only moderately related ($r = 0.61$).

The upper body size of the individual seems to play a role in rowing performance as evident by strong inverse relationship between performance time and sitting height ($r = -0.84$) and arm span ($r = -0.76$) however since these variables were not selected in the regression equations, do not as strong as the metabolic (VO2) and body composition (Lean%) measures. If these laboratory measures were not available, then these measures could provide explain some of the variance in rowing performance. In this study sample, the limb length did not relate to performance time however ($r = -0.25$).

The findings of this study support the idea that an elite rower should possess a high rate of oxygen consumption. If profiling an elite junior rower, using the relative rate of oxygen consumption to body mass (mL O2 per kg body mass) might be considered more appropriate. For this group, the relative rate for the entire group averaged 54.1 (sd =7.3) mL/kg/min, with the male rowers averaging 61.2 (sd = 5.1) mL/kg/min and for females 50.0 (sd = 4.6) mL/kg/min. These measures as peak values over a six to nine-minute period of rowing reflect a high contribution of aerobic metabolism. The corresponding heart rate responses indicate a near maximal exertion during this bout of exercise. These findings are similar to others in that a higher VO_{2max} was predictive of rowing performance (Yoshiga & Higuchi, 2003).

Further studies are needed to identify the race performance (on the water) and the impact cadence in a group (crew) requires a level of power (or force) in rowing to contribute to propelling the boat toward the finish line. Also if lean body mass, particularly skeletal muscle is predictive of rowing performance, what are the forces from the lower and upper body dynamic muscle contraction which generate an efficient stroke within the cadence of the crew. This study did not evaluate the anaerobic power nor body strength of these rowers. Akça (2014) reports that for college aged rowers, the anaerobic power evaluated using a modified Wingate test, along with strength measures (static strength) explained the majority of the variance in 2000-m rowing ergometer performances. As these variables are expected to improve in adolescents based upon maturation, more studies are needed to recognize the role of maturation in junior athletes.

In conclusion, these study results identify the role of aerobic power on rowing performance. In addition, the percentage of lean body mass offers an additional contribution to explaining the rowing performances in this age group. While rowing performances might be explained by these measured variables, more study into the movement mechanics and force applications along with the impact of strength and anaerobic energy in maturing adolescent rowers are needed.

CHAPTER 7: Sex differences in anthropometric and physiological profiles of Hungarian rowers of different ages (Study 4)

Note: This article has been accepted for publication and the final published version is presented in this dissertation. The final published version is available and can be downloaded online from the publisher's website:
Podstawski, Robert – Borysławski, Krzysztof – Katona, Zsolt Bálint – Alföldi, Zoltan [et al.] (2022): Sex Differences in Anthropometric and Physiological Profiles of Hungarian Rowers of Different Ages. In*: Int J Environ Res Public Health*, 19(3):8115.

7.1. Abstract

The aim of this study was to determine sexual differentiation in the anthropometric and physiological characteristics of Hungarian rowers in different age categories. These characteristics were measured for 15–16-year-old juniors (55 men and 36 women), 17–18-year-old older juniors (52 men and 26 women), and 19–22-year-old seniors (23 men and 8 women). The degree of sexual dimorphism was expressed in units of measurement as percentages and the dimorphism index. In allege categories, females had significantly higher body fat indices. Body fat percentage was estimated by electrical impedance and by the Pařízková formula (Pařízková, 1961), BMI, and skinfold thicknesses. Males had significantly higher body mass, body height, skeletal muscle mass, sitting height, arm span, lower limb length, and body surface area. Males also scored significantly higher values for the following physiological characteristics: peak power, relative peak power, ErVO2max, jump height, speed max, force max, and relative maximal power. Analysis of anthropometric and physiological characteristics in Hungarian rowers revealed that sexual dimorphism tended to increase with age, regardless of whether it was expressed in units of measurement, percentages, or dimorphism index values. The age-related increase in the sexual dimorphism of Hungarian rowers suggests that training methods should be carefully selected to accommodate the needs of various age and gender groups.

7.2. Introduction

Sex differences in motor performance have attracted considerable attention over the last 40 years. Sexual dimorphism can be generally defined as morphological and physiological differences between males and females of the same species, and this distinction can be based on differences in size, shape, stature, cranial and facial features, muscularity, strength, and speed (Frayer & Wolpoff, 1985). The majority of studies on sex differences have focused on running performance (Anderson, 1996; Cheuvront et al., 2005; Coast, Blevins & Wilson, 2004; Deaner, 2013; Deaner, Addona & Mead, 2014; Hoffman, 2008; Hoffman, 2010; Hunter & Stevens, 2013; Keenan, Senefeld & Hunter, 2018; Lepers & Maffiuletti, 2011; Leyk et al., 2007; Sparling, O'Donnell & Snow, 1998), followed by swimming (Stefani, 2006; Tanaka & Seals, 2008), cycling (Schumacher, Mueller & Keul, 2001), or triathlon (Lepers, 2008; Sultana et al., 2008), but few have analyzed these differences in the contexts of rowing. Partly due to anatomical and physiological sex differences, men generally exhibit higher levels of motor performance than women. The muscular strength of women is typically 40–75% of that of men (Miyashita & Kanehisa, 1979). Men have more muscle mass than women (Janssen et al., 2000; Stefani, 2006), which is the main factor underlying gender differences in maximal strength (Mayhew et al., 2001). Men are also more powerful than equally trained women (Garhammer, 1991), they have a higher maximum oxygen consumption (Sparling, 1980), and they demonstrate greater biomechanical efficiency (Zamparo, 2006). In terms of power per kg of body mass, sex differences are still evident (Harbili, 2012), and the difference in absolute strength between sexes is more noticeable in the upper body than in the lower body (Kanehisa, Ikegawa & Fukunaga, 1994). Women have proportionally more fat mass than men (Bartolomei et al., 2021; Schorr et al., 2018). This difference, along with the fact that women typically have a smaller heart, a lower hemoglobin concentration, less muscle mass per unit of body weight, and smaller maximal oxygen uptake (VO2max), explains the faster performance of men in distance running events (Cheuvront et al., 2005; Coast, Blevins & Wilson, 2004; Joyner, 1991; Sparling, O'Donnell & Snow, 1998). Although several studies have indicated that sex differences in strength may be attributable to lean body mass (LBM), they have also reported that sex differences in power performance were still apparent regardless of body composition and muscle mass (Mayhew & Salm, 1990; Mcmahon, Rej & Comfort, 2017). With regard to fixed-seat rowers (traditional rowing), Penichet-Tomas et al. (2021) demonstrated that in the group of the analyzed variables, performance was most highly correlated with body height in male rowers and with muscle mass in female rowers. The cited authors argued that athletic success is more likely to be determined by high lean body mass and a favorable power-to-body mass ratio than by high body mass, whereas high body mass and high BMI have a detrimental effect on performance. Similar observations were made by Winkert et al. (2019). However, there have been no papers comparing the two sexes in terms of anthropometric characteristics in rowing while taking age categories into account. In addition to differences in muscular strength and power, the physiological reasons for sex differences in motor performance are also attributable to differences in VO_{2max}, movement economy, and the exercise intensity at which a high percentage of VO_{2max} can be maintained (Cheuvront et al., 2005; Tanaka & Seals, 2008). The ability of men to consume more oxygen per unit of body weight than women appears to be the primary factor underlying sex differences in endurance running motor performance (Bunc & Heller, 1989; Cureton et al., 1986; Senefeld et al., 2016; Senefeld, Smith & Hunter, 2016) and in rowing (Ingham et al., 2008; Jurišić et al., 2014; Steinacker et al., 1986). To complement the existing information on the degree of sexual dimorphism in rowing, it would be interesting to obtain hither to missing information on the physiological characteristics of male and female rowers, such as relative peak power, jump height, speed max, and relative maximal power. The difference in power output between women and men ranges from 20–30% for running and speed skating to approximately 45% for swimming, which is consistent with the differences in lower- and upper- body muscle mass and maximal strength between the sexes (Ford et al., 2000; Janssen et al., 2000; Vanderburgh et al., 1997). However, to the best of the authors' knowledge, such information is missing for the sport of rowing, which involves substantial contributions from both upper-and lower-body muscles. Obtaining additional information on the sexual dimorphism of rowers provides an opportunity to compare this sport with others such as those presented above. Interestingly, sex differences in physiology may affect swimming performance differently than they affect performance in some other sports, and these specific swimming differences may have some relevance to rowing. For example, women are more energy-efficient than men during extreme endurance swimming because they experience less drag (Pendergast et al., 1977; Senefeld et al., 2016; Senefeld, Smith & Hunter, 2016; Tiller et al., 2021). Thus, in non-weight- bearing sports like swimming and rowing, sex differences in performance that are due to physiology may be less evident than those that are observed during weight-bearing exercises (e.g., running) (Maciejczyk et al., 2014). Competitions (regattas) are usually held over a distance of 2000 m, which corresponds to about 5.5–8 min to finish the race course and means that rowing is a strength-endurance sport (Jürimäe et al., 2010). This distinguishes rowing from other sports disciplines, and the results regarding sexual dimorphism in this type of effort (hybrid strength-endurance effort) may provide new and interesting information on this topic. Although the rowing literature contains a good number of papers examining men and women in different age categories (Klusiewicz & Faff, 2003; Klusiewicz et al., 2014), the number of published articles comparing the two sexes is very small (Keenan, Senefeld & Hunter, 2018; Li et al., 2020). Generally, rowing time has been shown to be slower in female rowers than in male rowers of similar body height and mass (Sandbakk, Solli & Holmberg, 2018).

According to Keenan, Senefeld & Hunter (2018), rowing is unique among team sports, and, given the gender shifts in the sport over the past 20 years, it provides an attractive field of research to evaluate predictors that arise from sociocultural conditions and evolved predispositions hypotheses. One reason for the gender shifts in this sport is the rise in popularity of women's rowing since 1997 when it became a National Collegiate Athletic Association sport, which resulted in an increase in the number of collegiate women's teams and a corresponding decrease in the number of men's teams (Keenan, Senefeld & Hunter, 2018). Therefore, the aim of this study was to determine the sex variation in the anthropometric and physiological characteristics of Hungarian rowers in different age categories. The research hypothesis postulates that age and sex influence the anthropomorphic and physiological parameters of rowers, rowing performance over a distance of 2000 m, and motor test scores.

7.3. Materials and methods

Participants

The study was conducted in the Gyor rowing club, and the sample consisted of 130 male and 70 female rowers from the seven largest Hungarian rowing clubs. The targeted sampling method was used to select the participants. The following inclusion criteria were applied: rowers from all age groups held a valid competition licenses and had participate in national and/or international events over a period of at least one year. In addition, all rowers were required to present a valid medical certificate, they had to train regularly, their physical activity was not limited (for whatever reason) to the extent that it would substantially affect their motor fitness levels. All rowers in each club that met these criteria were included in the study.

Each rower was assigned to one of the three age categories: juniors (15 – 16 years old, 36 women and 55 men), older juniors (17 – 18 years old, 26 women and 52 men), and seniors (over 18 years old, 8 women and 23 men). The senior groups were relatively young, and the oldest senior rower was only 22. The rowers' training programs were consistent with the guidelines of the Hungarian Rowing Federation Training Plan: 12-13 h/week for 15- to 16-year-olds, 14-15 h/week for 17- to 18-year-olds, and 16-17 h/week for 19- to 22-year-olds. The aerobic-to-anaerobic training ratio in the above groups was 80:20%, 75:25 and 70:30%, respectively. The study took place over three consecutive days in the middle of the racing season (8 days after one rowing regatta and 7 days before the next rowing regatta). The study was consistent with the guidelines and recommendations of the Health Science Council, Scientific and Research Ethics Committee (IV / 3067-3 / 2021 / EKU), Hungary, and the Declaration of Helsinki. The participants received comprehensive information about the research objective, the relevant risks, the applied methods of measurement, and the techniques that would be used in motor tests. These techniques could be practiced that could be practiced directly before the study. The rowers agreed to participate in the study on a voluntary basis by signing informed consent forms.

Procedures, data collection and equipment

Procedures

Each rower was subjected to anthropometric and physiological tests in the middle of the 2020 racing season. On the first day, anthropometric features were measured; on the second, the athletes performed motor tests; and on the third, they covered a distance of 2000 m.

The rowers' coaches assisted with the measurements. All coaches were instructed not to engage the subjects in any strenuous training on the day before testing. Each subject was always tested in the morning after eating a light meal (800-1200 kcals) containing mainly carbohydrates (60-70%) at least 3-4 h before the study (Williams, 1999). To measure body height to the nearest 1 mm, a calibrated Soehlne Electronic Height Rod 5003 (Soehlne Professional, Germany) was used according to standardized guidelines. To determine body mass (measured to the nearest 0.1 kg), BMI and body composition characteristics by bioelectrical impedance, including body fat percentage (BFP) and skeletal muscle mass (SMM), an InBody 720 body composition analyzer was employed. For the remaining anthropometric characteristics, such as arm span [cm], limb length [cm], sitting height [cm], and BSA [m^2], the Weiner and Lourie methods (Weiner & Lourie, 1969) were used. To obtain skin fold measurements (abdomen, thigh, lower leg, biceps, triceps, scapula, suprailiac), a Harpenden cailiper was used.

Estimation of relative body fat content

For caliper metric estimation of relative body fat content, the method developed by Pařízková (Pařízková, 1961) was used. This procedure is based on measuring 5 skinfold thicknesses: over the biceps and triceps, subscapular, suprailiac and medial calf. After the sum of the 5 skinfold values is multiplied by 2, the product is then used to find the estimated relative body fat content in a table.

Countermovement Jump Test

To measure the height attained by the center of body mass and the power output of the lower extremities during vertical jumps, a PJS-4P60S force plate ("JBA" Zb. Staniak, Poland) with a

400 Hz sampling rate (Batra et al., 2021; Gajewski et al., 2018; Mcmahon, Rej & Comform, 2017) was employed. MVJ v.3.4 software ("JBA" Zb. Staniak, Poland) was used to connect the force plate to a PC, and an A/D converter connected the amplifier to a PC. For calculations, the rower's body mass was treated as a point affected by the force of gravity acting on the body and the vertical component of the platform's reactive force. Three countermovement jumps (CMJ) were performed by each subject with maximal force. To complete a CMJ test, the subjects performed a vertical jump from a standing erect position, preceded by a countermovement of the upper limbs and lowering of the center of body mass before take-off. The CMJ tests were used to measure maximal force [N] and the rate of displacement [m/s], which provided the basis for determining jump height [cm] (by integrating ground reaction forces) and peak power [W]. Relative peak power [W/kg] was calculated based on body mass.

2000 m Maximal Rowing Ergometer Test

The participants performed all-out 2000 m tests on a certified rowing ergometer (Concept 2 D). The screen of the ergometer was set to display the number of meters remaining, the average 500 m time, and the accumulated time. The power output in watts (W) was measured over 2000 m. The calculation of watts was performed as follows: First, the distance was defined: distance = (time/number of strokes) × 500. In the next step, the concept of a "split" was clarified: split = 500 × (time/distance). The watts were calculated as 2.8/(split/500). There were slight differences in intensity due to individual changes in stroke value and the ability to keep the 500 m split time constant. Before the tests, the participants warmed up for 6 min over a 500 m distance, then rested for 6 min, during which time they performed stretching exercises. The estimated relative aerobic capacity (ErVO2) was calculated by using the formulas of McArdle, Katch & Katch (2006): for women the formula is ErVO2= (Y × 1000)/BM, where BM is body mass, and Y = [BM < 61.36 kg; 14.61−(1.5×time)]; BM => 61.3 kg; 14.6−(1.5 × time)]; for men it is ErVO2= (Y × 1000)/BM, where BM is body mass, and Y = [BM < 75 kg;15.1−(1.5 × time)]; BM => 75 kg; 15.7−(1.5 × time)]. The power produced over 2000 m was divided by body weight to obtain the relative performance (rW 2k). Due to time and logistical constraints, including the need to perform a relatively large number of measurements over three consecutive days, and the desirability of minimizing disturbances to the athletes' training and changes in their condition, this study did not examine heart rates (HR) and indicators of acid-base balance, such as the lactic acid concentration in the blood, alkaline deficiency or excess, blood pH, and current molecular pressure of CO_2.

Calculations and statistical analysis

For all studied male and female characteristics, basic statistical measures (e.g., mean, standard deviation) were calculated and the normality of the distributions was assessed. Since the distributions did not differ significantly from normality (Shapiro-Wilk test), Student's t-test was used to assess differences between the men and women. The results were regarded as statistically significant at $p < 0.05$. Additionally, the value of the Szopa dimorphism index was calculated, as given in Podstawski et al. (2020):

$$\boldsymbol{DI = \frac{2(x_m - x_f)}{S_m + S_f}}$$

where:

x_m– arithmetic mean of male students in a given age group,

x_f–arithmetic mean of female students in a given age group,

S_m–standard deviation of male students in a given age group,

S_f–standard deviation of female students in a given age group,

Note that differences in measurements (e.g., kg, N, W) between the sexes are presented as male value minus female value, whereas percent differences between the sexes were calculated assuming that the mean value for the male trait was the baseline of 100%.

7.4. Results

The results were presented in tabular form, separately for each age group: 15–16-year-olds (Table 1), 17–18-year-olds (Table 2), and 19–22-year-olds (Table 3). Overall, all analyzed age groups showed statistically significant sex differences with respect to the analyzed anthropometric and physiological characteristics except for BMI values. Additionally, the differences between sexes tended to increase with age, whether expressed in terms of the units of measurement, percentages, or DI values. More specific analyses of each age group are presented below.

Table 1. Sexual dimorphism of anthropometric, physiological and motor characteristics in rowers aged 15-16 years and statistical significance of differences.

Characteristic		Age category 15-16 [years]										
		Men			**Women**			**Differences**				
		Mean	**SD**	**Min-max**	**Mean**	**SD**	**Min-max**	**M–F**	**%**	**DI**	***t***	***p***
Body height [cm]		178.70	7.22	162.1-193.4	166.63	7.64	156.7-187.1	12.08	-6.8	1.63	7.63	<0.001
Body mass [kg]		66.39	10.89	39.6-91.5	60.70	7.08	49.2-76.4	5.69	-8.6	0.63	2.78	0.007
Body fat [%]		12.39	5.54	4.0-28.9	23.81	5.73	13.9-32.1	-11.42	92.2	-2.03	9.17	<0.001
SMM [%]		41.90	5.04	14.1-52.6	34.15	2.88	29.0-41.3	7.75	-18.5	1.96	8.24	<0.001
BMI [kg/m²]		20.71	2.68	15.02-28.31	21.86	2.01	18.81-26.42	-1.15	5.5	-0.49	2.19	ns
Sitting height [cm]		92.50	4.60	79.4-100.3	88.38	3.89	83.1-100.0	4.12	-4.5	0.97	4.43	<0.001
Arm span [cm]		181.13	13.00	104.3-196.0	168.22	8.08	155.4-188.0	12.91	-7.1	1.22	5.32	<0.001
Lower limb length [cm]		101.01	4.07	92.1-111.0	95.86	6.10	85.4-112.4	5.15	-5.1	1.01	4.81	<0.001
BSA [m²]		1.67	0.36	0.89-3.08	1.41	0.22	1.07-1.94	0.26	-5.4	0.90	3.89	<0.001
Skin fold thickness [mm]	Biceps	7.04	3.57	2-20	10.69	4.07	3-22	-3.66	52.0	-0.96	4.52	<0.001
	Triceps	14.16	5.66	5-29	18.89	4.73	10-29	-4.73	33.4	-0.91	4.15	<0.001
	Scapula	10.96	4.57	4-31	14.69	4.31	8-24	-3.73	34.0	-0.84	3.89	<0.001
	Suprailiac	9.95	5.66	4-33	14.33	4.50	6-24	-4.39	44.1	-0.86	3.91	<0.001
	Abdomen	14.06	6.89	5-42	17.31	6.65	8-36	-3.25	23.1	-0.48	2.23	0.028
	Thigh	20.36	7.84	6-46	24.25	7.19	10-38	-3.89	19.1	-0.52	2.39	0.019
	Lower leg	14.07	6.27	4-30	16.86	5.07	6-25	-2.78	19.8	-0.49	2.20	0.030
BFP^{PF} [%]		23.03	4.04	13.8-31.5	30.41	4.10	22.9-36.5	-7.38	32.1	-1.81	8.22	<0.001
Peak power 2000m [W]		250.55	44.60	138-322	182.09	30.12	129-246	68.46	-27.3	1.83	7.83	<0.001
RPP 2000m [W/kg]		3.76	0.53	2.11-4.71	3.01	0.42	2.25-3.73	0.75	-20.0	1.58	6.92	<0.001
Time 2000 m [min]*		7.51	0.51	6.85-9.09	8.34	0.47	7.50-9.30	-0.83	11.0	-1.69	7.57	<0.001
$ErVO_{2\,max}$ [mL/kg/min]		66.43	9.49	38.32-82.47	52.52	9.98	30.59-67.70	13.91	-20.9	1.43	6.48	<0.001
$ErVO_{2max}$ [L/min]		4.41	0.77	2.06-5.42	3.19	0.71	1.75-4.45	1.22	-27.7	1.65	7.39	<0.001
Jump height [cm]		36.02	4.97	23.5-44.4	28.77	4.61	20.7-37.6	7.25	-20.1	1.51	7.00	<0.001
Speed max [m/s]		2.59	0.19	2.06-2.91	2.29	0.21	1.89-2.65	0.30	-11.5	1.49	7.01	<0.001
Force max [N]		1551.35	323.58	899-2317	1282.25	194.7	950-1916	269.10	-17.3	1.04	4.48	<0.001
RPM [kg]		48.43	5.69	34.8-60.9	40.42	5.94	30.1-52.7	8.01	-16.5	1.38	6.45	<0.001

Notes: ns – non-significant difference ($P > 0.05$), ^{PF} - Pařízková`s formula, SMM – skeletal muscle mass, RPP – relative peak power, RPM – relative maximal power. M–F - difference (men minus women), % - percent difference between men women (male value is baseline, i.e., 100%), DI – Szopa dimorphism index, * - shorter time is a better result.

Table 2. Sexual dimorphism of anthropometric, physiological and motor characteristics in rowers aged 17-18 years and statistical significance of differences.

Characteristic		Age category 17-18 [years]										
		Men			Women			Differences				
		Mean	SD	Min-max	Mean	SD	Min-max	M–F	%	DI	*t*	*p*
Body height [cm]		183.02	7.27	167.7-197.4	170.21	6.74	160.0-187.4	12.81	-7.0	1.83	7.51	<0.001
Body mass [kg]		73.70	8.43	56.6-89.7	65.95	7.85	53.2-84.1	7.75	-10.5	0.95	3.91	<0.001
Body fat [%]		12.84	5.39	5.3-33.0	25.37	6.68	8.3-35.3	-12.54	97.7	-2.08	8.89	<0.001
SMM [%]		43.30	3.47	27.2-49.2	33.57	4.48	28.0-47.4	9.72	-22.5	2.45	10.52	<0.001
BMI [kg/m²]		21.98	2.10	18.28-29.47	22.74	2.15	18.48-27.19	-0.76	3.4	-0.36	1.49	ns
Sitting height [cm]		95.33	3.56	87.5-105.1	90.60	3.61	85.4-99.9	4.74	-5.0	1.32	5.51	<0.001
Arm span [cm]		188.43	8.56	168.5-203.0	172.30	7.72	159.5-192.0	16.13	-8.6	1.98	8.10	<0.001
Lower limb length [cm]		102.40	4.98	90.3-111.4	98.35	5.89	87.9-112.5	4.06	-4.0	0.75	3.19	0.002
BSA [m²]		1.88	0.26	1.32-2.31	1.56	0.23	1.21-2.19	0.31	-16.8	1.27	5.18	<0.001
Skin fold thickness [mm]	Biceps	5.69	3.13	3-21	9.73	3.34	5-17	-4.04	71.1	-1.25	5.24	<0.001
	Triceps	12.08	4.50	5-26	18.85	4.97	10-31	-6.77	56.0	-1.43	6.02	<0.001
	Scapula	9.96	3.16	6-23	15.27	4.41	9-23	-5.31	53.3	-1.40	6.08	<0.001
	Suprailiac	8.26	3.76	4-21	13.15	4.40	5-25	-4.90	59.3	-1.20	5.11	<0.001
	Abdomen	12.29	4.81	5-26	15.15	3.93	7-22	-2.86	23.3	-0.65	2.62	0.011
	Thigh	18.45	7.54	7-39	26.42	5.69	14-38	-7.97	43.2	-1.21	4.74	<0.001
	Lower leg	12.31	5.99	5-30	16.77	4.28	10-25	-4.46	36.2	-0.87	3.37	0.001
Body fat[PF] [%]		21.86	4.14	14.5-30.9	31.44	2.52	26.5-36.9	-9.58	43.8	-2.88	10.63	<0.001
Peak power 2000m [W]		326.80	54.48	210-435	212.92	27.85	155-261	113.88	-34.8	2.77	9.62	<0.001
RPP 2000 m [W/kg]		4.42	0.51	3.10-5.31	3.23	0.36	2.35-4.01	1.20	-27.0	2.76	10.27	<0.001
Time 2000m [min]*		6.87	0.41	6.20-7.90	7.90	0.36	7.35-8.75	-1.03	15.0	-2.70	10.55	<0.001
$ErVO_2$ max [mL/kg/min]		73.44	6.31	56.69-88.19	58.37	6.82	41.08-73.26	15.07	-20.5	2.30	9.34	<0.001
$ErVO_{2max}$ [L/ min]		5.40	0.61	3.84-6.40	3.85	0.53	2.58-4.67	1.55	-28.7	2.72	3.91	<0.001
Jump height [cm]		40.59	7.62	24.7-58.9	27.90	3.10	21.6-33.7	12.69	-31.3	2.37	8.13	<0.001
Speed max [m/s]		2.74	0.29	1.97-3.33	2.25	0.13	1.97-2.49	0.49	-17.8	2.31	8.16	<0.001
Force max [N]		1721.19	283.77	1180-2712	1370.39	145.40	1124-1690	350.81	-20.4	1.63	5.91	<0.001
RPM [kg]		52.41	7.88	30.2-63.4	38.95	3.86	30.6-45.7	13.46	-25.7	2.29	8.21	<0.001

Notes: ns – non-significant difference (P > 0.05), [PF] - Pařízková`s formula, SMM – skeletal muscle mass, RPP – relative peak power, RPM – relative maximal power. M–F - difference (men minus women), % - percent difference between men women (male value is baseline, i.e., 100%), DI – Szopa dimorphism index, * - shorter time is a better result.

Table 3. Sexual dimorphism of anthropometric, physiological and motor characteristics in rowers aged 19-22 years and statistical significance of differences.

Characteristic		Age category 19-22 [years]										
		Men			Women			Differences				
		Mean	**SD**	**Min-max**	**Mean**	**SD**	**Min-max**	**M–F**	**%**	**DI**	***t***	***p***
Body height [cm]		184.96	4.98	174.4-194.0	171.58	4.14	166.2-179-8	13.39	-7.2%	2.94	6.81	<0.001
Body mass [kg]		80.75	8.09	62.1-91.2	71.19	6.49	63.2-81.5	9.56	-1.08	1.31	3.01	0.005
Body fat [%]		16.67	4.33	9.4-22.9	30.15	5.52	19.9-36.2	-13.48	80.8	-2.74	7.01	<0.001
SMM [%]		41.12	3.83	29.9-46.6	31.60	4.02	28.0-40.9	9.52	-23.2	2.43	5.95	<0.001
BMI [kg/m^2]		23.61	2.29	18.28-26.68	24.17	1.84	21.12-26.47	-0.56	2.04	-0.27	0.62	ns
Sitting height [cm]		96.56	2.04	93.9-100.1	91.01	2.01	88.0-93.2	5.54	-5.7	2.74	6.64	<0.001
Arm span [cm]		189.29	5.53	179.7-197.5	176.19	5.56	168.4-185.0	13.10	-6.9	2.36	5.77	<0.001
Lower limb length [cm]		103.02	3.98	96.5-113.8	96.01	2.85	93.9-102.4	7.00	-6.8	2.05	4.56	<0.001
BSA [m^2]		2.09	0.25	1.50-2.63	1.70	0.18	1.52-2.04	0.39	-8.6	1.80	4.05	<0.001
Skin fold thickness [mm]	Biceps	5.96	2.69	3-12	9.88	2.85	6-15	-3.92	65.8	-1.42	3.50	0.002
	Triceps	12.65	4.57	5-20	22.75	3.45	20-29	-10.10	79.8	-2.52	5.69	<0.001
	Scapula	10.70	3.48	3-18	17.75	3.92	12-24	-7.05	66.0	-1.91	4.78	<0.001
	Suprailiac	8.52	2.29	5-13	15.00	1.31	13-17	-6.48	76.0	-3.60	7.52	<0.001
	Abdomen	12.48	3.82	7-22	18.00	4.75	15-29	-5.52	44.3	-1.29	3.31	0.003
	Thigh	18.48	6.01	4-29	31.38	5.26	26-41	-12.90	69.8	-2.29	5.38	<0.001
	Lower leg	13.39	4.46	4-22	20.13	3.23	15-24	-6.73	50.3	-1.75	3.91	<0.001
Body fat^{PF} [%]		22.43	3.62	12.2-26.6	33.00	2.73	27.9-35.6	-10.57	47.1	-3.33	6.64	<0.001
Peak power 2000m [W]		372.22	52.96	292-461	254.75	38.24	180-294	117.47	-31.6	2.58	5.75	<0.001
RPP 2000 m [W/kg]		4.59	0.45	3.57-5.35	3.57	0.37	2.79-4.12	1.02	-22.2	2.51	5.82	<0.001
Time 2000 m [min]*		6.56	0.32	6.08-7.08	7.45	0.41	7.07-8.32	-0.89	13.5	-2.43	6.30	<0.001
$ErVO_{2\,max}$ [mL/kg/min]		72.61	5.59	60.76-84.99	63.53	6.25	49.82-71.91	9.08	-12.5	1.53	3.84	<0.001
$ErVO_{2max}$ [L/ min]		5.83	0.46	5.08-6.58	4.53	0.62	3.22-5.10	1.30	-22.3	2.41	6.29	<0.001
Jump height [cm]		38.44	6.31	22.9-51.0	28.39	2.34	25.0-32.9	10.05	-26.1	2.33	4.36	<0.001
Speed max [m/s]		2.66	0.24	2.08-3.09	2.29	0.11	2.09-2.46	0.37	-13.9	2.13	4.21	<0.001
Force max [N]		1814.74	272.22	1328-2548	1489.38	146.00	1319-1708	325.36	-17.9	1.56	3.20	0.003
RPM [kg]		49.39	6.04	36.3-63.2	38.91	3.36	32.7-42.4	10.47	-21.2	2.23	4.63	<0.001

Notes: ns – non-significant difference ($P > 0.05$), ^{PF} - Pařízková`s formula, SMM – skeletal muscle mass, RPP – relative peak power, RPM – relative maximal power. M–F - difference (men minus women), % - percent difference between men women (male value is baseline, i.e., 100%), DI – Szopa dimorphism index. * - shorter time is a better result.

Analysis 1: Anthropometric and physiological characteristics of 15-16-year-old rowers

The range of sexual dimorphism with respect to the analyzed characteristics of the 15-16-year-old male rowers is presented in Table 1. In terms of anthropometric characteristics, the 15-16-year-old female rowers had significantly lower values of the following (the differences in measurements were calculated by subtracting the female value from the male value; male values were the baseline for calculating relative differences): body height (12.1 cm, -6.8%), body mass (5.7 kg, - 8.6%), SMM (7.8 kg, - 18.5%), sitting height (4.1 cm, -4.5%), arm span (12.9 cm, -7.1%), lower limb length (5.2 cm, - 5.1%) and BSA (0.3 m^2, -5.4%). In terms of physiological characteristics in all motor tests, the 15-16-year-old female rowers achieved significantly slower or lower performances than their male peers: peak power (68.5 W, -27.3%), RPP (0.75 W/kg, -20.0%), time 2000 m (-0.83 min, 11%), ErVO2 max (13.9 mL/kg/min, -20.9%; 4.4 L/min, -27.7%), jump height (7.25 cm, -20.1%), speed max (0.3 m/s, -11.5%), force max (269.1 N, - 17.3%) and RPM (8.01 kg, -16.5%) (Table 1). In contrast, the women significantly exceeded the men in terms of body fat as indicated by the following indices: BFP (-11.4%, a relative difference of 92.2% from the males), BFP PF (-7.4%, a relative difference of 32.1%) and measured skinfolds (biceps, triceps, scapula, suprailiac, abdomen, thigh, lower leg), which all displayed values elevated from 19.1 to 52.0% over those of the males (Table 1).

Analysis 2: Anthropometric and physiological characteristics of 17-18-year-old rowers

As above, all the analyzed characteristics in the 17–18-year-old age group differed significantly between the genders, except for BMI (Table 2). The 17-18-year-old female rowers were significantly shorter (12.8 cm, -7%), lighter (7.8 kg, -10.5%) and recorded lower values for SMM (9.72 kg, -22.5%), sitting height (4.7 cm, -5.0%), arm span (16.1 cm, -8.6%), lower limb length (4.1 cm, -4.0%) and BSA (0.31 m^2, -16.8%). In contrast, the female rowers had larger values for body fat percentage (12.5%, 97.7% difference relative to the males), skin fold thicknesses (ranging from 23.3 to 71.1% larger) and body fat PF (9.6%, 43.8% difference relative to the males).

In terms of physiological characteristics, the females recorded lower or slower performances in these tests: peak power (113.9 W, -34.8%), RPP (1.2 W/kg, -27.0%), time (-1.0 min, 15%), ErVO2 max (15.1 mL/kg/min, -20.5%; 5.4 L/min, -28.7%), jump height (12.7 cm, -31.3%), speed max (0.49 m/s, -17.8%), force max (350.8 N, -20.4%) and RPM (13.5 kg, -25.7%) (Table 2)

Analysis 3: Anthropometric and physiological characteristics of 19–22-year-old rowers

In this age category, the pattern of statistically significant differences between the sexes was very similar to those observed in the other two categories (Table 3). The women had lower values of the following anthropometric characteristics: body height (13.4 cm, -7.2%), body mass (10.0 kg, -12.3%), SMM (9.5 kg, -23.2%), sitting height (5.5 cm, -5.7%), arm span (13.1 cm, -6.9%), lower limb length (7.0 cm, -6.8%) and BSA (0.4 m^2, -8.6%). In turn, the women recorded larger values for body fat percentage (-13.5%, relative difference of 80.8%), skin fold thicknesses (ranging from 44.3 to 79.8%) and body fat PF (-10.6%, relative difference of 47.1%). In terms of physiological characteristics, the females recorded lower or slower values: peak power (117.5, -31.6%), RPP (1.0 W/kg, -22.2%), time (-0.89 min, 13.5%), ErVO2max (9.1. mL/kg/min, -12.5%; 5.8 L/min, -22.3%), jump height (10.1 cm, -26.1%), speed max (04 m/s, - 13.9%), force max (325.4 N, -17.9%) and RPM (10.5 kg, -21.2%) (Table 3).

7.5. Discussion

The purpose of this study was to assess the sex differences between male and female Hungarian rowers of different ages. We hypothesized that the anthropometric and physiological characteristics of the female and male rowers would differ significantly and that these characteristics would also differ between age categories. The results obtained in this study are consistent with the research hypothesis.

Sex differences in anthropometric characteristics

This study showed that there were significant differences in anthropometric characteristics between the sexes in all age categories, as reflected by the values of the dimorphism index (DI). Male Hungarian rowers had greater heights and weights than their female counterparts, and the differences between the sexes increased with age (e.g., for body height, DI values increased from 1.6 to 2.9; for body mass, from 0.6 to 1.3). These differences are likely to influence rowers' performance. Studies evaluating the anthropometric characteristics of female and male adult rowers (body mass and height) have emphasized the significance of body mass and height (Bourgois, 2000; Forjasz, 2011; Giroux et al., 2017; Maciejewski et al., 2019; Secher & Vaage, 1983) and have demonstrated that body size and proportions (Hebbelinck et al., 1980; Majumdar, Das & Mandal, 2017; Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019; Schranz et al., 2010) are important predictors of success in international-level rowing. Similar relationships have also been found between these characteristics and the rowing performance of juniors (Bourgois, 2000; Mikulić, 2008; Mikulić & Ružić, 2008).

Generally speaking, BFP and BFP PF differed the most between the sexes in each age category as shown by the respective DI values (in terms of increasing ages: −2.0, −2.1, −2.7; and −1.8, −2.9, −3.3), and these differences were highly statistically significant ($p < 0.001$). Interestingly, the difference in body fat was largest among the seniors (19–22 years), and the range of BFP in the male rowers was much wider than the 6 to 10% BFP observed in elite males by Hagerman & Toma (1997). Differences in BFP that depend on sex are typical in athletes (Manore, Barr & Butterfield, 2000). Although excess body fat can impair rowing performance, the importance of BFP in rowing compared to other sports is not entirely clear. Generally speaking, increased body mass, characterized by a high BFP and BMI, adversely affects 2000 m rowing ergometer performance (Ingham et al., 2002; Russel, le Rossignol & Sparow, 1998; Secher, 1983; Winkert et al., 2019), and increased muscle mass with a high lean body mass and a favorable power-to-body mass ratio are predictors of success in rowing (Penichet-Tomas et al., 2021; Penichet-Tomás, Pueo & Jiménez-Olmedo, 2019). Similarly, in studies designed to determine the best performance predictive parameters (Ingham et al., 2002; Russel, le Rossignol & Sparow, 1998), fat-free mass emerged as one of the strongest correlates with performance. These findings could explain the trend toward lower BFP in elite rowers observed by Mikulić (2008), and most experts concur that proper proportions of tissue components are important for rowers, along with low body fat content and high fat-free mass (Forjasz, 2011). According to Yoshiga and Higuchi (2003), this may be the case because an association between the fat-free mass and blood volume and stroke volume of the heart has been established (i.e., greater fat-free mass is associated with higher aerobic capacity, which is crucial for successful rowing performance). However, Majumdar, Das & Mandal (2017) found a positive correlation between rowing performance and body fat percentage and noted that a certain amount of fat is required for the maintenance of body metabolism, although excess adiposity negatively influences performance. In rowing, moreover, the body mass is typically supported by a sliding seat, and body fat in rowers does not put them at the same disadvantage as athletes who carry their own body weight (e.g. runners, jumpers, etc.). In contrast to BFP and BFP PF, BMI differed the least between the sexes in terms of the DI, and these differences decreased as the age of the rowers increased (15–16 years: −0.49, 17–18 years: −0.36, 19–22 years: −0.27). The mean BMI values in the oldest age categories (men — 23.6 kg/m^2, women — 24 kg/m^2), and particularly that of the women, were close to the upper limit of the normal range and near the value that is considered optimal for rowers, 24 kg/m^2 (Barrett & Manning, 2004; Riechman et al., 2002; Yoshiga & Higuchi, 2003). Forjasz (2011) found that World Cup and Olympic Games finalists had not only higher BMI values than non-finalists, but also higher SMM values. Therefore, when reviewing the results regarding the content of BFP and SMM, it is important to mention that, according to some authors, these are among the most important anthropometric determinants that substantially affect rowing performance. This hypothesis is supported in part by research conducted by Pinechet-Tomás et al. (2021) among traditional rowers, which indicated that body height is the best performance predictor for male rowers, whereas muscle mass is the best predictor for female rowers, which may be due to women having higher BFP values and lower SMM values. This suggests that body composition, including a high lean body mass, and an adequate power-to-body mass ratio, are better predictors of rowing performance than high body mass. Similar observations were made by Winkert et al. (2019) who demonstrated that high body mass and high BMI were negatively correlated with performance. Garrido-Chamorro et al. (2009) and Mazic et al. (2009) concluded that body composition and fat and muscle tissue distribution in the lower and upper half of the body can not be reliably estimated based on BMI alone. Thus, BMI values may not be the best way to assess the sexual dimorphism of rowers. Indeed, the males and females in this study differed very little in this regard although there were important differences between the sexes with regard to SMM and LBM, and among the older juniors, the two largest DI values were for SMM (2.7) and time for covering 2000 m on a rowing ergometer (−2.7). With regard to sitting height, lower limb length, and arm span, the males recorded higher values, and the DI increased with age. This increase in sexual dimorphism in older rowers has important implications for their rowing performance. For example, Penichet-Tomás, Pueo & Jiménez-Olmedo (2019) found that higher- performing traditional rowers have significantly longer trunk lengths than lower-performing ones, which led them to hypothesize that this is because trunk movement plays a significant role in traditional rowing, which was also the conclusion of Izquierdo-Gabarren et al. (2010), Ng et al. (2013) also observed differences in trunk and pelvic kinematics between male and female rowers. Similarly, Li et al. (2020) found that female rowers exhibit a greater range of motion in the lumbar spine, thorax, and shoulders than males due to more extended positions at the finish. Additionally, various authors have pointed out that female rowers may use their higher spinal flexibility (Ng et al., 2013) and possibly their spinal alignment (Mohan & Huynh, 2019) to alter their rowing technique and compensate for their lower body size, muscle strength, level of endurance abilities (Li et al., 2020) and maximal oxygen uptake (Riechman et al., 2002). Longer limbs are also an advantage because they allow more force to be generated during rowing and a longer stroke, as the catch and drive components of the stroke involve all four extremities (Secher, 1993; Secher, 2000). Longer stroke lengths are closely associated with high-level rowing performance (Ingham et al., 2002).

Sex and age differences in physiological characteristics

Regarding gender differences in physiological characteristics across all age categories, males outperformed females in all of the motor tests that were used. The highest DI values (given in order of increasing age category) were for peak power (1.8, 2.78, 2.6), then RPP (1.6, 2.8, 2.5) and time needed to complete 2000 m (−1.7, −1.69, −2.43), which was shortest in the senior males (6.6 min). The smallest differences in DI values were for force max (1.04, 1.63, 1.56). Additionally, small DI values were recorded for RPM (1.38) in the juniors, and relative ErVO2max (1.5) and force max (1.6) in the seniors. A study of elite Polish oarsmen (men and women) by Klusiewicz & Faff (2003) showed that the HR values obtained by women while covering a distance of 2000 m on a rowing ergometer were higher than those obtained by men (195±6 and 193±8 bpm, respectively), although the maximum values were higher in men (204 and 205 bpm, respectively). Keenan, Senefeld & Hunter (2018) studied rowers and observed that race times across years, weight classes, and finishing places were shorter among male than female athletes. Despite the above, the times relative to the first place at higher finish places were faster among women than men. In both Collegiate and Junior World Rowing Championships, female rowers improved their performance to a greater extent than male athletes between 1997 and 2016. Those authors also found that in the heavyweight class, the drop-off in rowing performance was greater for men than for women, but in the lightweight class, it was smaller for men than for women. In the present study, the absolute and relative VO2max of the female and male rowers differed significantly between age categories. Interestingly, Klusiewicz et al. (2014) found that, in elite Polish crews, Olympic medalists, and World Champions, the VO2max increased markedly as female rowers increased from 20 to 22 years of age and as males increased from 19 to 19.9 and from 21 to 22 years of age, reaching respective values exceeding 4.0 and 6.0 l/min for the females and males, respectively. When considering the percent increase in VO2max, it increased by 22.0 and 11.7% in Polish females and males, respectively.

7.6. Strengths and limitations

This study makes a useful contribution to the literature by shedding new light on sexual dimorphism in rowers in three different age categories and across all weight categories, which has heretofore received scant attention. The number of papers dealing with sexual dimorphism in rowing is very low. The strengths of this study include the inclusion of a relatively representative and numerous sample of rowers in three age categories, with the exception of the number of female senior rowers (eight rowers). However, it should be emphasized that we examined all (100%) licensed rowers from seven of the best and largest Hungarian rowing clubs, and these rowers trained in very similar environmental conditions and fulfilled the same selection criteria, which is very important for comparative analyses. It can also be noted that some studies of rowers had similar sample sizes [e.g., N = 10 (Senefeld, Smith & Hunter, 2016); N= 8 (Podstawski et al., 2019a); N = 8 (Podstawski et al., 2019b). The Hungarian rowers in this study are not particularly outstanding; instead, they are typical rowers like those who constitute the vast majority of the rowing community, which makes it possible to make relevant comparisons with regard to sexual dimorphism. This is a novelty because the vast majority of studies have focused on finalists at the Olympics, World Championship or other major regattas —such individuals are very few and are spread across continents or countries, making comparisons very difficult. In this study, the differences in sexual dimorphism are presented in the form of numerical value's, percentages, and values of the sexual dimorphism index, which is very rare in this type of study, especially when such a large number of anthropometric and physiological measurements were taken. However, the limited amount of time available to conduct this large number of measurements meant that, inevitably, some measurements had to be omitted (HR and acid-base balance indices). Nevertheless, it should be emphasized that, given the limited time and organizational possibilities, a mass study (with relatively large study groups) that includes such additional analyses is very difficult to conduct. Although a certain limitation of the present study may also be the measurement of estimated values of VO2max, the scientific literature shows that these measurements are quite commonly used in this type of research (Podstawski et al., 2019a; Podstawski et al., 2019b), including research on rowers (Alföldi et al., 2021; Klusiewicz & Faff, 2003).

7.7. Future research

An interesting topic for future research on sexual dimorphism in rowers would be the ratio between the length of the index finger (2D) and the ring finger (4D). This ratio is already formed during the early stages of human fetal development and does not change throughout life. Manning et al. (1998) found that sexual dimorphism of this index becomes apparent as early as 2 years of age. The differences are due to exposure to sex hormones present in the amniotic fluid during the prenatal period. Manning et al. (2014) considered the 2D:4D ratio a prenatal biomarker that determines the balance between testosterone and estrogen levels. Testosterone has a masculinizing effect and stimulates the growth of the fourth finger, while estrogen elongates the second finger, which means that, in men, the index finger is most often shorter than the fourth finger, with a ratio close to 0.98, while in women, this ratio is higher at about 1 (Manning et al., 1998). This sexual dimorphism has been noted across Africa, Europe, Jamaica, and Asia in 13 different populations (Manning et al., 2004). Low values of the index tend to be possessed by successful male athletes, especially in sports requiring efficient cardiovascular function (soccer, cross-country skiing, middle and long-distance running) (Manning & Taylor, 2001), although this phenomenon has not been found in women (Longman, Stock & Wells, 2011). However, the 2D:4D has not been examined and compared in male and female rowers.

7.8. Conclusions

The results of our study indicate that, from the age of 15 to 22 years, there are significant sex differences in anthropometric and physiological characteristics in Hungarian rowers. The women have significantly larger values for body fat (BFP, BFPPF, BMI, and skinfold thicknesses), while the men have significantly larger values for body mass, body height, SMM, sitting height, arm span, lower limb length and BSA. Regarding physiological characteristics, male rowers significantly outperform female rowers in all motor tests, including peak power, RPP, ErVO2max, jump height, speed max, force max, and RPM. Moreover, the DI values for the analyzed anthropometric and physiological characteristics increase with age. The age-related increase in the sexual dimorphism of Hungarian rowers suggests that training methods should be carefully selected to accommodate the needs of various age and gender groups.

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Informed Consent Statement: This research was conducted in accordance with the guidelines and policies of the Health Science Council, Scientific and Research Ethics Committee (IV/3067–3/2021/EKU), Hungary, and the Declaration of Helsinki. Each participant was provided with detailed information about the purpose of the study, any potential risks, the measurement methods, and the techniques used in motor tests that could be practiced during training sessions held directly before the study. All rowers signed consent forms to indicate their voluntary informed consent to participate in the study.

Data Availability Statement: The data used to support the findings of this study are restricted by the Ethics Committee of the University of Warmia and Mazury in Olsztyn (UWM), Poland in order to protect the participants' privacy. The data are available from R.P., E-mail: podstawskirobert@gmail.comfor researchers who meet the criteria for access to confidential data.

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CHAPTER 8: Physiological and psychological characteristics among competitive rowers (Study 5)

Note: This article has been accepted for publication and the final published version is presented in this dissertation. The final published version is available and can be downloaded online from the publisher's website:
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8.1. Abstract

Introduction: Elite rowing athletes participated in anthropometric, psychological and physiological tests.
Aim: This study aimed to investigate the relations between the traits of sport-confidence and competitive orientation, as well as to compare state measures of sport-confidence, self-efficacy and anxiety. Furthermore, this study targeted to examine the associations of these state measures with performance, in our case the 2000m rowing ergometer run time.
Materials and methods: Rowers (N=15) were subjected to anthropometric, psychological and physiological tests: max 2000 m on Rowing Ergo-test, Athletic Coping Skills Inventory- 28, Competitive State Anxiety Inventory-2 and Sport Competition Anxiety Test.
Results: CSAI-self-confidence showed a statistically significant difference between genders with boys having a higher score. Overall, SCAT (anxiety) scores were low (normal anxiety) in the sample for the vast majority (12 rowers), only 3 participants showed high anxiety.
Conclusion: The psychological profile does not contribute significantly performance on 2000m Rowing Ergo-test, but affects it. Girls completed the distance in a longer period of time, and cognitive anxiety was relatively greater among girls. Additionally, our study pointed out that if the physical parameters are 'inadequate,' then the psychological profile does not contribute to better performance.
Keywords: rowing, anxiety, psychological profile, psychological profile

8.2. Introduction

It is critical to identify any psychological factors related to endurance performance. The psychobiological model predicts that any psychological or physiological factor that increases potential motivation or reduces perception of effort will improve endurance performance. A psychological or physiological factor that reduces potential motivation or increases perception of effort will erode endurance performance (Marcora, Bosio & de Morree, 2008; Sarkar & Fletcher, 2014).

Related literature suggest that many athletes are concerned with the competitive outcomes. Although the desire to win can sometimes be a beneficial behavior, it can also have negative consequences (Orlick, 1986). Specifically, athletes with unrealistic goals often experience low self-confidence, high anxiety and ultimately poor performance. In contrast, athletes who strive to perform well in their sport appear more confident, less anxious and may be more likely to reach their potential (Martens, 1987). Some experiential knowledge suggests these tendencies, and few empirical studies have been conducted (Vealey, 1986, 1988). The athlete's interpretations determine the emotions and associated somatic and cognitive symptoms that the athlete experiences in response to the stressor (Martinent & Ferrand, 2015; Uphill & Jones, 2007). Following the emotional response, it is proposed that the athletes evaluate whether the emotion is relevant to their performance (tertiary interpretations) and what options they have to cope with (quaternary interpretations). The athlete's perceived ability to control and manage the emotional response is suggested to determine whether the athlete discerns it as facilitative or debilitative to their performance.

Anxiety has densely been cited as having an essential role in athletics (Burton, 1989) and (Gould et al., 2003) suggested that cognitive anxiety (worry) is negatively related to self-confidence. Finally, related research and self-reflection of athletes have suggested that self-confidence and anxiety influence performance (Ward & Cox, 2004). Self-confidence enhances performance, whereas cognitive anxiety impairs it (Feltz, 1988).

This study aimed to investigate the relations between the traits of sport confidence and competitive orientation, as well as to compare state measures of sport-confidence, self-efficacy and anxiety, furthermore, to examine the associations of these state measures with performance, in our case the 2000 m rowing ergometer run time.

8.3. Materials and methods

PARTICIPANTS

15 participants (6 boys, 9 girls), aged between 15 and 18 years (M = 16.1, SD = 1), with training age between 1 and 7 years (M = 4.2, SD = 1.9) were included in this study. The following inclusion criteria were applied in the targeted sampling procedure: rowers in all age groups had to hold a valid competition license and participate in national and international competitions for at least one year. All rowers had valid medical certificates, and they regularly participated in trainings. Additionally, they did not limit their physical activity levels (for

whatever reason) to the extent that could significantly affect their physical fitness. The training program was consistent with the Hungarian Rowing Federation Training Routine guidelines: 12-13 hours/week for 15- to 16-year-olds, 14-15 hours/week for 17- to 18-year-olds, and 16-17 hours/week for 19- to 22-year-olds. The aerobic-to-anaerobic training ratio in the above groups was 80:20 percentages, 75:25 and 70:30 percentages, respectively. Athletes with an international ranking participated in training camps organized by the Hungarian Rowing Federation two to three times a year (depending on age group). This research was conducted according to the guidelines and policies of the Health Science Council, Scientific and Research Ethics Committee (IV / 3067-3 / 2021 / EKU), Hungary, and in following the Declaration of Helsinki. Each participant was provided with detailed information about the purpose, potential risks and measurement methods of the study. All rowers gave voluntary informed consent to participate in the study by signing the consent forms.

PROCEDURES, DATA COLLECTION AND EQUIPMENT

Each rower performed selected anthropometric and physiological tests in the middle of the 2020 racing season. On day one, anthropometric features were measured; on day two, the athletes performed additional tests, while on day three, they covered a distance of 2000 m on rowing ergometer. The coaches in charge of the rowers in the sports clubs helped us with the measurements. At all times, the coaches were instructed not to engage the subjects in any strenuous training the day before the testing took place. Body mass (BM) was measured to the nearest 0.1 kg, body height was measured to the nearest 0.1 cm. Body Mass Index (BMI) is a simple calculation using a person's height and body weight. The formula is BMI = kg/m^2, where kg is a person's weight in kilogram and m^2 is their height in square meter. The remaining anthropometric characteristics, such as arm span [cm] were measured using international standards developed by the International Society of Advancement of Kinanthropometry (ISAK) (Krüger, De Ridder & Grobbelaar, 2006).

2000 M MAXIMAL ROWING ERGOMETER TEST

The participants were asked to perform an all-out 2000 m test on a certified rowing ergometer (Concept 2 D-model). The Concept2 RowErg® sets the standard for indoor rowing machines. This is the same machine used by Olympic- and elite-level athletes to train for their sport, but it is also popular among people of all ages and abilities worldwide, who want a total-body, low-impact workout.

Prior to all tests, each participant warmed up for 6 minutes on a 500 m distance. Participants rested for 6 minutes, while performing stretching exercises. The ergometer screen was set to display the remaining meters, the average 500 m split time and the accumulated time. The power output in watts (W) was measured over 2000 m. The watt's calculation was performed in the following way: First, the distance was defined as *distance = (time / number of strokes) ×500*. In the next step, the concept of a "split" was clarified: *split = 500 × (time / distance)*. The watts were calculated as *watts = 2.8 / (split / 500)*. There were slight differences in intensity due to personal changes in stroke value and the ability to keep the 500 m split time constant. The estimated relative aerobic capacity (ErVO2) was calculated by using the formula of McArdle, Katch & Katch (2006) for men: ErVO2 = (Y × 1000) / BM, where BM is body mass in kilograms, and Y = [BM <75kg; 15.1- (1.5 × time); BM ≥ 75kg; 15.7- (1.5 × time)].

SPORT COMPETITION ANXIETY TEST (SCAT)

The Sport Competition Anxiety Test (Martens, 1987), commonly known as SCAT test, is a self-reporting questionnaire about anxiety. The SCAT analyses an athletes' responses to a series of statements about how they feel in a competitive situation. From the results, it is possible to determine their level of anxiety.

PROCEDURE

There was no time limit to answer the 15 questions in the SCAT test questionnaire. The test was suitable to monitor the performance anxiety of an athlete.

ATHLETIC COPING SKILLS INVENTORY-28 (ACSI-28)

The Athletic Coping Skills Inventory-28 (ACSI-28) is a refined psychology assessment, used in several previous studies to measure individual differences in psychological skills within a sport context. lt was developed utilizing a psychometric strategy that involved the use of confirmatory factor analysis to derive subscales that conformed closely to an underlying structural model of psychological skills. The ACSI was initially developed in the mid-1980s as part of a research project on psychosocial vulnerability and resiliency factors related to athletic injury. The study design supported the characteristics of life stress, social support and psychological coping skills (Smith & Smoll, 1990). To measure the latter variable, we utilized a scale measuring individual differences in general psychological and specific psychological skills such as stress management, concentration, control of worry and mental preparation.

COMPETITIVE STATE ANXIETY INVENTORY-2 (CSAI-2)

The test is a sport-specific measure of the competitive state anxiety subcomponents of somatic and cognitive anxiety. Thus, CSAI-2 measures the separate components of state somatic anxiety, mental anxiety and self-confidence (Ward & Cox, 2004). Athletes are asked to indicate "how you feel right now" for each item on a 4-point Likert scale ranging from "not at all" to "very much so". Each of the three subscales has nine items. The total score represents how intensively the athlete feels for each component of anxiety and for the self-confidence about performing. The participants rated the perceived intensity of their feelings on a 7-point scale ranging from -3 (too much debilitative) to +3 (too much facilitative). Hence, scores ranging from -27 to +27 for each of the cognitive anxiety, somatic anxiety and the self- confidence.

TRAIT SPORT CONFIDENCE IINVENTORY (TSCI)

The Trait Sport Confidence Inventory (TSCI) was developed to assess how confident athletes generally feel when they compete in sport. Items on the inventory ask the participants to compare themselves to the "most confident athlete you know". The inventory consists of 13 items with no subscale components, utilizing a 9-point Likert scale anchored by 1 (low) and 9 (high). An item of the TSCI read "Compare your confidence in your ability to perform under pressure to the most confident athlete you know". The item scores represent low (scores from 1 to 3), moderate (scores from 4 to 6) or high (scores from 7 to 9) confidence. Trait sport confidence scores are obtained by a mean score or a total score. Total scores between 13 and 39 reflect a low level and scores between 91 and 117 demonstrates a high level of overall competition confidence.

STATISTICAL ANALYSIS

Basic statistical measures (e.g., mean (M), standard deviation (SD)) were calculated and the normality of the distributions was assessed. Since the distributions did not differ significantly from normality (Shapiro-Wilk test), Student's t-test was used to determine the differences between boys and girls. Linear regression analyses were employed to constitute two different prediction models. We used anthropometric measurement results (arm span, BMI), physiological parameters (resting pulse (rP), estimated aerobic capacity ($ErVO_{2max}$), Peak Power (PP in Watts)) and psychological variables (SCAT, ACSI, CSAI, TSCI). The variables that resulted in the lowest possible standard error of estimate (SEE) were used for all equations. R^2 and the SEE expressed reliability of the regression models. The adjusted R^2, as opposed to the sample R^2, was used to assess the proportion of variance that could be explained by the independent variables.

8.4. Results

DESCRIPTIVE STATISTICS

The participants were 6 males and 9 females, aged between 15 and 18 years (M = 16.1, SD=1), with training age between 1 and 7 years (M = 4.2, SD = 1.9). There was no statistically significant difference in the age of boys (M = 16, SD = 0.9) and girls (M = 16.2, SD = 1.1) ($t(13) = -0.431$, $p = 0.647$). By training age, boys were older (M = 6, SD = 0.6) than girls (M = 3, SD = 1.3) ($t(13) = 5.871$, $p < 0.001$).

Table 1: Anthropometric and physical variables for the total sample of males and females

	Total (N=15)				Mas (n=6)		Females (n=9)		t	p
	Min.	Max.	M	SD	M	SD	M	SD		
Time 2000 m [sec.]	395,00	497,00	453,27	36,72	414,17	21,69	479,33	12,44	-6,664	< 0,001
BMI [kg/m^2]	20,20	24,40	22,07	1,11	21,70	0,96	22,31	1,19	-1,094	0,295
Arm span [cm]	160,10	200,00	179,30	10,00	186,05	8,46	174,80	8,55	2,512	0,029
rP [beat/min]	69,00	85,00	78,07	4,88	78,17	5,74	78,00	4,58	0,06	0,954
PP [W]	183,00	364,00	250,33	65,75	319,83	44,88	204,00	16,36	6,06	0,001
ErVO2 max [mL/kg/min]	43,24	69,53	54,50	7,28	61,19	5,07	50,05	4,56	4,339	0,001

Abbreviation: Time 2000 m [min]=time of the 2000 m rowing ergometer test, ErVO2 max [mL/kg/min] = estimated relative maximal aerobic capacity, PP [W]= calculated power output in watts at the peak of the performance, BMI= Body Mass Index, rP=resting pulse [beat/min].

Females completed the 2000 m distance in a significantly longer time (414.2±21.7 - 479.3±12.4 sec) than the boys did. They also had lower aerobic capacity (61.2±5.07 - 50.05±4.56 mL/kg/min) and lower power output at peak of the exercise (319.8±44.8 - 204.0±16.4 W). No significant difference was found between BMI and resting heart rate (rP) averages.

Table 2: Psychological variables for the total sample of males and females

	Total (N=15)				Males (n=6)		Females (n=9)		t	p
	Min.	Max.	M	SD	M	SD	M	SD		
SCAT_MARTENS	17	26	22,47	2,29	22,33	1,21	22,56	2,88	-0,206	0,840
ACSI_COPING_ CAPACITY_SUM_H	58	95	79,47	10,25	80,50	12,94	78,78	8,81	0,285	0,783
CSAI Cognitive_anxiety	11	31	23,13	5,97	19,33	5,89	25,67	4,77	-2,198	0,055
CSAI_Somatic_anxiety	15	30	23,33	5,39	20,00	4,94	25,56	4,67	-2,181	0,053
CSAI_Self-confidence	16	35	24,47	6,00	28,33	5,47	21,89	5,06	2,304	**0,043**

Only the CSAI-self-confidence showed a statistically significant difference between genders as boys having higher score. Overall, SCAT (anxiety) scores were low in the sample, the vast majority (12) with normal anxiety and 3 with high anxiety. ACSI (coping capacity) scores were relatively high, averaging 71% of the total score (SD = 9.1%). CSAI Cognitive Anxiety and Somatic Anxiety scores indicated rather higher than moderate levels of anxiety, averaging 64.3% (SD = 16.6%) of the total score for cognitive anxiety and 64.8% (SD = 15%) for somatic anxiety. The CSAI self-efficacy score indicates greater than medium self-efficacy, with 68% (SD = 16.7%) of the total score. Sport self-confidence scores were relatively high across the sample, with the vast majority, 13 participants, showing high self-confidence and 2 participants showing medium self-confidence.

Table 3.: First scheme: predictability based on physical parameters

	B	SE	Beta	t	p
Age [year]	-14,491	6,083	-0,391	-2,382	**0,038**
BMI [kg/m^2]	8,859	5,392	0,268	1,643	0,131
rP [beat/min]	-0,159	1,123	-0,021	-0,141	0,891
gender× $ErVO2_{max}$	1,435	0,261	0,825	5,495	< **0,001**

Dependent variable: 'Time 2000 m (sec.)'. Independent variables: age, BMI, heart rate, gender×$ErVO2_{max}$. One of the criteria for regression models is multicollinearity, i.e. no correlation between independent variables above 0.5-0.7. Since arm span and watt (0.760); watt and $ErVO2_{max}$ (0.815); arm span and $ErVO2_{max}$ (0.595) do not meet the regression fit conditions, the solution was to choose the estimated aerobic capacity $ErVO2_{max}$. The non- deterministic is related to the dependent variable, so the solution may be to treat males and females together. In this scheme, the conditions are met: the model is significant ($F(4,10) = 8.831$, $p = 0.003$. Model power and prediction: 77.9% ($R^2 = 0.779$, $R^2_{ajd} = 0.691$). Age is significant ($t(11) = -2.382$, $p = 0.007$). One-unit increase in age reduces time by -14.491. Gender×rVO_{2max} is significant ($t(11) = 5.495$, $p < 0.001$).

Table 4: Second scheme: predictability based on psychological profile

	B	SE	Beta	t	p
Age [year]	-7,701	4,497	-0,208	-1,713	0,121
SCAT	-6,227	2,103	-0,389	-2,961	**0,016**
ACSI	0,522	0,512	0,146	1,020	0,335
TSCI	-0,538	0,370	-0,232	-1,454	0,180
gender×cognitive anxiety	1,791	0,279	0,883	6,414	< **0,001**

Dependent variable: 'Time 2000 m (sec.)', Independent variables: 'age, SCAT, ACSI, CSAI cognitive, somatic, self-confidence, TSCI'. Some independent variables, measuring very similar constructs, should be omitted from the model. Based on this consideration: Individual factors of CSAI are unsurprisingly correlated: cognitive anxiety - somatic anxiety: 0.805; cognitive anxiety - self-consciousness: -0.821; somatic anxiety - self-consciousness: -0.877. CSAI self-confidence and TSCI: 0.549, no relationship with other CSAIs. No relationship between ACSI and CSAI, no relationship between SCAT and TSCI.

Based on the above, it is recommended to include the following variables in the analysis: ACSI (coping capacity), CSAI cognitive anxiety, SCAT (~somatic anxiety), TSCI (~self-confidence), age and gender.

In this model, the conditions are met:

Model is significant ($F(5,9) = 11.912$, $p = 0.001$. Model power and prediction: 86.9% ($R2 = 0.869$, $R2ajd = 0.796$). SCAT is significant ($t(10) = -2.961$, $p = 0.016$). One unit shift in SCAT reduces time by -6.227. Of the two significant independent variables, non×cognitive anxiety has greater explanatory power: ($B = 0.883$; SCAT: $B = 0.389$).

8.5. Conclusions

The main influencing factors on the result of the 2000m performance are age, gender and ErVO_{2max}, which explain nearly 80% of the variability in results of the rowing tests. Time decreases with increasing age; time is greater for females and ErVO_{2max} is decreased in case of females Furthermore, time decreases with increasing ErVO_{2max}. The inclusion of the psychological profile does not significantly contribute to explaining the variability of time.

The psychological profile affects time variability, with time decreasing as SCAT increases, time being more significant factor among girls, cognitive anxiety being relatively greater among girls and performance decreases as anxiety increases (Weinberg & Genuchi, 1980). However, if the physical performance characteristics demonstrate a lower level of physical fitness the psychological profile does not contribute to better performance.

LIMITATIONS OF THE STUDY

There are a relatively small number of athletes participated in the study. Generalization of the results is limited due to restricted number of male and female participants.

CHAPTER 9: Conclusions and novel findings

Modern Olympic and Professional sport is characterized by result orientation. This is due to the laws of the market such as contest for sponsorships and wide public appearance provided by the media (Johnston et al., 2018). Thus, talent identification at young ages is becoming an increasingly urgent issue for national sport federations and club teams. Talent identification programs facilitate to involve young people in training work earlier (Johnston et al., 2018; Vaeyens et al., 2008). Theoretical researchers have already developed several selection methods, however, there are many studies which question the accuracy and applicability of these models and programs (Rongen et al., 2018; Till & Baker, 2020; Žvan & Čoh, 2018). Different sports demand different physiques and cognitive skills and abilities (Liu et al., 2021). The unique requirements of each sport claim for sport-specific instead of general talent identification models (Vaeyens et al., 2008). The identification of those specific characteristics which are beneficial in a given sport is needed to establish an appropriate selection models. Similar procedures have been established for coaches' team sports (Liu et al., 2021). As the selection is a long, difficult and extremely complex process, it includes many possibilities for error and it can be inaccurate (Johnston & Baker, 2020).

As for rowing, many examinations (investigating anthropometric, physiological and psychological parameters) have already been conducted among rowers from several nations searching those factors that influences rowing performance the most significantly and later should be kept in mind in the process of selection for this sport. Based on various principles, different selection models for rowing have already been created (Liu et al., 2021; Nurjaya, Abdullah & Ma'munRusdiana, 2020). However, Hungarian rowers have not been subjected to such measurements and coaches did not applied talent identification programs so far. Based on these consideration, this doctoral dissertation aims to contribute to the improvement of Hungarian rowing both in national and international level.

The main goal of this study is to present those anthropometric, physiological and psychological factors that may affect children's rowing performance.

9.1. Anthropometric and physiological parameters compared by age groups and their effect on rowing performance

245 rowers, 101 females (17.24 ± 1.38 years old) and 144 males (18.22 ± 1.33 years old) from 16 rowing clubs in 10 Hungarian cities were included in these examinations. 3 groups were formed according to age, namely the first group consist of 15-16 year olds, the second includes 17-18 year olds and the third 19-22 year olds.

H1 is True, our study found a relationship between anthropometric variables (height, sitting height, arm spam) and performance.

Connection was found between the anthropometric variables (body mass, sitting height and arm span) and performance. Regarding the females' 3 groups most importantly the significantly greater values of sitting height and arm span showed parallels increasing performance. Former investigations also came to this conclusion (Akça, 2014; Barrett & Manning, 2004; Mikulić, 2009; Mikulić & Ružić, 2008). The anthropometric characteristics of males are almost the same in the second and the third groups coupled with similar performance. There is no real difference between the means of body mass, nutrition index and body surface area in the whole sample. Formerly, some similar examinations indicated lean body mass as the most important anthropometric characteristic influencing performance (Cosgrove et al., 1999; Yoshiga et al., 2000). Among females the estimated relative aerobic capacity (e.r. VO2max) showed an ever greater significant increase in all age groups. Among males – in agreement with the anthropometric variables – the mean values of the second and third groups are almost the same, and increase can be observed only compared to the first group's mean values.

H2 is True: our regression analyses suggest that cardiorespiratory characteristics are stronger predictors than anthropometric variables.

Based our regression analyses the cardiorespiratory characteristics are better predictors than anthropometric variables. Consistently with previous studies (Cosgrove et al., 1999; Kendall et al., 2011; Mikulić & Ružić, 2008), estimated relative aerobic capacity is proved to be stronger predictor than performance referred to body mass. Close relationship was observed between performance per body mass (rWatt) and estimated relative aerobic capacity (e.r. VO2max). Former investigations drew similar conclusions (Cosgrove et al., 1999; Mikulić, 2009; Mikulić & Ružić, 2008; Yoshiga et al., 2000).

H3 partially True: power per body mass (rWatt) showed a medium correlation with estimated relative aerobic capacity (e.r.VO2max) in our sample.

In the 2000m rowing ergometer time trial the significantly greater estimated relative aerobic capacity observed in the whole sample means a significantly increasing performance per body mass (rWatt), except for the difference in performance of the females' first and second groups. Researchers have pointed out that maximal aerobic performance (in Watt) is an important predictor for the time result of the 2000m tests (Ingham et al., 2002; Jürimäe et al., 2000; Riechman et al., 2002; Womack et al., 1996). According to their opinion, it is essential to pay enough attention to include the anthropometric characteristics we examined in the process of future competitors' selection. All the more that cardiorespiratory system (which have significant relationship with performance and thus with success) of children with optimal attributes can be developed with appropriate training work.

The predictive value of the variables examined in our studies should be considered as important supplement among the purpose of talent identification for rowing. If the relations between body height, body mass, arm span and performance are taken into account, it is logical to use these variables in the early stages of talent identification.

In rowing, the results of the presented studies can be utilized in the latter part of the talent identification process as matured movement technique and athletic experience are required to perform the tests used for our examinations. Close relationship was observed between some anthropometric and physiological variables and performance. Consequently, the physical effects of these indicators should not be underestimated.

9.2. The role of psychological profile

Talent identification programs often ignore the role of psychological factors. However, these are important performance-influencing parameters, thus greater emphasis should be placed on them in the development of talent identification programs (Johnston et al., 2018; Macnamara, Button & Collins, 2010).

H4 partially True: the psychological profile does not contribute significantly, but has an effect on ergometer times.

If an athlete does not have adequate mental skills, it may happen that can not perform well in a decisive situation due to competitive anxiety (Peng & Zhang, 2021). Studies have already identified several psychological variables needed to reach success, which distinguishes successful athletes from their less prosperous opponents (e. g. determination, short- and long-term goals, focus, dedication, mental preparedness, self-confidence, motivation etc.) (Durand-Bush & Salmela, 2002; Gould, Dieffenbach & Moffett, 2002; Orlick & Partington, 1988).

Based on these considerations I find it essential to examine psychological factors in addition to anthropometric, cardiorespiratory and motoric characteristics. For this purpose, different tests explained in the study presented in Chapter 8 were utilized (CSAI-2, SCAT, ACSI-28, TSCI), that served to measure the effect of self-confidence and anxiety on performance. In terms of self- confidence, males reached significantly higher scores compared to females. Scores in case of SCAT tests show normal level of anxiety in our sample. With the increase of anxiety, the performance worsens, in agreement with results of former studies (Weinberg & Genuchi, 1980). In spite of the above mentioned results, in my opinion it is essential to conduct multidimensional examinations, which investigate both physical and psychological parameters, however, the overall conclusion can be drawn, that without adequate physical aptitude, a beneficial psychological profile is not sufficient to reach outstanding results in rowing.

9.3. Summary of the parameters suggested to be used in the process of selection

The studies presented in Chapter 4, 5, 6, 7 and 8 provides useful information that should be utilized for the selection of Hungarian rowers. This is all the truer, as no similar talent identification program has been developed so far.

This doctoral dissertation contributes to the existing literature in a novel way as it provides information of the anthropometric and physiological characteristics of rather younger Hungarian athletes with ambitions to become successful rowers in the future. This is the first attempt to capture differences in the anthropometric and physiological characteristics of intermediate level rowers. According to my opinion this fact is the clear strength of this study, since the number of non-elite athletes exceeds substantially the fairly small group of champions. This approach contributes to the novelty of this dissertation, however, it is difficult to compare the results of the present study with former examinations, because the number of investigations that include intermediate level athletes is quite limited. The conclusions of this dissertation can be considered decisive with great certainty, as the size of the sample is relatively great than in similar studies (Klusiewicz et al., 2014; Mikulić, 2008).

To sum up, from the investigations included in this dissertation it can be concluded, that anthropometric characteristics should be examined in the early stage of talent identification for rowing, since unlike these attributes, the cardiorespiratory system of a young talented athlete with adequate physiological characteristics can be developed with appropriate training work. Great emphasis should be placed on different skills and needs of the athletes in different ages and genders while the training plans are being made. Then later, for example in the process of assembling teams, the evaluation of cardiorespiratory variables can be expedient to distinguish the athletes expected to reach outstanding results. For this purpose, for instance the outcomes of the 2000m ergometer test is an effective tool.

9.4. Novel findings

The novelty of the research is that such a large sample study has not yet been carried out in this target group in Hungary.

1. Our study found a relationship between anthropometric characteristics (height, sitting height, arm span) and performance in the Hungarian sample.

2. Our findings suggest that cardiorespiratory characteristics are stronger predictors than anthropometric variables.
3. Based on our study the cardiorespiratory characteristics are more reliable predictors than anthropometric characteristics.
4. The psychological profile does not contribute significantly to better performance, but has an effect on ergometer times.

9.5. Limitations and future directions

Numerous investigations pointed out that current talent identification programs are yet insufficient and run into several problems, their credibility and validity are rather questionable and actually their applicability for predictive purposes is limited (Bailey & Collins, 2013; Till & Baker, 2020). Researchers invest great efforts to develop the right, eventually useful method for talent identification.

Cross-sectional studies are often used to collect data, thus in the examinations presented in my doctoral dissertation this methodology was used. The drawback of this method is that athletes who seems to be promising talent at young age, later go through changes during maturation which effect their performance as well and thus not necessarily become successful in senior ages (Malina, 1994). In the future, it would be useful to conduct longitudinal studies on rowers, since researchers pointed out in connection with other sports that in different age categories different characteristics should be used as the indicators of performance (Vaeyens et al., 2008). In addition, the involvement of more variables in the examinations would be useful, as excellence in a sport is not corresponding to a standard set of physical characteristics or skills; it can be achieved in unique ways through different combinations of skills and capabilities. If only some selected factors are examined, then individuals who score low on one specific variable may be deselected from the talent pool (Vaeyens et al., 2008).

Results presented in this doctoral dissertation provides useful help in the process of rowing talent identification for professionals not only from Hungary but from other nations as well.

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CHAPTER 10: List of publications

10.1. PUBLISHED ARTICLES RELATED TO THE THESIS

Alföldi, Zoltán – Katona, Zsolt Bálint – Gyömörei, Tamás [et al.] (2022): Physiological and psychological characteristics among competitive rowers. In: *Stadium*, 5(1):2676.

Alföldi, Zoltán – Katona, Zsolt – Suszter, László [et al.] (2020): Kiválasztási kritériumok vizsgálata utánpótláskorú evezős leányok és fiúk körében=Examination of selection criteria among male and female of junior rowing age. In: *Magyar Sporttudományi Szemle,* 21(6):3-10.

Alföldi, Zoltan – Borysławski, Krzysztof – Ihasz, Ferenc [et al.] (2021): Differences in the Anthropometric and Physiological Profiles of Hungarian Male Rowers of Various Age Categories, Rankings and Career Lengths: Selection Problems. In: *Front Physiol*, 12:747781.

Podstawski, Robert – Borysławski, Krzysztof – Katona, Zsolt Bálint – **Alföldi, Zoltan** [et al.] (2022): Sex Differences in Anthropometric and Physiological Profiles of Hungarian Rowers of Different Ages. In: *Int J Environ Res Public Health,* 19(3):8115.

10.2. ARTICLE RELATED TO THE THESIS CURRENTLY UNDER REVIEW

Alföldi, Zoltan – Kósa, Lili – Soós Imre [et al.]: Anthropometric and physiologic characteristics of elite male female junior rowers Revista Brasileira de Medicina do Esporte

10.3. ADDITIONAL PUBLISHED ARTICLES "HEALTH SCIENCES"

Podstawski, Robert – Bielec, Grzegorz – **Alföldi, Zoltán** [et al.] (2022): Changes in the Blood Pressure, Heart Rate and Body Mass of Physically Active Menin Response to Thermal Stress. In: *Cent Eur J Sport Sci Med,* 37(1):65-76.

Suszter, L. - Ihász, F. - Szakály, Zs. - Nagy, D. - **Alföldi, Z.** [et al.] (2020): Effect of a five-week beta-alanine supplementation on the performance, cardio- respiratory system, and blood lactate level in well-trained rowing athletes: A double-blind randomized pre–post pilot study. In: *JPES,* 20(5):2501-2507.

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10.4. ABSTRACTS RELATED TO THE THESIS

Alföldi Z. - Soós I. - Katona Zs. [et al.] (2020): Magyar evezős utánpótlás válogatott sportolók antopometriai és teljesítményélettani vizsgálata [előadás]. *X. Tudományos Fórum,* Pécs. 2020 október 20-21.

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versenyhelyzetben (Pilot study) [előadás]. *PTE ETK Egészségtudományi Doktori Iskola és az MTA TAB Egészségtudományi Munkabizottság IX. Tudományos fóruma*, Pécs. 2019. november 22.

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Alföldi Zoltán - Ihász Ferenc (2020): Utánpótláskorú evezős leányok és fiúk antropometriai és keringési jellemzőinek bemutatása. In: *Magyar Sporttudományi Szemle*, 21(3):33-33.

10.5. ADDITIONAL ABSTRACTS "HEALTH SCIENCES"

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APPENDICES

Appendix 1

ACSI-28

UTASÍTÁS: Néhány olyan megállapítást olvashat az alábbiakban, melyekkel a sportolók szokták jellemezni önmagukat. Olvassa el valamennyit és húzza át a jobboldali számok közül a megfelelőt attól függően, hogy mennyire tartja igaznak az alábbi állításokat önmagára vonatkozóan.

Nincsenek helyes vagy helytelen válaszok. Ne gondolkozzon túl sokat, hanem a jelenlegi érzéseit legjobban kifejező választ jelölje meg.

1-szinte soha 3-gyakran

2-néha 4-majdnem mindig

1. Hétről hétre jól meghatározott célokat tűzök ki magam elé, és azok szerint cselekszem.	1	2	3	4
2. Tehetségem és képességeim legjavát hozom ki magamból	1	2	3	4
3. Ha az edző vagy a manager megmondja, hogyan javítsam ki a hibámat, hajlamos vagyok azt személyeskedésnek venni, és ideges leszek	1	2	3	4
4. Sportolás közben jól tudok koncentrálni, és ki tudom zárni a zavaró ingereket.	1	2	3	4
5. Verseny közben bizakodó és lelkes maradok, függetlenül attól, hogy mennyire kicsi a nyerési esélyem.	1	2	3	4
6. Tétversenyen jobb a teljesítményem, mert tisztább a fejem.	1	2	3	4
7. Egy kicsit szorongok amiatt, hogy teljesítményemet mások hogyan értékelik.	1	2	3	4
8. Sokat töprengek azon, hogy miként valósítsam meg céljaimat.	1	2	3	4
9. Az önbizalmam segít abban, hogy jól játsszam.	1	2	3	4
10. Az edző vagy a manager kritikája inkább idegesít, mint segít.	1	2	3	4
11. Amikor figyelek valamire, vagy hallgatok valamit, könnyen távol tudom tartani a zavaró gondolatokat.	1	2	3	4
12. A teljesítményemmel kapcsolatos aggodalmak, túl nagy lelki terhet jelentenek	1	2	3	4

számomra.				
13. Az elérendő teljesítményt minden edzésen meghatározom a magam számára.	1	2	3	4
14. Nincs szükségem arra, hogy edzésen vagy versenyen kemény munkát követeljenek tőlem; mindig 100%-ot teljesítek.	1	2	3	4
15. Ha az edző valamiért kritizál, vagy kiabál velem, a hibát nyugodtan kijavítom.	1	2	3	4
16. Jól oldom meg a sportágamban felmerülő helyzeteket.	1	2	3	4
17. Ha rosszul állok, igyekszem nyugodt maradni, és ez beválik.	1	2	3	4
18. Minél nagyobb a tét egy versenyen, annál jobban élvezem.	1	2	3	4
19. Verseny alatt aggódom amiatt, hogy hibát vétek vagy nem leszek sikeres.	1	2	3	4
20. Jóval a játszma kezdete előtt a fejemben van a játéktervem.	1	2	3	4
21. Amikor úgy érzem, hogy kezdek túlzottan feszültté válni, képes vagyok gyorsan ellazítani testemet, és megnyugtatni magamat.	1	2	3	4
22. Szeretem a téthelyzetek nyújtotta kihívásokat.	1	2	3	4
23. Gondolok arra és elképzelem, hogy mi fog történni, ha kudarcot vallok vagy hibázok	1	2	3	4
24. Bárhogyan is mennek a dolgok, uralkodni tudok érzelmeimen	1	2	3	4
25. Figyelmemet könnyen tudom irányítani, és képes vagyok egyetlen dologra vagy személyre koncentrálni.	1	2	3	4
26. Ha nem sikerül elérnem a kitűzött célt, az a korábbi keményebb munkára ösztönöz.	1	2	3	4
27. Az edzők és managerek tanácsait és utasításait megfogadva fejlesztem képességeimet.	1	2	3	4
28. Téthelyzetben kevesebb hibát vétek, mert jobban koncentrálok.	1	2	3	4

Appendix 2

CSAI-2 ÖNÉRTÉKELÉSI LAP

NÉV KOR KELT

UTASÍTÁS: Néhány olyan megállapítást olvashat az alábbiakban, melyekkel a sportolók verseny előtti állapotukat szokták jellemezni. Olvassa el valamennyit és húzza át a jobboldali számok közül a megfelelőt attól függően, hogy ebben a pillanatban – éppen most – hogyan érzi magát.

Nincsenek helyes vagy helytelen válaszok. Ne gondolkozzon túl sokat, hanem a jelenlegi érzéseit legjobban kifejező választ jelölje meg.

	egyáltalán nem	Valamennyire	Eléggé	Nagyon
1. Nagyon foglalkoztat ez a verseny.	1	2	3	4
2. Ideges vagyok.	1	2	3	4
3. Gondtalanak érzem magam.	1	2	3	4
4. Kevés az önbizalmam.	1	2	3	4
5. Nyugtalannak érzem magam.	1	2	3	4
6. Kellemesen érzem magam.	1	2	3	4
7. Aggódom amiatt, hogy ezen a versenyen nem fogok úgy szerepelni, ahogy szeretnék.	1	2	3	4
8. Feszültséget érzek magamban.	1	2	3	4
9. Elég önbizalmat érzek magamban.	1	2	3	4
10. Félek attól, hogy veszíteni fogok.	1	2	3	4
11. Összeszorul, remeg a gyomrom.	1	2	3	4
12. Biztonságban érzem magam.	1	2	3	4
13. Arra gondolok, hogy verseny közben le-blokkolok.	1	2	3	4
14. A testem ellazult.	1	2	3	4

15. Bízom abban, hogy kiállom a próbát.	1	2	3	4
16. Félek attól, hogy rosszul fogok szerepelni.	1	2	3	4
17. A szokásosnál gyorsabban ver a szívem.	1	2	3	4
18. Bízom abban, hogy jól fogok szerepelni.	1	2	3	4
19. Arra gondolok, hogy elérem-e a célomat.	1	2	3	4
20. Valami furcsa émelygést érzek a gyomromban.	1	2	3	4
21. Nyugalmat érzek magamban.	1	2	3	4
22. Félek attól, hogy teljesítményem csalódást okoz.	1	2	3	4
23. Nedves a tenyerem.	1	2	3	4
24. Bizakodó vagyok, mert el tudom képzelni, hogy elérem a célomat, győzök.	1	2	3	4
25. Félek attól, hogy nem tudok koncentrálni.	1	2	3	4
26. Megfeszülnek az izmaim.	1	2	3	4
27. Tétversenyen is sikeresen szerepelek.	1	2	3	4

Appendix 3

Sport Competition Anxiety Test (SCAT)

Név:………………………………………………………Kor:………………..Kelt:……………

Olvasd el az alábbi kijelentéseket és döntsd el, hogy „Ritkán”, „Néha” vagy „Gyakran” érzel, úgy amikor versenyhelyzetben vagy, majd jelöld be egy X-el a megfelelő oszlopban a válaszodat.

Kijelentések	**Ritkán**	**Néha**	**Gyakran**
1. Élvezek másokkal versengeni			
2. Verseny előtt nyugtalannak érzem magam			
3. Mielőtt versenyzek, aggódom amiatt, hogy nem fogok jól teljesíteni			
4. Amikor versengek jó sportolónak érzem magam			
5. Amikor versengek, aggódom amiatt, hogy hibákat követhetek el			
6. Verseny előtt nyugodt vagyok.			
7. A célkitűzés fontos, amikor versenyről van szó.			
8. Verseny előtt émelygést érzek a gyomromban.			
9. Közvetlenül a verseny előtt észreveszem, hogy a szívem gyorsabban dobog (megnő a pulzusom), mint általában			
10. Szeretek olyan sportokban/játékokban versengeni melyek sok fizikai energiát igényelnek			
11. Verseny előtt lazának érzem magam.			
12. Verseny előtt ideges vagyok			
13. A csapat sportok sokkal izgalmasabbak, mint az egyéni sportok			
14. Egyre idegesebb leszek, ahogy várom, hogy megkezdődjön a verseny			
15. Verseny előtt általában feszült vagyok			

Appendix

Sport önbizalmi állapot kérdőíve (SOAK)

Robin, S. Vealey, 1986
Nagykáldi,C., Galloway,S. 2000

Név:

Gondolj arra, hogy most mennyire vagy magabiztos, a következő versenyen sikerében. Tehát válaszolj a következő kérdésekre aszerint, hogy mennyire vagy magabiztos a versenyen való szerepléssel kapcsolatban. A válasz alapja egy összehasonlítás: a saját önbizalmadat az általad ismert legmagabiztosabb versenyzőjével kell összehasonlítani. Ha távol állsz tőle, alacsony számot karikázz be, ha közel, akkor nagyobb számot.

MENNYIRE VAGY JELENLEG MAGABIZTOS A KÖVETKEZŐ VERSENYT ILLETŐEN HA A LEGMAGABIZTOSABB VERSENYZŐVEL HASONLÍTOD MAGAD ÖSSZE? **(Karikázd be a megfelelő számot)**

	Alacsony				Közép				Magas
1. Mennyire tudod a sikerhez szükséges mozgást végrehajtani?	1	2	3	4	5	6	7	8	9
2. Mennyire tudod a kritikus döntéseket a verseny alatt meghozni?	1	2	3	4	5	6	7	8	9
3. Mennyire tudsz "nyomás" alatt teljesíteni?	1	2	3	4	5	6	7	8	9
4. Mennyire tudsz sikeres stratégiát (taktikát) végrehejtani?	1	2	3	4	5	6	7	8	9
5. Mennyire tudsz koncentrálni, hogy sikeres légy?	1	2	3	4	5	6	7	8	9
6. Mennyire tudsz különböző helyzetekben alkalmazkodni és még sikeres is lenni?	1	2	3	4	5	6	7	8	9
7. Mennyire tudod a teljesítménycélokat elérni a versenyen?	1	2	3	4	5	6	7	8	9
8. Milyen képességed van a sikerre?	1	2	3	4	5	6	7	8	9
9. Mennyire tudsz gondolkodni és eredményesen reagálni verseny alatt?	1	2	3	4	5	6	7	8	9
10. Mennyire tudsz a verseny kihívásainak megfelelni?	1	2	3	4	5	6	7	8	9
11. Mennyire vagy képes a sikerre, amikor rosszak az esélyeid?	1	2	3	4	5	6	7	8	9
12. Mennyire tudsz egyenletesen teljesíteni, hogy sikeres légy?	1	2	3	4	5	6	7	8	9
13. Hogyan tudsz rosz teljesítmény után talpra állni és ismét sikeres lenni?	1	2	3	4	5	6	7	8	9

7. sz. melléklet

DOKTORI ÉRTEKEZÉS BENYÚJTÁSA ÉS NYILATKOZAT A DOLGOZAT EREDETISÉGÉRŐL

Alulírott

név: ALFÖLDI ZOLTÁN

születési név: ALFÖLDI ZOLTÁN

anyja neve: MECSEKI TÜNDE

születési hely, idő: MOHÁCS, 1985.02.02.

Anthropometrical, physiological and psychological characteristics among competitive rowers című doktori értekezésemet a mai napon benyújtom a PÉCSI TUDOMÁNYEGYETEM EGÉSZSÉGTUDOMÁNYI DOKTORI ISKOLA 7. program / PR-7/ SPORT és EGÉSZSÉGTUDOMÁNY Programjához/témacsoportjához
Témavezető neve: DR. IHÁSZ FERENC

Egyúttal nyilatkozom, hogy jelen eljárás során benyújtott doktori értekezésemet
- korábban más doktori iskolába (sem hazai, sem külföldi egyetemen) nem nyújtottam be,
- fokozatszerzési eljárásra jelentkezésemet két éven belül nem utasították el,
- az elmúlt két esztendőben nem volt sikertelen doktori eljárásom,
- öt éven belül doktori fokozatom visszavonására nem került sor,
- értekezésem önálló munka, más szellemi alkotását sajátomként nem mutattam be, az irodalmi hivatkozások egyértelműek és teljesek, az értekezés elkészítésénél hamis vagy hamisított adatokat nem használtam.

Továbbá nyilatkozom, hogy hozzájárulok a doktori értekezésem DOI azonosító igényléséhez.

Dátum: PÉCS, 2023.03.02.

Alföldi Zoltán
....
doktorváromány os aláírása

....
témavezető aláírása

....
társtémavezető aláírása