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Science of Gymnastics Journal (ScGYM®)

Science of Gymnastics Journal (ScGYM®) (abrevated for citation is SCI GYMNASTICS J) is an international journal that provide a wide range of scientific information specific to gymnastics. The journal is publishing both empirical and theoretical contributions related to gymnastics from the natural, social and human sciences. It is aimed at enhancing gymnastics knowledge (theoretical and practical) based on research and scientific methodology. We welcome articles concerned with performance analysis, judges' analysis, biomechanical analysis of gymnastics elements, medical analysis in gymnastics, pedagogical analysis related to gymnastics, biographies of important gymnastics personalities and other historical analysis, social aspects of gymnastics, motor learning and motor control in gymnastics, methodology of learning gymnastics elements, etc. Manuscripts based on quality research and comprehensive research reviews will also be considered for publication. The journal welcomes papers from all types of research paradigms.

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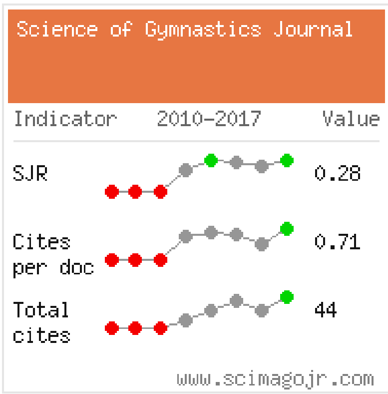

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F.I.G.

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EDITORIAL

Dear friends,

SCOPUS announced results of 2017 journals evaluation. I was pleasantly surprised as Science of Gymnastics Journal Cite Score reached 0.65, SNIP 0.787 and SJR 0.28. By Cite score our journal is ranked into third quarter of journals. We have to be glad our fellow researchers cited our work in their work. Hope this trend continues in future.

In this issue we have twelve articles with authors from Greece, Brazil, Czech, Slovakia, Germany, Australia and Slovenia. Articles cover psychology (motor learning), history, philosophy (terminology), anthropometry, physiology and kinesiology.

For our October issue we are preparing a special issue about gymnastics at the Olympic Games, with special guest editors Myrian Nunomura and Laurita Marconi Schiavon from Brazil to remember the OG in Rio 2016.

Anton Gajdoš prepared with help of Michal Babela a new contribution to the history of gymnastics, refreshing our knowledge of Zoltan Magyar, incredible gymnast, pommel horse rider, elements inventor on pommel horse from Hungary .

In last issue we introduced Istvan Karacsony’s book ‘130 years of Hungarian Gymnastics’ - 904 pages with 4000 pictures/photos; for this issue he prepared slight inside into book content.

Just to remind you, if you quote the Journal: its abbreviation on the Web of Knowledge is SCI GYMN J. I wish you pleasant reading and a lot of inspiration for new research projects and articles,

Ivan Čuk
Editor-in-Chief

IS VEGAN DIET APPROPRIATE FOR COMPETITIVE ARTISTIC GYMNASTS?

Boštjan Jakše, Barbara Jakše

Slovenia

Review article

Abstract

The majority of scientific evidence strongly associates a well-planned vegan diet with health, a successful control of body weight, a preventive measure, and, in some cases, with the termination and the reverse of the most common chronic non-communicable diseases, such as cardiovascular diseases, type 2 diabetes, certain cancers, and some other diseases. Numerous athletes have accepted these findings and adopted this lifestyle choice. Furthermore, the athletes choose well-planned vegan diet with the intention of optimizing their athletic abilities. The position of The British Dietetic Association (BDA) and The Academy of Nutrition and Dietetics (AND) on the vegetarian diet states that well-planned vegetarian diets, including the vegan diet, are healthy and nutritionally adequate and appropriate for all stages of the life cycle, including pregnancy, lactation, infancy, childhood, adolescence and older adulthood. What is more, AND repeats its view from nearly ten years ago on the appropriateness of the vegan diet for the needs of athletes. The aim of this article is to justify the appropriateness of a well-planned vegan diet for the needs for competitive artistic gymnasts and to do so with a relative scientific transparency.

Keywords: *vegan diet, gymnasts, health, body weight, athletic abilitie.*

INTRODUCTION

With a constant increase of scientific evidence that support the health benefits of a well-planned vegan diet, there is also a growing number of people who decide on this type of diet (Melina, Craig & Levin, 2016). With appropriate nutrition and a generally healthy lifestyle (absence of smoking, regular physical activity, a controlled alcohol intake) we can prevent 90% of type 2 diabetes, 80% of cardiovascular diseases, 70–90% of strokes, and 70% of bowel cancer (Willet, 2002) or 90–95% of all cancers (Anand et al., 2008). Vegan diets have been associated with lowering overall and ischemic heart disease mortality, supporting sustainable weight management, reducing medication needs, lowering the risk for most chronic diseases, decreasing the incidence and severity of high-risk conditions, including obesity, hypertension, hyperlipidemia, and hyperglycemia, certain types of cancer, and even possibly reversing advanced coronary artery disease and type 2 diabetes (Hever &

Cronise, 2017; Melina, Craig & Levin, 2016). The evidence shows that vegan diets can lower the risk of coronary artery diseases by 40%, cerebral vascular diseases by 29%, and the onset of the metabolic syndrome and type 2 diabetes by 50% (Rizzo, Sabaté, Jaceldo-Siegl & Fraser, 2011). Potential mechanisms for the mentioned effects are an increased intake of fiber, antioxidants, and plant-based proteins on one hand and a reduced intake of saturated and total fats, dietary cholesterol, and a lower caloric intake on the other hand (Kahleova, Levin & Barnard, 2017).

With the increasing interest in the potential benefits for health due to vegan diet, this topic also became interesting for the researchers, who studied the effect of different vegetarian diets on weight control, recovery after training, and sports performance. Physical efficiency is a broad term, yet researchers usually study the influence of nutrition on various motor skills, such as power, speed, and endurance, while they usually do not measure the influence of different diets on balance or flexibility (Craddock, Probst & Peoples, 2016). A balanced nutrition on one side and an absence or restriction of the intake of substances in the food that are harmful for health on the other side are crucial not only for the athlete's health but also for the recovery after training or performance, the support during physical preparation, and for preventing injuries. A well-designed vegan diet (Fuhrman & Ferreri, 2010) may present a nutritionally adequate diet that provides energy, maximizes performance, offers resistance to illnesses (not being absent on trainings or competitions), enables a simple control of appropriate body weight while enjoying regular meals to full satiety, and offers an efficient recovery after repeated daily strains. Certain nutrients (Melina, Craig & Levin, 2016) are less present in a vegan diet than in a diet that includes animal source foods, e.g. protein, saturated fats, zinc, vitamin D, and vitamin B_{12}, but the manifestation of nutritional deficiency is no more distinct with the vegetarian population than with people with a mixed diet. In this article, the authors will justify why a well-planned vegan diet, supplemented with vitamin B_{12} and most likely also with long chains of omega-3 fatty acids (EPA, i.e. eicosapentaenoic acid and DHA, i.e. docosahexaenoic acid), is a healthy and a nutritionally adequate diet, especially for a competitive gymnast, despite some concerns in the professional public about the appropriateness of a vegan diet for an athlete.

This article is the first attempt of a comprehensive overview of the potential appropriateness of a well-planned vegan diet for the needs of a gymnast due to the long-term health and sport performance that they are faced with (e.g. appropriate control of body weight, optimizing athletic abilities, efficient recovery, nutritional adequacy, etc.). Numerous experts (coaches, nutrition experts, physicians) received an education that talked about a balanced mixed diet, following moderation in everything, and enjoying less food and training more in order to be healthy and achieve appropriate body weight control. In addition, a lot of university professors still lecture their students solely on this outlived paradigm of a healthy lifestyle as the only healthy and officially accepted possibility on one side while usually stigmatizing the vegan diet on the other (e.g. that it is dangerous, nutritionally inadequate, hard to implement, still without reliable scientific evidence, etc.). There exists a problem of a lack of awareness of the current scientific evidence about well-planned vegan diet, since the majority of the scientific evidence about the positive effects of a well-planned vegan diet was only researched in the last 10 to 20 years. Therefore, it is hard to communicate to people (and athletes) objective information that helps them make an informed decision. Frequent concerns of the appropriateness of the vegan diet can, on the other hand, also result from the expected behaviors and norms, or in other words old habits (it is difficult to change dietary patterns), as well as personal strain and conflict of interests, often wrongly associating a well-planned vegan diet with an inappropriately structured vegan diet where the motive for this type of diet can often also be associated with the ideology (ethical, environmental, and philosophical standpoints). Despite the urgent need of well-designed randomized controlled studies, the authors wish to contribute to changing the conservative thinking about the possibilities of a healthy and for sports performance appropriate diet for a gymnast by providing an overview of scientific evidence about the vegan diet, the publications of standpoints of some health and dietetic authorities about the vegan diet, and finally the examples of good practice of vegan athletes. The aim of this article is also to encourage researchers to decide on executing well-designed short-term and long-term clinical researches of a well-planned vegan diet on gymnasts, especially in relation to other dietary patterns.

The starting point of nutritional needs and the state of artistic gymnast's eating habits

When talking about competitive gymnasts and the potential appropriateness of a vegan diet, we must keep in mind that their gymnastic development starts quite early (Burke, 2007; Sands et al., 2016), that the majority of gymnasts are female[1], and that, especially elite female gymnasts, often end their career in late teenage years or early 20s (Atiković, Delaš Kalinski & Čuk, 2017; Louer, Elferink-Gemser & Visscher, 2012), while many of them remain involved in different roles in the world of gymnastics (Ba, Jakše, personal communication, November, 2016). We cannot ignore the fact that competitive gymnastics is, among other things, a sporting discipline "for life" and that gymnasts are first and foremost people, so it is only ethical that they do not achieve their goals in sport at the expense of their long-term health (Jakše & Jakše, 2017). Besides the basic energy, motor, and cognitive requirements for a successful sports performance of a gymnast on individual gymnastics tools and in all-around gymnastics, we must also recognize the needs of a successful recovery after every training in the various eras of periodization[2]. The absence of injuries is generally the basis of every successful development of the athlete and competitive gymnasts can often experience delayed onset muscle soreness or DOMS, various chronic tendon inflammations, and repetitive injuries due to repeated extreme burdens on the musculoskeletal system. A successful performance on the floor, the pommel horse, the rings, the vault, the uneven and parallel bars, the balance beam and the horizontal bar (Sleeper, Kenyon, Elliot & Cheng, 2012) requires a number of motor skills, such as speed, strength, endurance, agility, flexibility, and balance, while the level of gymnast's skills is tightly associated with the absence of injury. Appropriate body weight, excellently developed motor skills, and a high level of various perceptual abilities enable the gymnasts to control their posture while executing demanding elements, despite the fact that they cannot completely rely on their eyesight (personal experience of one of the authors, who is a former successful competitive gymnast). Because competitive gymnastics demands a combination of explosive and submaximal muscle contractions when executing numerous demanding elements, there is also a relatively high heart rate (from 170–190 beats/min with women and from 150–180 beats/min with men). Due to repetitive gymnastics elements with short breaks (lasting up to 90 seconds), competitive gymnastics primarily includes anaerobic metabolism (average assessment is 80% of energy requirements) and blood lactate concentration between 8 and 11 mmol/l. The performance on the floor can be an

[1] E.g. data for Portugal for the year 2012 shows that from the sample of 14742 gymnasts from all gymnastic disciplines 81.2% are female and only 16.7% are male (Silva & Barata, 2016). In the USA (USAGym, 2016) there are over 5 million registered gymnasts over the age of 6 and the majority of them are female (76%).

[2] Elite competitive gymnasts usually train 2 times a day from 1 to 4 hours per training and they have one day off in a week. A typical amount of training usually consists of 10–20 hours per week, while the preparations for an important competition may include even 30–40 hours of training per week (Burke, 2007).

exception in certain cases, because there remains a possibility that the gymnast will reach up to 85% of maximal oxygen consumption (Marina & Rodríguez, 2014).

Based on the stated, the appropriate eating habits are very important for effective trainings and a successful performance in competitions. Due to repeated trainings, gymnasts usually train in a constant state of exhaustion, using their physical and cognitive abilities to extreme capabilities. Muscle and nervous system fatigue can weaken the immune system and general health, despite the potentially sufficient glycogen stores, especially due to caloric restriction with the intention of maintaining appropriate body weight. This can lead to a less effective recovery, an increased possibility of injuries, and a lower quality of trainings. All this can at some point complicate the ability to effectively control the appropriate body composition, especially with the need of simultaneous maintenance of high level of motor skills (Batatinha et al., 2013; Coelho, Gomes, Ribeiro & Soares, 2014; Dallas, Dallas & Simatos, 2016). A well-planned vegan diet, especially in its unrefined form, can be low in energy and without nutritional inadequacy, even without the control of the quantity of the portion, while in the case of greater energy needs (e.g. training on the floor) a well-planned vegan diet can be enriched with more calorically-dense refined or minimally refined foods that enable the body a sufficient energy and micronutrient intake and consequently a more efficient recovery after practice or performance. Burke (2007) lists a literature review of the actual intake of energy and nutrients in different age groups of competitive gymnasts, include elite ones, and compares them with the recommended daily intake. The author notes that numerous researchers report, in addition to energy and fluid inadequacy of the gymnasts' diet, on the micronutrient inadequacy for calcium, zinc, iron (below 70% of RDI), and a number of vitamins. In one of the more recent researches that evaluated the dietary intake and the body composition of female gymnasts, the researchers measured nutritional inadequacy of 67 elite rhythmic gymnasts with the average age of 18.7. The examined gymnasts had a low mean intake of carbohydrates (below the minimum recommended level of 55%) and a low intake of micronutrients, such as pantothenic acid, folate, vitamins D, E, and K, and of minerals, including calcium, iron, and magnesium (Silva & Paiva, 2015). Eating disorders (ED)[3], which are proven to be associated with hormonal imbalance (reproductive disorders), are more frequent with female athletes in aesthetic sports than in endurance and team sports (Torstveit & Sundgot-Borgen, 2014). Estimates of incidence of eating disorders, which can have negative, sometimes even fatal, consequences on health as well as on physical performance, reach up to 62% with female athletes and 33% with male athletes (Bonci et al., 2008). Competitive gymnastics holds the highest percentage of eating disorders among all sporting disciplines (Coelho, Soares & Ribeiro, 2010; Rosen & Hough, 1988). In older researches, Rosen and Hough (1988) even found that 75% of female gymnasts admitted to using inadequate weight loss methods. In one study (Andersen & Petrie, 2012) researchers surveyed 414 National Collegiate Athletic Association (NCAA) Division-I female athletes from 26 universities, who participated in either gymnastics (n=280) or swimming/diving (n=134), to examine the prevalence of clinical and subclinical EDs as well as the extent of pathologic eating (binging) and weight control methods (purging, vomiting, dieting). 65% of the surveyed gymnasts were found to be asymptomatic, 28.9% of gymnasts subclinical and 6.1% as having EDs. We can only speculate what percentage of these cases manifests into a mental disorder later in life, after the

[3] Eating disorder (ED) in athletes is characterized by a wide spectrum of maladaptive eating and weight control behaviors and attitudes. These include concerns about body weight and shape; poor nutrition or inadequate caloric intake, or both; binge eating; use of laxatives, diuretics, and diet pills; and extreme weight control methods, such as fasting, vomiting, and excessive exercise (Bonci et al., 2008).

finished period of competing, due to different pressures of the environment and the expected behavior. One of the more recent studies also examined the nutritional status of two elite female artistic (18.5 years) and rhythmic gymnasts (16.1 years) who were randomly selected among 20 eligible members of the Greek national team. Using a 7-day weighed food record protocol, the researchers found that only vitamin C, zinc, and vitamin B6 exceeded the daily recommended amounts for an artistic gymnast athlete, whereas the calcium intake was insufficient and had the highest deviation from the recommended daily amounts. The study also showed a large energy deficit during the training of the athletes, where one of the athletes presented a strong predisposition to nutritional risk factors, pathological eating behavior, and negative emotions with both the external appearance and body weight (Dallas, Dallas & Simatos, 2016). The assessed eating habits of female gymnasts in scientific literature are by no means optimal, which is why it is worth considering the potential appropriateness of a well-planned vegan diet as one of the possible forms of dieting for a competitive gymnast.

The content of vegan diet

The concept of vegan diet (Williams & Patel, 2017) can have very different definitions in scientific literature; from excluding all animal source foods to including "only" a greater intake of vegetables, fruit, fruit juices, cereals, and legumes, while still excluding the intake of fish, pork, and yoghurt. Some vegan diets reduce or exclude even the intake of highly refined plant-based food, e.g. white flour, sugar, and vegetable oils. Other scientific publications categorize vegan diets by its actual content, e.g. semi-vegetarian (typically western nutrition with a small part or frequency of consuming animal source foods), pesco-vegetarian (consuming seafood with or without eggs and dairy products), lacto ovo-vegetarian (consuming eggs and dairy), and vegan diet (no animal source foods). Unfortunately, the dichotomous division to vegetarian and non-vegetarian diet does not offer an overall insight into the quality of diet. Williams and Patel (2017) continue that a plant-based diet, which includes whole-grain cereals as a basic source of carbohydrates, unsaturated fats as the dominant source of dietary fats, an abundance of fruit and vegetables, and an adequate intake of omega-3 fatty acids, can have a decisive influence on the prevention against cardiovascular diseases and numerous other chronic diseases. Strict vegan diet, often referred to as "plant-based diet" (Ostfeld, 2017), includes minimally processed fruit, vegetables, wholegrain cereals, legumes, nuts, seeds, herbs, and spices, while it excludes all animal source foods, including red meat, pork, fish, eggs, and dairy. The recommended well-planned vegan diet, as it is usually defined by some advocates of a vegan diet[4], usually contains the following macronutrient balance: 10–15% fat, 10–20% protein, and 70–80% carbohydrates (Esselstyn et al., 2014; McDougall et al., 2014; McMacken & Shah, 2017; Ornish et al., 2005). Other advocates of the vegan diet are more inclined to define the diet based on the content or plant-based food groups and the frequency or the consumed portions in a day. This makes it easier for people to successfully implement the well-planned vegan diet in order to improve their health (Fuhrman & Singer, 2015; Hever & Cronise, 2017) and achieve more effective trainings and recovery and resistance to illness (Fuhrman & Ferreri, 2010). If we wish to talk about dietary intervention and therapeutic or sports effects of the vegan diet, the term "vegan diet" is simply not representative enough, since it can include too many highly refined and caloric foods, such as vegetable oils

[4] Scientists, doctors, and dietetics, who in their clinical researches and practices use terms such as "plant-based", "starchy", "low-fat", or "nutrient-dense, plant-rich diet" to describe nutrition, usually do not wish to declare themselves as advocates of vegan diet. Their view on the frequently used and generally accepted term "vegan diet" is primarily associated with the credibility of scientific evidence and not so much with personal, ethical, environmental, and philosophical views, even though they can be noble and important for humanity.

(sunflower, olive, pumpkin oil), exotic fats (coconut and palm fat, cocoa)[5], refined cereals, highly refined packaged food, too much salt, refined sugar, and so on, which can completely change the nutritional composition of the diet and, consequently, the effect on the body. A well-planned vegan diet does not only include the absence of animal source foods but also a much larger intake of fruit, vegetables, nuts, and legumes in comparison with other non-vegetarian and vegetarian diets (Tantamango-Bartley et al., 2016). A "well-planned" also means that we take into account the macronutrients and micronutrients, which should be adjusted according to the individual's needs (Kahleova, Levin & Barnard, 2017). The term "well-planned vegan diet" is in this article associated solely with the context of scientific evidence or the effects on human health and the potential appropriateness for the needs of a competitive gymnast. In this article, the term "well-planned vegan diet" replaces the terms "plant-based diet" or "whole food plant-based diet", which are frequently used even in scientific literature and which more clearly define the level of whole or refined plant-based foods.

A well-planned vegan diet is high in carbohydrates

When talking about a well-planned vegan diet, we cannot ignore the fact that the main source of calories are carbohydrates (usually from 70–80% of all calories), which can be found in cereals, legumes, fruit, and vegetables. Researches about cereals (wheat, oats, brown rice, etc.) consistently show that they are beneficial for health. Two systematic reviews and meta-analyses (Chanson-Rolle et al., 2015; Ye, Chacko, Chou, Kugizaki & Liu, 2012) have unequivocally demonstrated that consuming cereals is inversely related with the state of being overweight and with reducing the risk of type 2 diabetes and the risk of cardiovascular diseases. The same is true of legumes, where a 20-gramme intake per day can reduce the mortality rate by 8%, while their consumption is considered the most important global dietary predictor of longevity (Dermadi-Blackberry et al., 2004). The next carbohydrate food is potato, which is often regarded as the main culprit for the epidemic obesity and type 2 diabetes, but is usually not controlled in scientific researches due to different ways of preparation (roasting and frying with the use of vegetable oils or by adding butter or margarine). Potato has been an important food in the nutritional system of numerous cultures for centuries and is today, at a global level, the most widely used food, not counting cereals (rice, wheat, and corn). An overview of 13 researches about the influence of potato on obesity (5), diabetes (7), and cardiovascular diseases (1) has shown that consuming fried potatoes is associated with obesity and type 2 diabetes, whereas the researchers have not found that association with potato as a food (Borch et al., 2016). Veronese et al. (2017) have confirmed the findings of the overview of researches that, due to the inappropriate way of preparation, the problem lies in French fries, not the potato as a food. White potato is a nutrient rich food, while sweet potatoes of different kinds are even more so (Bovell-Benjamin, 2007; Drenowski, 2013). The potato offers a significant amount of important nutrients in a small number of calories and it also contains numerous substances that are good for the human health and have been proven to improve the lipid profile, the glucose in the blood, and blood pressure (Visvanathan, Jayathilake, Chaminda Jayawardana & Liyanage, 2016). It is most likely unnecessary to lose words over the usefulness and health effects of a regular consumption of fruit as the next

[5] An overview of researches studying the effect of dietary fats on cardiovascular diseases, performed by the American Heart Association (AHA), showed that reducing or replacing saturated fats (found in animal source foods, vegetable oils, and exotic fats) with polyunsaturated and monounsaturated vegetable oils, but not with refined carbohydrates, lowers the incidence of cardiovascular diseases and other major causes of mortality (Sacks et al., 2017). Consuming vegetable oils (e.g. olive oil) and exotic fats (e.g. coconut fat), which are most refined and caloric foods, is scientifically proven to be potentially harmful to optimal health (Blankenhorn, Johnson, Mack, el Zein & Vailas, 1990; Eyres, Eyres, Chisholm & Brown, 2016; Rueda-Clausen et al., 2007; Sacks et al., 2017; Vogel, Corretti & Plotnick, 2000).

food group that includes carbohydrates. Despite that, Jenkins et al. (2001) measured the effect of consuming 20 portions of fruit daily in a period of two weeks and measured a decrease in lipids and blood pressure and an increase in the volume of feces. Similar positive benefits to health also occur when consuming nuts, which – in addition to other nutritients (protein, primarily unsaturated fats, fiber, minerals, phytonutrients, etc.) – contain complex carbohydrates. An overview of researches and their analysis showed that their consumption could support cardiovascular health (Freeman et al., 2017). For a competitive gymnast this kind of dietary pattern is potentially optimal in all respects, because it allows them to eat tasty food to full satiety with every meal. A simple control of energy intake, with a "spontaneous" caloric restriction and without nutritional inadequacy, allows them to eat unrefined (unprocessed or minimally processed) plant-based food. With greater energy needs (e.g. training on the floor), a competitive gymnast can choose from a number of ways to increase the energy adequacy of vegan diet (Venderley & Campbell, 2006), e.g. with more frequent meals and snacks and by including highly concentrated carbohydrates (spaghetti, bread, polenta, dried fruit, fruit juices, honey, marmalades) and high-fat, unrefined and fermented plant-based foods (avocado, nuts, seeds and their spreads, tofu, and tempeh).

Nutritional adequacy of a vegan diet

The Academy of Nutrition and Dietetics (AND) states that a well-planned vegetarian diet, including vegan diet, is healthy and nutritionally adequate and appropriate for all stages of life, including pregnancy and lactation, infancy, childhood and adolescence, and also for athletes (Melina, Craig & Levin, 2016). Vitamin B_{12} probably deserves the greatest attention in the vegan diet. It is not synthesized by plants or animals, even though it can be found in animal source foods (formed by the intestinal bacteria in the large intestine). In their diet, vegans need a reliable source of vitamin B_{12}, which can be consumed with conventional foods enriched with vitamin B_{12} (twice a day) or with a dietary supplement, in quantities of 500–1000 mg several times a week (Melina, Craig & Levin, 2016). Despite the dietary pattern, the recommended intake of a reliable source of vitamin B_{12} also applies to people older than 50 years, due to the weakened ability of the cleavage of vitamin B_{12} from the binding proteins (impairment of protease and stomach acid), to people with intestinal abnormalities, e.g. with Crohn's disease and ulcerative colitis, and to people using certain medications for lowering stomach acid, lowering blood sugar levels, etc. (NIH, 2016; USAIM, 1998).

Based on the Healthy Eating Index and the assessment of the Mediterranean diet, which were tested on 1475 subjects (104 vegans, 573 vegetarians, 498 semi-vegetarians, 145 pescatarians, and 155 people with a mixed diet), a group of researchers (Clarys et al., 2014) assessed that the vegan diet is the "most" healthy diet (the lowest energy and protein intake, a better profile of the consumed fats, and the highest intake of fibers), while the mixed diet received the lowest grade from both indicators of the quality of diet. In a 22-week long, randomized controlled study, Turner-McGrevy et al. (2008) divided 99 people with type 2 diabetes into two groups, where one of them followed a vegan diet and the other followed recommendations of the American Diabetes Association (the ADA diet). Researchers measured the quality of the diet assessed by the Alternate Healthy Eating Index (AHEI)[6], where a lower AHEI score is strongly negatively associated with the risk of major chronic

[6] The AHEI is a nine-component dietary index used to rate foods and macronutrients related to the risk of chronic diseases. AHEI scores were calculated for each participant based on food categories, including vegetables (servings per day), fruit (servings per day), nuts and soy protein (servings per day), the ratio of white to red meat (grams), cereal fiber (grams per day), trans fat (percent of energy), and the ratio of polyunsaturated to saturated fatty acids (grams). Each of these categories received a score ranging from zero to ten. A higher score is associated with a lower risk of developing a major chronic diseases and cardiovascular disease, but not most cancers.

diseases and cardiovascular diseases, but not most cancers. The vegan group improved every AHEI food category, including the fact that they consumed significantly more vegetables, fruit, nuts, soy protein, and dietary fibers and less common, saturated and trans fats, while also achieving a better ratio between polyunsaturated and saturated fats. Based on the fact that the group with the ADA diet did not improve the AHEI result, the authors conclude that a long-term low-fat vegan diet can be associated with a significantly lower risk of chronic diseases, especially cardiovascular ones. Ma et al. (2007) have studied the AHEI, this time as a useful tool in grading various popular methods for weight loss, namely Glucose Revolution, Weight Watchers, Atkins, South Beach, Zone, Ornish, and 2005 US Department of Agriculture Food Guide Pyramid (2005 Food Guide Pyramid) diet, which maximize two things: weight loss and a prevention against cardiovascular diseases. The quality of diet was the highest with the Ornish vegan diet (result 64.6 out of 70 possible), while other low-carb diets had AHEI between 42.3 and 50.7 and Food Guide Pyramid 48.7. In the largest prospective research of the vegan diet (Nurses' Health Study, Nurses' Health Study 2, and Health Professionals Follow-up Study), Satija et al. (2017) studied the association between different qualities of vegan diet with the incidence of cardiovascular diseases. The vegan diet was divided into three index levels; overall plant-based diet index (PDI), healthful plant-based diet index (hPDI), and unhealthful plant-based diet index (uPDI). They found that a healthier vegan diet (whole-grain cereals, legumes, fruit, vegetables, nuts, tea) is associated with a lower risk of cardiovascular diseases and type 2 diabetes, while the less healthy vegan diet (fruit juices, refined cereals, unhealthy preparation of potato, sweets) and consuming animal source foods are associated with a higher risk. An analysis of the vegetarian dietary pattern for the control of body weight on 13,292 adults, including 851 vegetarians, showed that vegetarian diets are nutritionally adequate and are therefore recommended for weight control without compromising the quality of diet. Due to the used method of this research, we must put the results into context (defining who is vegetarian, a one-day questionnaire about diet). However, even with a caloric restriction of 500 calories less than the estimated energy requirement, vegetarians still had a nutritionally adequate diet, which showed as a greater intake of fibers, vitamin A, C, and E, folates, calcium, magnesium, iron, and potassium and a lower intake of total and saturated fats and dietary cholesterol when compared with non-vegetarians. Meanwhile, the intake of protein with vegetarians was consistent with the recommended (Farmer, Larson, Fulgoni, Rainville & Liepa, 2011). As long as the diet is adequate in energy, the risk of a potential lack of protein, iron[7], calcium, or essential fatty acids is low and there are no scientific reports about these shortages for any of the natural human diets (Millward, 1999, in McDougall & McDougall, 2013). Protein deficiency is most likely not a concern for anyone in the developed world. It is almost impossible to consume too little protein, no matter what you eat, unless your diet is significantly deficient in calories or if you consume too much junk food (nutritionally empty food). As a reply to the letter by McDougall and McDougall (2013) with the title Plant-Based Diets Are Not Nutritionally Deficient, Tuso, Ismail, Ha, and Bartolotto (2013) wrote an original article, stating that it is true that a healthy vegan diet enables an optimal amount of the majority of needed nutrients. However, as not all individuals will adhere to a good diet, it is important that the authors warn about the potential shortcomings from a clinical perspective, even if these risks are small. A well-planned vegan diet, contrary

[7] Even though numerous cohort researches (e.g. Clarys et al., 2014; Shridhar et al., 2014) state that vegetarians, and especially vegans, have a greater intake of iron than people who eat meat, an overview of 27 crossover and 3 intervention studies on the status of iron among vegetarians showed that vegetarians have lower body iron stores in comparison with people who eat meat, which can potentially increase the risk of anemia (Haider, Schwingshack, Hoffmann & Emekcioglu, 2016).

to common beliefs, is not associated with a lack of protein intake or with the need for a conscious combination of plant-based foods (AHA, 2014; Golden, 2002; Mclaren, 1974; Young & Pellett, 1994; Waterlow, 1984). Although marketing and education usually focus on animal sources of protein, it is scientifically unequivocal (Young & Pellett, 1994) that all essential amino acids derive from a bacterial synthesis and synthesis in plants, which means a person can conveniently obtain them through plant-based foods.[8] The greatest research today, which studied the adequacy of protein intake among vegans, compared the nutritional profile of approximately 30,000 non-vegetarians, 30,000 different vegetarians, and 5,000 strict vegans, and discovered that vegetarians and vegans consume 70% more protein than is needed,[9] while non-vegetarians consume even more (Rizzo, Jaceldo-Siegl, Sabate & Fraizer, 2013).

Omega-3 fatty acids are the next essential nutrient that is sometimes seen as problematic in vegan diet. Under the term "omega-3 fatty acids" we usually think of the essentially short chain of omega-3 fatty acids (ALA), which the body converts into SDA (i.e. *stearidonic acid*) and long chains (EPA and DHA) of omega-3 fatty acids[10]. ALA can be found in flaxseeds, hemp seeds, and chia seeds, in walnuts, soya, and, in smaller amounts, also in dark green vegetables, e.g. Brussels sprouts, spinach, and sea vegetables. SDA can be directly consumed with blackcurrant, hemp seeds, or fish, while EPA and DHA are present in marine microalgae and plankton and also in fish that feed on marine microalgae, e.g. salmon, sardines, tuna, mackerel, and others (Saunder, Davis & Garg, 2013). According to AND, a person may already consume the RDI of ALA with one spoon of flaxseeds and chia seeds, and partly by eating dark green vegetables and various berries (Vannice & Rasmussen, 2014). The conversion from ALA into EPA and DHA is slow and inefficient and generally depends on heredity, gender, age, and dietary patterns (Saunder, Davis & Garg, 2013). Clinical studies have shown a potential inadequate or inefficient conversion[11], which results in the current consensus of health authorities that recommend daily intakes of EPA and DHA ranging from 250 to 550 mg/day for adult males and non-pregnant/non-lactating adult females (Flock, Harris & Kris-Etherton, 2013; Harris et al., 2009). Meanwhile, Simopoulos (2007) states, based on the available scientific evidence, that it is recommended for most athletes to consume omega-3 fatty acids in quantities of 1–2 g of EPA and DHA daily in the ratio 2:1, which should, with the changes and improvements in the background diet, prevent the inflammation in muscles and joints. For the needs of EPA and DHA, the vegan diet can be supplemented with laboratory-grown seaweed. From the standpoint of clinical efficiency, it is comparable with fish oil, without any traces of industrial chemicals (Doughman, Krupanidhi & Sanjeevi, 2007) and signs of digestive problems (diarrhea) or any consequences of the taste of fish after consumption (burping) or belching (Neff et al., 2011).

[8] The American Heart Association (AHA, 2014) states that it is not necessary to consume animal source foods in order to get enough protein. Plant-based protein can provide enough essential and non-essential amino acids on its own, as long as we consume various sources of protein and the caloric intake is large enough to cover the individual's energy needs. Wholegrain cereals, legumes, seeds, and nuts include both, essential and non-essential amino acids. There is no need to consciously combine these foods ("complementarity" of proteins) with every meal.

[9] The RDA of protein is the same for all types of nutrition, although some experts recommend a 10% greater intake of protein for adults and 15–20% for children older than 6 years, as a compensation for a decreased absorption of plant sources of protein due to fibers (Melina, Craig & Levin, 2016). Vegetarian athletes were advised to increase their protein intake by 10% to 1.3–1.8 g/kg bodyweight/day for aerobic and strength sports (Agnoli et al., 2017).

[10] EPA and DHA are not technically "essential" because they can be produced endogenously, but the process is slow and inefficient and is affected by genetics, gender, age, and dietary composition (Saunder, Davis & Garg, 2013).

[11] The researchers discovered that a low-fat diet enabled a higher percentage of conversion of ALA into EPA and DHA compared with the high-fat diet (Raatz, Bibus, Thomas & Kriss-Etherton, 2001). However, in one of the researches (Kornek, Kucharska & kamela, 2016) vegans had almost a 40% higher intake of ALA than non-vegetarians.

Competitive gymnasts also face the problem of a potential lack of vitamin D[12]. Vitamin D, or calciferol, is also known as the "sunshine vitamin" because it is the only nutrient that is acquired from the sun. Although vitamin D is classified and treated as a fat-soluble vitamin, it is actually a prohormone produced in the skin upon exposure to ultraviolet B sun radiation and then activated by the liver and kidneys (Hever, 2016). Sources of preformed vitamin D can be found in natural sources of food, e.g. when consuming fatty fish, fish liver oil, egg yolk, milk, enriched with vitamin D, and so on (Ross, Taylor, Yaktine & Del Valle, 2011). Adequate vitamin D and calcium[13] intake are important for bone mass accrual and long-term skeletal health. Lovell (2008) measured the status of vitamin D in 18 Australian competitive gymnasts, aged 10 to 17, and found that 15 of them had a lower content of serum vitamin D when compared with the current recommendations (75 nmol/l), while 6 of them had values even lower than 50 nmol/l. The American Institute of Medicine (USAIM) recommends 600 IU of vitamin D from a source of dietary supplement as a preventive measure for bone health to all adults who get little or no exposure to the sun. This would help them achieve 50 nmol/l of vitamin D in the blood, thereby meeting the needs of 97.5% of the population (Ross et al., 2011) or 1100 IU of vitamin D per day (up to 4000 IU without credible evidence about the side effects), achieving 75–110 nmol/l of vitamin D in the blood. Based on intervention studies, this still has proven positive effects on certain types of cancer (colorectal cancer, breast cancer, ovarian cancer, lymphoma) or, in other words, a longer life expectancy (Bischoff-Ferrari et al., 2010; Keum & Giovannucci, 2014). Sensible sun exposure can provide an adequate amount of vitamin D_3, which is stored in body fat and released during winter, when vitamin D_3 cannot be produced. An individual who is exposed to sunlight (arms, legs, and face) twice a day, from 10 AM to 3 PM, from 5 to 30 minutes (depending on time of day, season, latitude, and skin pigmentation), gets the adequate amount of vitamin D. For light-skinned people 5 to 10 minutes are quite enough, while dark-skinned need at least 30 minutes. We must emphasize that excessive exposure to sunlight, especially when it causes sunburn, will increase the risk of skin cancer. Thus, sensible sun exposure and the use of supplements are needed to fulfill the body's vitamin D requirements (Holick, 2007). In the end, we are faced with the problem of an institutionalized lifestyle and, in some places, a lower exposure to sun, which is also associated with the geographical area with a lower or higher UV index, especially in autumn, winter, and early spring (from October to March), when the day is shorter and the clock shifts to winter time. With gymnasts the problem lies in daily trainings in the gym and the daily rest between two trainings, which can be spend more or less institutionally. The scientific public often mentions the potential introduction of a screening test to measure the possible lack of vitamin D. USAIM and numerous osteoporosis societies do not recommend the screening test because the costs of the tests are incomparable with the benefits (which may not be relevant for athletes). The values in the blood of healthy people can already be improved by mere exposure to sunlight or by consuming a responsibly prescribed dietary supplement. Furthermore, the test is not reliable and the results are very fluctuating (Fuleihan et al., 2015). In one of the studies, the researchers sent one blood sample into testing to 1090 different laboratories around the world and

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[12] The incidence of vitamin D deficiency in elite gymnasts is up to 83% (Lovell, 2008; Willis, Peterson & Larson-Meyer, 2008).

[13] Calcium, a macromineral, is the most abundant mineral in the human body. Excellent plant sources of calcium include leafy green vegetables as well as fortified plant milks, calcium-set tofu, dried figs, sesame seeds and tahini, tempeh, almonds and almond butter, oranges, sweet potatoes, and beans. However, because bone metabolism is multifactorial and complex, it is important to emphasize the consumption of ample sources of calcium as well as vitamins K and $B1_{12}$, fluoride, magnesium, phosphorus, and potassium in order to maintain serum vitamin D levels and to ensure consistent exercise. Many variables affect calcium levels via absorption or excretion, including overall calcium consumption, age, phytates, oxalates, serum vitamin D levels, and the intake of sodium, protein, caffeine, and phosphorus (Hever, 2016).

the results about the vitamin D content varied between 20 and 100 nmol/l (Lucas & Neale, 2014).

Vegan diet and health

Vegan diet is becoming more and more popular due to the increasing amount of scientific evidence about the beneficial effects on numerous health conditions. Vegetarians and vegans have a lower risk of certain health conditions, including ischemic heart disease, type 2 diabetes, hypertension, certain types of cancer, mortality for any reason, and obesity. A low intake of saturated fats and a high intake of vegetables, fruit, wholegrain cereals, legumes, soy-based food, nuts, and seeds (all rich in fiber and phytonutrients) are characteristic of vegetarian and vegan diets, resulting in a lower total and LDL cholesterol and a better control of blood sugar (Melina, Craig & Levin, 2016). These factors contribute to a lower risk of chronic diseases. In a scientific overview of the most common ways of dieting, authors concluded that the majority of scientific evidence strongly associates vegan diet with health and prevention against a wide range of health conditions, while also offering advantages for other beings, the environment, and ecology (Katz & Meller, 2015). Well-planned vegan diet is nutritionally adequate, safe, affordable, and has the potential to end the epidemic of cardiovascular disease (Esselstyn Jr., Gendy, Doyle, Golubic & Roizen, 2014; Ornish et al., 1998) and cancer[14], the first two causes of death.

Besides a lower risk of cardiovascular diseases and certain types of cancer, type 2 diabetes, and some other chronic diseases (Hever & Cronise, 2017; Melina, Craig & Levin, 2016), science also associates vegan diet with a successful control of body weight (Barnard, Levin & Yokoyama, 2015; Huang, Huang, Hu & Chavarro, 2016; Turner-McGrievy, Mandes & Crimarco, 2017), with a reverse of progressive cardiovascular diseases (Esselstyn Jr., Gendy, Doyle, Golubic & Roizen, 2014; Ornish et al., 1998), with a reverse of type 2 diabetes (Anderson & Ward, 1979; Barnard et al., 2009; Dunaief, Fuhrman, Dunaief & Ying, 2012), with a reverse of the early stage of prostate cancer (Ornish et al., 2005), etc., which significantly lowers the need for medication (Hever & Cronise, 2017) and most likely increases longevity (Orlich et al., 2013; Ornish et al., 2013). Numerous reputable researches, such as the EPIC Oxford, Adventist Health Study 1 and 2[15], and GEICO Study (Wirnitzer et al., 2016) and an overview of researches (Dinu, Abbate, Gensini, Casini & Sofi, 2016) have shown that vegans have the lowest incidence of cardiovascular diseases and cancer. A research by Loma Linda University (Adventist Health Study 2), financially supported by the American National Cancer Institute (NCI), has shown that vegans not only have a lower ITM and a lower incidence of type 2 diabetes and other chronic diseases, but also a longer life expectancy (9.5 years for men and 6.1 for women) in comparison with people with a mixed diet (Orlich et al., 2013).

100% vegan diet or mixed diet with less animal source foods and more fruit and vegetables

A Swedish research (Bellavia, Stilling & Wolk, 2016) on 74,646 men and women tried to answer the frequently asked question whether a greater intake of fruit and vegetables, while simultaneously consuming meat, acts as a counterbalance to the increased risk of cardiovascular disease

[14] Two systematic reviews and meta-analyses of researches (Dinu et al., 2015; Yokoyama, Levin & Barnard, 2017) showed that vegan diets are associated with a lowest risk of incidence of all types of cancer and lower values of lipids in comparison with a mixed diet.

[15] According to the EPIC Oxford and AHS-2 research, vegans consume more fiber, vitamin C and E, folates, magnesium, iron, copper, and polyunsaturated fats, while people who eat meat consume more protein, total, saturated, and trans fats, vitamin B_2, B_{12}, and D, zinc, and iodine (Wirnitzer et al., 2016). The research is all the more important because it included a "well-planned" mixed diet (a lot of fruit and vegetables) and a poorly planned vegan diet (28% of all calories from the source of fats – a well-planned diet has up to 15%, 28 g of fiber – a well-planned diet has at least 45 g, and 54% of all calories from the source of carbohydrates – a well-planned diet has at least 70%).

and premature mortality. Researchers discovered that people who consume more red meat suffer a 29% greater risk of premature mortality due to cardiovascular diseases (21% of all-cause mortality) than those who enjoy less red meat. The research showed that even the greatest intakes of various fruit and vegetables did not cancel the negative effect of meat and, consequently, the increased risk of death due to cardiovascular diseases. The authors concluded that there remains an increased risk with the intake of red meat and with a low, middle, or high intake of fruit and vegetables, including the lowest intake of red meat (on average 30 grams per day). So far, a group of researchers from Taiwan offers us the best answer to the question "Where is the limit of enjoying animal source foods without the potential 'significant' negative influence on the human health?" Chiu et al. (2014) compared two equally health-conscious groups that consumed traditional Asian food (cereals, vegetable, soy, nuts), where one group consumed strictly plant-based food and the other group "occasionally" consumed meat and meat products (women once a week and men twice a week). They discovered that, despite observing the ITM and other factors, the group that consumed only small amounts of meat (which is still seen as primarily vegan diet, since the women consumed meat and meat products once a week, which is approximately 3% of the meat and meat products that a typical European woman consumes, and men consumed it twice a week, which is approximately 5% of the amount that a typical European man consumes) had a higher degree of type 2 diabetes than the group that did not consume meat (without the case of diabetes). On the other hand, Singh et al. (2014) researched (Adventist Mortality Study and Adventist Health Study 1) how a change in diet from vegetarianism (no meat) to non-vegetarianism (a weekly consumption of meat) affects weight gain, type 2 diabetes, cardiovascular diseases, and life expectancy. People who changed their diet from vegetarian to non-vegetarian (consuming meat at least once a week) have been exposed to an increased risk of weight gain, diabetes, and heart attack in a period of 17 years, while their life expectancy lowered for 3.6 years in a period of 12 years.

Vegan diet and athletes

AND states that well-planned vegetarian diets, including vegan diets, are healthy and nutritionally adequate and appropriate for all stages of the life cycle, including pregnancy, lactation, infancy, childhood, adolescence and older adulthood, and for athletes (Melina, Craig & Levin, 2016). The Italian Society of Human Nutrition (Agnoli et al., 2017) also states that well-planned vegetarian diets, as well as the vegan diet, are compatible with successful athletic performance. Numerous former and current top athletes, e.g. Tony Gonzalez (American football), Carl Lewis (sprinter and long jumper), Scott Jurek and Brendan Braizer (triathlon), Kenneth Williams (bodybuilder), Novak Djoković and Venus Williams (tennis), Mac Danzig and David Haye (martial arts), Salim Stoudamire and Marc Gasol (basketball) and others, are proof that the highest achievements in competitive sports can be achieved or maintained even without consuming animal source foods (Fuhrman & Ferreri, 2010; Gatto, 2016; GreatVeganAthletes, 2017; McDougall, 2015; Tachdjian, 2017; Viva, 2017). At this point we must emphasize that the diet of these athletes is most likely also supported by specific supplementation, so their diet does not rely exclusively on conventional plant-based sources of food (author's assumption). According to the typical modern diet of athletes in power sports, we would expect that the athletes in ancient Rome (gladiators) consumed high-protein food. However, the analysis of their bones reinforced the hypothesis that their diet was actually vegan and that 78% of all calories came from a source of carbohydrates, primarily from wheat and barley (Curry, 2008; Longo, Spiezia & Maffulli, 2008;

Losch, Moghaddam, Grossschmidt, Risser & Kanz, 2014). Science has also documented a number of successful endurance and ultra-endurance athletes with a vegan diet, so we can therefore conclude that a well-planned and a potentially supplemented vegetarian or vegan diet with high nutrient density successfully and efficiently supports the factors that have an effect on the immune system and a successful endurance and ultra-endurance performance (Wirnitzer et al., 2016). Excellent Kenyan runners are a good example of "vegan" endurance athletes, since they consume 90% of caloric intake from plant-based foods or, to be more exact, 75% of all calories from a source of carbohydrates, 15% from a source of dietary fats, and 13% from a source of protein – 1.6 grams on kilogram of bodyweight (Christensen, Van Hall & Hambraeus, 2002). The same applies to Ethiopian endurance runners (Beis et al., 2011), whose diet consists of 88% of plant-based foods; 65% of all calories comes from a source of carbohydrates, 23.3% from a source of dietary fats (73% plant-based), and 12.4% from a source of protein (76% plant-based). In a cross-over study, Lynch, Wharton, and Johnston (2016) examined 70 endurance athletes; 27 vegetarian ones and 43 athletes with a mixed diet, aged 21–58 (average of 35 years), who competed on a national university level or have prepared themselves for a greater endurance competition, such as a marathon, triathlon, cycling race, and so on. The results of the research have again shown that vegetarian diets offer adequate support for the development of strength and cardiovascular development in sports, while vegan diet, with a higher intake of carbohydrates, fiber, and iron in comparison with vegetarian diet, can even present an advantage in supporting cardiovascular endurance. Well-planned vegetarian and vegan diet that is highly nutritional and properly supplemented with certain dietary supplements can adequately support the nutritional needs of an athlete, which affect the sports performance (Rodriguez et al., 2009) of e.g. a tennis player, basketball player, skier, football player (Fuhrman & Ferreri, 2010). Numerous researches have shown that the identified shortages of certain nutrients are more a problem of poorly planned meals than vegan diet as such (Katz & Meller 2015; Leitzmann, 2005; Nieman, 1999; Rogerson, 2017). One of the last overviews of research (Craddock, Probst & Peoples, 2016), which compared the influence of vegetarian and mixed diet on sports performance, analyzed 7 randomized controlled studies and 1 cross-over study (3 for muscular strength, 4 for anaerobic and aerobic performance, and 1 for immune parameters). The researchers discovered that vegetarian diet is not associated with a worsened or improved sports performance, which is consistent with the results of an overview of 17 researches almost 20 years ago (Nieman, 1999), which were not included in the abovementioned 7 studies. With a strategic selection and management of food choices, with special attention to the achievement of energy, macro and micronutrient recommendations, and with an appropriate supplementation a vegan diet can satisfactorily achieve the needs of most athletes (Rogerson, 2017). Having said that, it is important to emphasize that there exists a great need for well-planned randomized controlled studies that would compare the long-term effects of a vegan diet on sports performance, the immune system, weight control, and health in comparison with athletes with a mixed diet. Based on the stated, we can conclude with great certainty that, as long as a well-planned vegan diet presents results in representative aerobic and anaerobic individual and group sports, it is most likely also appropriate for a competitive gymnast.

Animal-based and plant-based proteins

Different types of protein (animal-based vs. plant-based) have different effects on the human body. Animal-based proteins, not plant-based (Chen et al., 2016), are associated with an increased risk of chronic diseases, such as kidney disease (Haring et al., 2017), cardiovascular disease (Richter, Skulas-Ray, Champagne & Kris-Etherton, 2015), type 2 diabetes (Sluijs et al., 2010), and cancer (Levine et al., 2014). On the other hand, consuming plant-based proteins reduces the lipid concentration in the blood, the risk of increased weight and obesity and cardiovascular diseases, while also having an anti-inflammatory and anti-carcinogenic effect (Kahleova, Levin & Barnard, 2017). The relative protein restriction of conventional plant-based proteins, especially methionine, leucine, and tryptophan, which is traditionally seen as a restriction of vegetarian or vegan diets, is today recognized as potentially beneficial for mechanisms associated with health, slower aging, and longer life expectancy (Hever & Cronise, 2017; Levine et al., 2014; McCarty, Barroso-Aranda & Contreras, 2009).

All plant-based foods include proteins, but in different amounts. According to dry weight, the majority of proteins in plant-based foods can be found in legumes, which contain the same (if not a higher) amount of proteins compared with animal source foods, while also lacking sodium and saturated fats (Freeman et al., 2017). In general, consuming plant-based proteins results in a lower synthesis of muscle proteins in comparison with the same amount of animal-based proteins (Wilkinson et al., 2007; Yang et al., 2012), which is supposedly due to the differences in protein metabolism, amino acid composition, and the absorption of amino acids (van Vilet, Burd & van Loon, 2015). Here, the content of the amino acid leucine is particularly important, since it is seen as the strongest trigger of protein capacity that influences the synthesis of muscle proteins (Philips, 2016). The majority of the more representative plant-based proteins (van Vilet et al., 2015) has a leucine content of approximately 7–8% of the total content of proteins (with the exception of corn that has 12.2%), while most of the more frequently used animal-based proteins usually contain 9–10% of the total content of proteins (whey even contains 13.6%). Studies that compare different proteins according to their weight (e.g. grams per gram) do not necessarily offer us a complete understanding of the topic, since some studies have shown that a greater content of “low-quality” proteins, especially in the form of a dietary supplement, can result in a comparable muscle growth as with “high-quality” proteins (Babault et al., 2015; Joy et al., 2013). This may indicate that the key is the correct amount or mixture of amino acids and not the source of protein (plant or animal) in itself. Van Vilet et al. (2015) state that this realization can result in the use of many strategies in sports practice, among other things adding individual amino acids to plant-based proteins in the form of a dietary supplement, e.g. methionine, lysine, and/or leucine, by consuming greater amounts of plant-based sources of protein, or by consuming more plant-based sources of protein, which can ensure a more balanced profile of amino acids.

Protein dietary supplements of animal or plant origin

Supplementing a diet with proteins in the form of dietary supplements is one of the popular choices, yet theoretically unnecessary for the majority of athletes who follow a well-planned vegan diet (and especially the ones following a mixed diet), especially when they pay attention to an adequate energy intake and the frequency and amount of the intake of representative plant-based foods with a greater content of protein. Due to numerous myths (complete proteins, recommended needs, biological value, the speed of absorption, etc.), athletes very much like to consume animal-based proteins (which are very concentrated) and more often also animal-based and plant-based proteins in the form of dietary supplements. The most commonly used sources are whey and casein when it comes to animal-based proteins and soy, rice, pea, and hemp proteins when it comes to plant-based proteins. With this they easily exceed the necessary (and for the body still safe) amount of protein.

Regardless of certain doubts about nutritional adequacy, the professional public is well aware of the positive effect of a well-planned vegan diet and, with it, the intake of proteins from unrefined plant-based sources of protein. On the other hand, the effect of refined plant-based proteins is little less known; that is in the form of dietary supplements, e.g. pea, hemp, wheat, and other protein concentrates and isolates. A high intake of proteins, rich in essential amino acids, especially from animal sources (milk and dairy, meat and meat products, fish), and soy proteins (soy milk and soy tofu) most likely increase IGF-1[16] (Dewell et al., 2007). Some interventional studies (Dewell et al., 2007; Li et al., 2008; Ornish et al., 2005) performed on patients with prostate cancer show that plant-based sources of protein in a minimally refined and processed form (e.g. tofu) or in the form of a dietary supplement (e.g. soy isolate) with a low-fat vegan diet are not associated with the effect of excessive increase of the hormone IGF-1. The results of Ornish et al. (2005) have shown that an additional increase of soy isoflavones (soy tofu, flaxseeds) and soy proteins in the form of dietary supplements (soy isolate) in a low-fat vegan diet (10% of calories) did not significantly affect the IGF-1 of patients with prostate cancer, despite the increased total intake of proteins (from 80 grams daily or 16% of calories before the intervention to 115 grams daily or 20% of calories during the intervention; the fiber intake increased from 31 to 59 grams daily) in a period of one year and in the context of a greater change in lifestyle (physical activity, relaxation techniques, support group). In addition, the researchers measured a decrease of prostate cancer for 70%, which indicates that a low-fat diet and physical activity most likely lower the effect (increase IGF – binding protein level) of a potential increase of IGF-1 due to consuming soy isolate, which has a higher value of essential amino acids (Dewell et al., 2007). These results are consistent with the results of Li et al. (2008) who performed a low-fat and high-fiber dietary intervention (15% fat, 5–8 portions of fruit and vegetables, and 8–11 portions of cereals and flakes), adding 40 grams of soy protein isolate, on 40 cancer patients (26 in the intervention group and 14 in the control group) who had undergone radical prostatectomy. They discovered a decrease of the serum IGF-1 from the initial 260 ng/ml to 221 ng/ml by the end of a 6-month intervention. It seems that both the quantity and the amino acid distribution of dietary protein determine whether IGF-1 production is overstimulated and these results imply that the soy protein (supplemental or unrefined and minimally refined), though it may raise IGF-1 levels, is still not as detrimental to health as animal proteins. Saxe et al. (2001) carried out a 4-month dietary intervention with a vegan diet on 10 men who underwent radical prostatectomy, where the cancer has already metastasized (PSA was increasing), and discovered that the dietary intervention worked (it slowed the progress) with 8 out of 10 patients and even reversed the course of the disease with three of them. Patients who had the highest intake of dietary fibers had the best PSA results. Teixeira et al. (2004) examined the effect of consuming soy protein isolate in patients with nephropathy and type 2 diabetes and discovered that consuming soy isolate improves numerous factors that are beneficial for patients with nephropathy and type 2 diabetes, while consuming casein (milk protein) worsens them.

A protein dietary supplement is by definition a supplement to a normal

[16] The hormone insulin-like growth factor 1 (IGF-1) is the most important stimulant for growth and the development of the fetus and the body in the period of childhood and until the end of puberty. In adulthood, high levels of IGF-1 accelerate aging and growth of the cells, potentially leading to common types of cancer, especially prostate, breast, and colorectal cancer (Fontana et al., 2016). Diet is, among hereditary factors and age, one of the main factors influencing IGF-1 (Dewell et al., 2007). A greater intake of proteins rich in essential amino acids, especially from animal sources (milk and dairy products, meat and meat products, fish), is in a mixed diet associated with an increase of the hormone IGF-1 (Dewell et al., 2007), while a decreased intake of animal-based proteins, fasting, and regular exercise decrease the hormone (Barnard, Gonzalez, Liva & Ngo, 2006; Fontana et al., 2016). A long-term caloric restriction, even without malnutrition, has no effect on the IGF-1 in the blood, but does have an effect on its desirable lower bioavailability (Fontana et al., 2016).

nutrition because of the simplicity of nutrition or an easier recommended daily intake of protein. It is commonly accepted that exercises for strength increase the muscle size (hypertrophy) as well as their strength (Yang et al., 2012). In scientific literature, animal-based proteins in the form of a dietary supplement after a workout for strength of the entire body do not offer an ever-increasing synthesis of muscle proteins in comparison with plant-based proteins. For example, soy proteins (isolate) cause greater muscle growth than casein and a smaller one than hydrolysis of whey proteins (Tang et al., 2009). Even though one overview of studies showed that when an individual consumes additional proteins during an exercise for strength, the intervention will additionally increase the strength and size of the muscle (Cermak et al., 2012), this result was not found in all systematic reviews that studied the effect of adding proteins in the form of a dietary supplement on muscle strength and hypertrophy (Pasiakos, McLellan & Lieberman, 2015; Schoenfeld, Aragon & Krieger, 2013). The cause of different results lies in the design of the scientific research, how trained the athlete is when it comes to exercises for strength, the training protocol, the used source of protein, the total intake of proteins and the intake of proteins after the exercise for strength, the choice of the right moment of consuming additional proteins, the control of other nutritional factors, etc. (Cermak et al., 2012; Pasiakos, McLellan & Liberman, 2015; Samal & Samal 2017; Schoenfeld, Aragon & Krieger, 2013). When talking about various protein sources in the form of dietary supplements, we can conclude that the refined plant-based sources of protein, e.g. soy isolate, pea concentrate, or wheat gluten, have a similar digestibility (>90%) as animal-based proteins (van Vilet et al., 2015). In a randomized controlled, double blind study with placebo, researchers compared the effect of consuming whey and pea proteins after a muscle workout on 161 young men (aged 18–35). This was carried out three times a week in a period of 12 weeks. The participants were divided in three groups. The first one consumed whey proteins, the second one pea proteins, and the third one placebo. The beverage was consumed twice a day, in the morning and in the evening or after workout on the days of the workout. Each of the two beverages (together 50 g daily from a source of a dietary supplement) in the two intervention groups included 25 g of pea (isolate) or 25 g of whey protein (concentrate), while the placebo group consumed maltodextrin instead of proteins. The research showed that they all became stronger, which shows that the basis for gaining muscle mass are exercises for strength not protein consumption. The group that consumed pea protein showed significantly greater progress in muscle mass than the placebo group and was completely comparable to the group that consumed whey protein. After 6 weeks of the training protocol, the placebo group no longer progressed in muscle mass. The mentioned results are consistent with the results of the predecessors who studied a similar intervention, which lasted 8 weeks and compared whey concentrate with rice isolate on men who were well trained in exercises for strength. What was interesting was the fact that the study discovered that the differences in protein composition[17] were less important if an individual consumed an adequate amount of protein. The group that consumed rice proteins achieved comparable results to the group that consumed whey protein, namely a reduction in body fat and an increase in lean muscle mass and strength (Joy et al., 2013). One of the last comprehensive analyses that studied the benefits and disadvantages of consuming protein supplements concluded that, despite the general conviction that an intake of protein supplements results in "better" and faster growth of muscle mass and a more efficient sports performance, studies show that the recommended intake

[17] Whey isolate had a total of 285 mg BCAAs per gram of protein (5.5 grams of leucine in two meals), while rice isolate had 151 mg (3.8 grams of leucine in two meals of supplementation). However, rice protein had 3.3 times more of the amino acid arginine.

of protein should be consumed from natural food sources. Protein supplements should only be enjoyed when a conventional diet nutrition fails to provide an adequate protein intake (Samal & Samal, 2017). Besides promoting excellent health, a carefully designed and thoughtfully supplemented vegan diet can meet the caloric needs and can supply adequate protein without excess (Fuhrman & Ferreri, 2010). To conclude, the relative protein restriction of conventional plant-based sources of protein (consumed with food), traditionally viewed as a restriction of vegetarian and vegan diets, especially methionine, leucine, and tryptophan, is today recognized as potentially beneficial in mechanisms associated with health, slower aging, and longer life expectancy (Hever & Cronise, 2017; Levine et al., 2014; McCarty, Barroso-Aranda & Contreras, 2009).

Vegan diet and control of body weight

Researchers of a non-profit Physicians Committee for Responsible Medicine (PCRM) analyzed 15 studies on 755 participants from Europe and USA and concluded that vegan diet helps lose weight without a calorie count or including regular exercise (Barnard, Levin & Yokoyama, 2015), which could drastically reduce the rising trend of excess weight and obesity. Huang et al. (2016) conducted a scientific overview of 12 randomized controlled studies on 1511 participants, where researchers compared the effect of vegetarian and non-vegetarian diet on the loss of excess weight. The results showed that vegetarian diets, especially vegan, are more effective in losing excess weight (in average even up to 2.02 kg more than non-vegetarian) in comparison with non-vegetarian diets with an approximate intervention of 18 weeks. Turner-McGrievy, Mandes, and Crimarco (2017) conducted an overview of observational and intervention studies on the effects of vegan diet, excess body weight, and obesity and discovered that the vegan diet offers an effective preventive response to excess weight and obesity as well as an efficient intervention (treatment) for the loss of excess weight. Based on the available evidence, the authors conclude that vegan diet should be offered to people as a way of losing excess body weight, improving the quality of their diet, taking preventive measures, and, in some cases, even affecting the treatment of chronic disease. The largest randomized controlled study that researched the effect of vegan diet on the loss of excess body weight, on type 2 diabetes, and on cardio-vascular diseases (Broad Study) showed that vegan diet could present a safe and effective diet that significantly improves the ITM, diabetes, cholesterol, and other risk factors for the development of cardiovascular diseases, where the participants could eat up to full satiety without limiting the amount of the consumed food and without including exercise (Wright, Wilson, Smith, Duncan & McHugh, 2017). Vegan diets are rich in carbohydrates and a comparison of popular low-carb and high-carb diets showed (Bowman & Spence, 2002) that high-carb diets (more low-fat foods, e.g. cereals and fruit) have a lower energy intake, a higher nutritional density, and a more successful control of body weight. A well-planned vegan diet can be regarded as a kind of low-energy diet for weight control, with a lower calorie intake, which is something normal for vegans and not a part of a deliberate energy-restricted diet. In one of the researches (Thedford & Raj, 2011) a vegetarian group without a restriction of calorie intake (not on a diet) spontaneously consumed around 363 calories less than the non-vegetarian group. This means that a well-planned vegan diet naturally leads to a loss of excess weight and later on presents an easy way of long-term maintenance of healthy body weight. Vegetarian, vegan, and low-fat diets were studied for over a year, proving the permanence of maintaining the lost body weight over a longer period of time, which was most likely not only due to the loss of body weight but also due to a greater well-being and a better quality of life in general (Berkow, Barnard, Eckart & Katcher, 2010). One of the greatest challenges of a competitive gymnast, especially with the female population, is a constant and often unsuccessful struggle for an appropriate body weight (with an optimal general physical preparation and excellent health). According to the majority of scientific evidence, a well-planned vegan diet is probably quite optimal for a competitive gymnast.

RECOMMENDATIONS AND CONCLUSION

1. A well-planned vegan diet, supplemented with vitamin B_{12} and most likely also with EPA and DHA omega-3 fatty acids, is healthy and nutritionally adequate and appropriate for all stages of the life cycle, including pregnancy, lactation, infancy, childhood, adolescence and older adulthood, and for athletes. An adequate intake of vitamin D is usually a problem of an institutionalized lifestyle and living in a geographical area with a lower or higher UV index, especially in autumn, winter, and early spring. Besides regular and sufficient exposure to sunlight, competitive gymnasts can also consume vitamin D in the form of a dietary supplement.
2. In case of greater energy needs, competitive gymnasts who follow a well-planned vegan diet can consume either more unrefined high-carb meals or they can include in their composition more concentrates from the source of unrefined but more processed carbohydrates, e.g. foods from whole grain flour (spaghetti, bread, polenta, meal) and dried fruit, and from the source of high-fat, unrefined and fermented plant-based foods (avocado, nuts, seeds and their spreads, tofu, tempeh).
3. Conventional plant-based sources of food, which are especially rich in protein, contain in a typical portion a lower content of some essential amino acids in comparison with animal source foods. However, this difference presents an advantage for health and a longer life expectancy. If competitive gymnasts believe that they need a higher intake of protein, they can resort to greater or more frequent intakes of foods with a higher content of protein, e.g. legumes, nuts, seeds and their spreads, soy foods (tofu, tempeh), and products from whole grain cereals (buckwheat or oatmeal, spaghetti, seitan). They can also wisely choose plant-based protein in the form of a dietary supplement tested on illicit substances by the world class sports anti-doping laboratory.
4. Based on the available evidence on the benefits of vegan diet for the needs of an appropriate control of body weight, we can conclude that a well-planned vegan diet is a perfectly viable option for those competitive gymnasts who wish to lose excess weight, control the nutritional adequacy with a smaller energy intake (which is often their need), improve the quality of diet, and at the same time reduce the risk of modern chronic diseases in the long term.
5. A well-planned vegan diet is often seen as something that is hard to implement, especially because of eating habits that usually represent our cultural, family, and personal identity. Nevertheless, we can overcome these challenges by a more objective and widespread reporting on the benefits of a well-planned vegan diet, through numerous examples of good practice among vegan athletes and through the availability of healthy vegan meals outside of our home environment (restaurants, sport camps) and by respecting the decisions of those who have decided on vegan diet.

To conclude, there is a scale of scientific evidence about the wide range of benefits of a well-planned vegan diet and the energy and nutritional needs of a competitive gymnast for a variety of goals (support of the strenuous and repeated training with gymnastics apparatus or in all-around gymnastics, effective recovery, simple control of appropriate body weight, and long-term health). Furthermore, the actual inadequate nutrition of competitive gymnasts, especially female ones, is relatively well documented so we can safely conclude that a well-planned vegan diet can be one of the appropriate and undoubtedly healthy forms of dieting for a competitive gymnast.

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EPIDEMIOLOGY OF WRIST PAIN IN AUSTRALIAN GYMNASTS

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Original article

Abstract

Wrist pain in adolescent gymnasts is generally considered a 'normal' consequence of the sport. If pain is ignored it may lead to an injury of the distal radial growth plate and subsequent long term wrist dysfunction. There is a lack of epidemiology research on the prevalence of wrist pain in adolescent gymnasts with previous research documenting wrist injuries as part of general injury statistics. We aimed to investigate the life time and point prevalence of wrist pain in Australian gymnasts. A survey was designed to collect data from 10-18 year gymnasts who participated in gymnastics. Data was collected on: (i) historical experience of wrist pain (ii) current wrist pain; (iii) the influence of apparatus on wrist pain; and (iv) treatment modalities utilised. Results found there was a high life time (92.6%) and point prevalence (70.6%) of wrist pain in adolescent gymnasts. When grouped by age there was no significant difference in life time or point prevalence between genders. When grouped by training 1-10 hours per week, females had significantly higher life time prevalence (p = 0.013) than males. When grouped by training 11-25 hours per week males showed a significantly higher life time prevalence (p = 0.005) and point prevalence (p = 0.004). Wrist braces were reported as the primary method of management for wrist pain. This study promotes research into injury prevention strategies aimed at decreasing the prevalence of wrist pain and the consequence of wrist injury in adolescent gymnasts.

Keywords: *adolescence gymnast, distal radial growth plate, ground reaction forces, wrist brace, apparatus.*

INTRODUCTION

Although the positive benefits of gymnastics are well recognised (Gustavsson, Thorsen, & Nordstrom, 2003; Zanker, Osborne, Cooke, Oldroyd, & Truscott, 2004) consequent wrist pain is endemic in gymnasts (Di Fiori, Puffer, Aish, & Dorey, 2002; Guerra et al., 2016; Kox, Kuijer, Kerkhoffs, Maas, & Frings-Dressen, 2015). Gymnasts spend most of their training and competition weight bearing through their hands. This results in challenges to their wrists which are exposed to repetitive axial compression and torsional loading in varying degrees of wrist extension and ulnar and radial deviation (Webb & Rettig, 2008; Zetaruk, 2000). Typically, wrist injuries fall into two main categories: bone injury, such as fractures and the distal radial growth plate (physis) compromise; and soft tissue trauma, such as ligament sprains and ruptures. The younger the age a gymnast starts his or her career, the growth phases in adolescence and the training pre-competition are factors influencing the development of wrist pain (Dobrescu & Zaharia, 2010; Kerr, Hayden, Barr, Klossner, & Dompier, 2015). In addition, the ground reaction forces acting on the wrist when gymnasts learn new skills or increase intensity of training cause repetitive submaximal loading which may result in microscopic tissue damage (Zanker et al., 2004). It is acknowledged that wrist pain is related to compressive loading with the apparatus, muscular strength, neuromuscular performance and technique (Malina et al., 2013). Wrist pain and subsequent injuries may occur when excessive wrist loading results in premature closing of the radial physis with consequent delayed closure of the ulna resulting in positive ulna variance. The radial physis is most vulnerable to injury during growth periods whereas, after puberty, the area of vulnerability shifts to the ligamentous tissues particularly the triangular fibrocartilage complex (Dwek, Cordoso, & Chung, 2009). Gymnasts and coaches generally regard wrist pain as a natural and acceptable consequence of the sport and often refrain from seeking medical attention (Bak, Kalms, Olesen, & Jorgensen, 1994).

Wrist injury studies of both National and International elite and non-elite competitive gymnasts (9-17 years of age) have indicated abnormalities consistent with distal radial stress syndrome (physis) in 10-85% of the cohort (Caine, Di Fiori, & Maffulli, 2006; Caine, Roy, Singer, & Broekhoff, 1992). Research on elite female gymnasts, who were diagnosed with radial physis injury, indicated that 58% of those who reported wrist pain had not missed or modified training sessions (Di Fiori et al., 2002) and, in a recent study of elite male gymnasts diagnosed with physis injury, they had continued to train with wrist pain for up to 6 months (Guerra et al., 2016).

Wrist pain and injuries in Australian gymnasts have been recorded as part of general injury statistics in gymnasts since the early 1990s. Injury prevalence in elite gymnasts (mean age 15 years, training 36 to 40 hours per week) over a 10 year period indicated that wrist injuries represented 29% of all physical injuries (Dixon & Fricker, 1993). A study over 12 months of 47 elite female gymnasts (mean age 11.3 years, training 21 to 37 hours per week) and 115 non-elite female gymnasts (mean age 13.1 years, training 6 to 30 hours per week) determined the number, site and type of injury sustained (Kolt & Kirkby, 1995). These researchers combined wrist and hand injury and indicated that these injuries constituted 11.5 % of total injuries recorded. The same authors also compared the results from their initial study with findings over a further 18 months in a similar cohort and found that wrist and hand injuries were 9.7% of the total injuries recorded (Kolt & Kirkby, 1999). The increased participation in gymnastics over the last 20 years (Morgan, 2015) combined with evolving techniques and more difficult routines to gain better scores at competition , there have been no published data on wrist pain prevalence in Australian gymnasts. Therefore, the purpose of this study was to obtain current data on: (i) the lifetime prevalence (LTP) and point prevalence (PP) of wrist pain in Australian gymnasts between 10-18 years of age; (ii) how gymnasts treated their wrist pain; and (iii) the use of wrist braces.

METHODS

A cross sectional descriptive survey was designed to collect data from 10 to18 year old male and female gymnasts who participated in Artistic Gymnastics, Rhythmic Gymnastics, Trampoline and Acrobatic Gymnastics. The survey was administered using a standard website with an open-source survey application (Survey Monkey; http://www.surveymonkey.com). The project was granted approval by the Human Research Ethics Committee of the University of the Sunshine Coast (S/12/446) and endorsed by the Australian Institute of Sport.

The survey was designed with the objective of collecting data from Australian gymnasts on: (i) historical experience of wrist pain (life time prevalence: LTP); (ii) current wrist pain (point prevalence: PP); (iii) the influence of apparatus on wrist pain; and (iv) treatment modalities utilised. Questions were formulated in consultation with a panel of coaches, physiotherapists, and doctors involved with the management of gymnast injuries. The primary objectives of these preliminary consultations were to ensure that the questions were both relevant and easily understood by the target age group. The survey was circulated by Gymnastics Australia to affiliated clubs via its monthly newsletter and through social media (Facebook). The survey was voluntary and anonymous and active online between 30th May 2013 and 30th September 2013.

The survey was divided into three sections with all questions requiring either a yes/no response or the selection of the most appropriate option from a drop-down menu. Section 1 sought demographic data about participant age, gender, the state or territory of their gymnastic club, number of years of gymnastics participation, and number of days and number of hours trained per week. The participants nominated their performance level which, for the purposes of this study, were categorised into three groups: Club, National and International. Section 2 sought information on the participants' experiences of wrist pain. Because gymnasts are known for their high pain threshold and frequent denial of pain (Harringe, Lindblad, & Werner, 2004) it was considered appropriate to document wrist pain with a simple yes/no answer as opposed to requesting a description of the pain on a visual analogue scale. Questions on wrist pain included lifetime prevalence (i.e. whether at any stage during their gymnastic career they had experienced wrist pain while performing gymnastics), point prevalence (whether they were currently experiencing wrist pain) and whether the wrist pain was thumb side, mid dorsum or fifth finger side. Participants were also asked: (i) if wrist pain had prevented them from participating in gymnastics training in the four weeks prior to completing the survey; (ii) on what apparatus wrist pain was experienced on when participating; and (iii) whether they currently had any treatment for their wrist pain and, if so, did they self-manage or consult a health professional. Section 3 asked whether they ever wore wrist braces, and, if so when.

Analysis of the gymnast's responses were categorised by their indicated performance level and age groups (10 to12, 13 to15 and 16 to18 years). The time that gymnasts trained each week were grouped into 1 to10 hours, 11 to 25 hours and 26 to 40 hours.

Data analysis was performed using Statistical Package for the Social Sciences (SPSS -22 Inc. Chicago, USA). Descriptive statistics, means and standard deviations were used to summarise and compare variables. Independent t- tests were used to determine whether there were differences of life time and point prevalence of wrist pain between males and females, age groups, levels of gymnastics, and hours trained per week. Fisher's exact test was used to determine whether there were gender differences between lifetime prevalence and point prevalence of wrist pain. An alpha level of $p = < 0.05$ was used for all statistical tests.

RESULTS

A total of 399 gymnasts (15% male, 85% female) agreed to participate in the survey. However, 162 answered less than 30% of the questions and, because of the incomplete responses, were not included in the analysis. Thus, data from 237 gymnasts, 47 male gymnasts (46 artistic and 1competitive acrobatic gymnast), and 190 female gymnasts (186 artistic, 3 competitive trampoline, and 1 competitive acrobatic) were analysed. The mean age of the gymnasts was 14.8 years (SD ± 2.5years) and there was no significant difference (P=0.582) for gender (males 14.35 ± 2.6), (females 14.89 ± 2.5). Respondents were from all states and territories: Queensland (31.2%), Victoria (29.5%), New South Wales (18.1%), Tasmania (5.2%), Australian Capital Territory (4.6%) and Western Australia (4.6%) South Australia (4.2%) and Northern Territory (2.5%).

Twenty-two percent of the respondents had participated in gymnastics for 1-5 years, 54.7% between 6 to 10 years and 23.3% between 11 to 13 years. Club gymnasts trained between 3 and 16 hours per week, the National group between 8 to 20 hours per week and the International group between 20 to 35 hours per week. Twenty one percent of the gymnasts made up the Club group, 53% the National group and 26% the International group.

There was a high LTP (92.6%) and PP (70.6%) of wrist pain in adolescent male and female gymnasts (Table 1). The prevalence rates recorded for males were not significantly different to those for females (Table 1). There was no significant difference between gender for LTP, PP or ever having experienced wrist pain during gymnastics activities and current wrist pain.

When grouped by age, there was no significant differences in LTP or PP between gender (Table 1). When grouped by level, there was no significant differences in LTP or PP between males and females (Table 2). However, when grouped by hours of training, females had significantly higher LTP (p = 0.013) when training between 1 to10 hours per week than males (Table 3). For those respondents who trained 11 to 25 hours per week, males displayed a significantly higher LTP (p = 0.005) and PP (p = 0.004) when compared to females.

Gymnasts reported their wrist area of pain as mid dorsum of wrist (53.2%), the radial side (30.3%) and little finger side (17%). Wrist pain had prevented (35.4%) gymnasts from upper limb weight bearing training over the previous month. Of this group, 68 % were females training between levels 4-10 and 31% were males training between levels 6-10. Twelve percent of the females and 20% of the males in this group indicated they wore braces for training, 32% of females 30% of the males for training and competition and none indicated they wore braces for competition only.

Male gymnasts who reported current wrist pain identified the cause as: the pommel (75%), the parallel bars (23%), the high bar (8.6%), the floor (41%), handstands (16%), the vault (11%) and the rings (4.3%). The percentage of females who experienced current wrist pain identified the vault (30%), the floor (64%), handstands (19%), the balance beam (25%), and uneven bars (15%).

Gymnasts, in consultation with their team coach or physiotherapist, treated their wrist pain with a combination of braces (39.6%), taping, icepacks and stretches (29%), exercises (20.7%), massage (16.4%) and heat packs (10.4%). Three gymnasts used wrist splints, one used anti-inflammatories and one had had a cortisone injection into the affected wrist. Further advice was sought from medical practitioners, physiotherapists, coaches and trainers by 59% of gymnasts. Wrist braces had been worn by 28% of the gymnasts at some stage during their gymnastic career. At the time of the survey 15% of all the gymnasts wore wrist braces for training, 22.8% wore braces for both training and competition and 1.3% wore braces for competition only.

Table 1
Differences between male and female age groups and prevalence of wrist pain.

Participants			Lifetime prevalence					Point prevalence				
Age years	Males	Females	Males n (%)	Females n (%)	p	Mean Diff	95% CI	Males n (%)	Females n (%)	p	Mean Diff	95%CI
10-12	17	43	17 (100)	41 (95)	0.708	-0.041	-0.26,0.17	11 (65)	32 (74)	0.347	0.165	0.18,0.51
13-15	12	58	12 (100	53 (92)	0.334	0.075	0.07,0.23	12 (75)	45 (71)	0.794	0.039	0.25,0.33
16-18	18	89	17 (94)	79 (97)	0.484	0.033	0.12,0.01	17 (76)	74 (74)	0.856	0.021	0.21,0.25
Total	47	190	46 (98)	173 (90)		0.067	0.46,0.46	40 (85)	151 (79)		0.225	-0.657,.1.10

Table 2
Differences between male's and female's performance level of gymnastics and prevalence of wrist pain.

Participants			Lifetime Prevalence					Point Prevalence				
Level	Males	Females	Males n (%)	Females n (%)	p	Mean Diff	95% CI	Males n (%)	Females n (%)	p	Mean Diff	95%CI
Club	10	42	10 (100)	38 (90)	0.985	0.0013	0.13,0.13	7 (70)	34 (81)	0.495	0.055	0.103,0.212
National	22	102	21 (95)	93 (91)	0.664	0.019	0.006,0.06	19 (86)	82 (80)	0.446	0.068	0.12,0.108
International	15	46	14 (93)	41 (89)	0.32	0.073	0.072,0.21	14 (93	35 (76)	0.502	0.55	0.10,0.215
Total	47	190	44 (94)	172 (90)		0.0553	0.314,0.42	40 (85)	151 (79)		0.673	0.23,0.53

Table 3
Differences between male's and female's hours trained and prevalence of wrist pain.

Participants			Lifetime Prevalence					Point Prevalence				
Hours trained	Males	Females	Males n (%)	Females n (%)	p	Mean Diff	95% CI	Males n (%)	Females n (%)	p	Mean Diff	95%CI
1-10	7	60	5 (71)	56 (93)	**0.013***	-0.186	0.13,0.13	7 (70)	47 (78)	0.502	0.055	0.10,0.21
11-25	34	101	34 (100)	90 (89)	**0.005***	0.232	0.006,0.06	19 (86)	79 (78)	**0.004***	0.068	0.12,0.10
26-40	6	29	5 (83)	27 (93)	0.664	-0.019	0.07,0.21	14 (93	25 (86)	0.307	0.55	0.10,0.21
Total	47	190	44 (94)	173 (90)		0.027	-0.63,.0.5	40 (85)	151 (79)		0.241	-0.21,0.69

***** Denotes significance (p= < 0.05) between genders

DISCUSSION

The results of this study indicate that Australian gymnasts (aged 10 to 18) have both a high LTP and PP of wrist pain. This is higher than studies overseas (47% to 84%)(Caine & Harringe, 2013; De Smet, Claessens, Lefevre, & Beunen, 1994; Di Fiori et al., 2002) however, direct comparison is difficult as study designs vary considerably in the definition of injury, how injury rates are determined, reporting system of pain/injuries and diversity of study populations. In this study, the 16-18 year old national level artistic male gymnasts who trained 11-25 hours per week had the highest reported LTP (100%) and PP (86%) This correlates with previous research consistent with the older artistic gymnasts having had a greater accumulated exposure to training with more complex and increased difficulty of skills. However, research has shown that regardless of age or competition level both injury rate and proportion of time loss were greatest among those gymnasts experiencing rapid growth (Caine & Harringe, 2013; Caine & Nassar, 2005; Di Fiori, 2006) This correlates with our study with 100% of the males and 95% of the females aged 10 to12 years (club and national) reporting LTP of wrist pain. This was closely followed by the 13-15(club and national) year age group with 100% of the males and 92% of the females reporting LTP. The 10 to 12 year old gymnasts are at the beginning of a rapid growth phase and have a greater risk of sustaining long term wrist pain and injury to the distal radial epiphysis (Dobyns & Gabel, 1990). Ossification of the radial epiphysis and non-union of the epiphysis and metaphysis is observed in females between 10.1 years and 13.2 years and in males between 10 years and 13.4 years (Baumann et al., 2009). Therefore, repetitive compression loading during gymnastic training may predispose this age group (10-15 years) to wrist injury of the distal radius and ultimately influence carpal development and function (Hsu & Light, 2006). Compressive loads at the wrist have been found to be 1.5 body weight (BW) for handstands increasing to 10.6 BW for flairs on the pommel (Bradshaw & Hume, 2012; Markolf, Shapiro, Mandelbaum, & Teurlings, 1990). Mechanical loading of the soft tissue structures during athletic activity is one possible stimulus to maintain and or increase the strength of biological tissue (Brueggerman, 2010). However, overuse of the soft tissues occurs from the repetitive submaximal loading particularly when inadequate time is allowed to complete normal processes of repair and adaptation (Brueggerman, 2010). In our survey 70% of the males reported PP of pain when performing on the pommel. This confirms previous evidence that the loads on the wrists while performing on the pommel are the single most important factor contributing to wrist pain in male gymnasts (Markolf et al., 1990). An elite male gymnast may perform up to 300 circles on the pommel each training session and then repeat these four day a week. This activity places potentially damaging loads on the wrist. Gymnasts accept these risks as part of their normal training model but there is no evidence that the Australian training model is influencing the development of wrist pain in our gymnasts. When the overseas epidemiology studies are considered, it suggests that the problem of wrist pain in gymnasts is global and of long standing.

The definition, reporting and recording of gymnastic injuries has varied over the years from injuries only being reported if they produced disabilities that were considered serious enough to be seen by a doctor (Snook, 1979) to the current recommended procedure of Gymnastics Australia for medical injury reporting which states that ‘any incident that requires active treatment or alters gymnastic training or competition is considered reportable’. This definition, however, is open to interpretation by gymnastic clubs. If common reporting criteria defines ‘reportable wrist pain’ as only that which requires the gymnast to miss training it may underestimate the long-term risks to gymnasts who persist in training, self manage and only consider reporting the problem when the pain is intense and ‘alters’ their training schedule. Pain or functional limitation, are often of gradual onset and intermittent and many gymnasts will continue to train and compete despite the presence of the symptoms. Inadequate diagnosis and treatment of overuse injuries, many of which involve radial epiphyseal changes, may delay the healing process and furthermore result in permanent disability (Frush & Lindenfield, 2009). The apparent reluctance to seek advice needs to be addressed by the gymnasts and their medical team.

The results of our survey found that the gymnast’s primary management for wrist pain was self- management including wearing commercially available wrist braces (either Panda Paws or Reisport wrist extension block) taping, ice packs, massage, stretching and strengthening in combination with advice from their coaches on training modification. Further management included advice from professionals such as a Doctor or physiotherapist.

Despite the wearing of braces, there is only one study, designed for male gymnasts with physis injury, to support how a brace may be of benefit in dissipating compression loading acting on the wrist while performing on the pommel (Grant-Ford, Sitler, Kozin, Barbe, & Barr, 2003) and none on the current commercially available braces gymnasts tend to use. Wrist braces studies in other sports have shown them to be effective in protecting athletes from sustaining wrist fractures, ligament sprains and ligament ruptures when they fall onto an outstretched hand (Russell, Hagel, & Francescutti, 2007) by blocking wrist hyperextension. When considering that gymnasts will often ‘fall onto an outstretched hand’ loading through the wrist as part of their normal gymnastic activity it would be advantageous to have a brace design effective as an adjunct to current injury prevention in the adolescent gymnasts. Also, as suggested in a review of wrist injuries in athletes aged 10 to 14 years (Kox et al., 2015), a specific protocol for wrist screening and preventative strategies with a proactive rather than a reactive approach to gymnast’s wrist pain is warranted. Furthermore, if these strategies were implemented when symptoms occur, and athletes encouraged to report injuries there would be a decrease in prolonged wrist pain, injury and re-injury. Finally, education of the gymnasts and coaches is paramount to teach awareness of the long-term effects of wrist pain. The coach’s duty of care, knowledge and management of injured gymnasts has a major influence on the culture of athletes. The coach is involved with each gymnast from preparation and training regimes through to decisions about whether a gymnast is fit to train or compete. The coach is best placed to understand the potential consequences of growth plate injury during periods of growth and respond appropriately. Coaches also need to be aware of the culture they are creating and mindful of each of their gymnasts physical and psychological needs. No two gymnasts are the same, reacting differently to training methods and the ‘no pain, no gain’ attitude expressed by many coaches is not appropriate (Sands, Caine, & Borm, 2003).

CONCLUSION

Australian adolescent gymnasts had both a high reported lifetime and point prevalence of wrist pain which is largely unreported. Wrist pain does not need to be endemic in adolescent gymnasts. The paradigm needs to change from wrist pain acceptance to wrist injury prevention.

LIMITS TO SURVEY

Clearly these data are limited to the cohort of Australian gymnasts who completed the survey. Although the survey recruitment was for all gymnasts between

10-18 years we acknowledge that there is always possibility for bias with potentially only gymnasts with injury or pain completing the survey as it was topical for them. Issues such as these are typical to all pain/ injury research survey with some care required to avoid over interpreting results. Although the survey and research information was widely publicised on gymnastic web sites, in gymnastics Australia's monthly newsletter to clubs and Facebook, posters in clubs and personal contact with coaches, the number of respondents was less than anticipated. Numbers were also compromised as 162 of the 399 respondents answered less than 30% of the questions so were removed from the data. The higher number of female respondents was expected as within the 199,000 members of gymsports registered with Gymnastics Australia 76% are female.(Australia, 2016).

RECOMMENDATIONS

Defining reporting procedures for wrist pain is strongly recommended with ;

1. Early reporting of wrist pain, correct diagnosis, and appropriate management to avoid long term pain
2. Once wrist pain is reported any musculoskeletal issues should be addressed,
3. training modified such as decreasing repetitions, changing the order in which circuit training is done to avoid overload on the wrist and shorter training sessions.
4. Prior to returning to normal training implement a physical ability test to measure the gymnast's current functional fitness to the level of training expected.

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ARE BODY ESTEEM, EATING ATTITUDES, PRESSURE TO BE THIN, BODY MASS INDEX AND TRAINING AGE RELATED IN RHYTHMIC GYMNASTICS ATHLETES?

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Original article

Abstract

Rhythmic gymnastics athletes participate and compete from a very young and critical period of their lives, as childhood and adolescence. Purpose of the present study was to examine the relationship between body esteem, eating attitudes, perceived pressure to be thin by coaches, parents and friends, Body Mass Index (BMI) and training age in rhythmic gymnastics athletes. Eighty-three rhythmic gymnastics athletes participated (49 current and 34 former). They completed self reported questionnaires assessing demographic and personal characteristics, body esteem, global eating attitudes, and pressure to be thin by coaches, parents and friends. The results revealed that body esteem was predicted significantly by pressure to be thin by parents, BMI and training age. Also, former athletes had more positive body esteem and eating attitudes than current athletes, and current athletes felt more pressure to be thin by their parents, than former athletes. The results of the present study led to several suggestions for further studies.

Keywords: *rhythmic gymnastics, athletes, body esteem, eating attitudes, pressure to be thin.*

INTRODUCTION

Rhythmic gymnastics (RG) is a popular aesthetic female sport with a particular training process, including early specialization before bone maturation, big volume of training, many hours of intensive training per week, high level of technical elements performed by many repetitions, variant abilities required (Bobo-Arce & Méndez-Rial, 2013). Elite gymnastics seems to be a relatively closed and stable setting where gymnasts generally reach the peak of their powers in adolescence or very early adulthood and retire by their mid-20s (Tan, Bloodworth, McNamee, & Hewitt, 2014). Training in gymnastics affects goal orientation (Koumpoula, Tsompani, Flessas, & Chairopoulou, 2011), self confidence (Zisi, Giannitsopoulou, Vassiliadou, Pollatou, & Kioumourtzoglou, 2009) and self esteem (Donti, Theodorakou, Kambiotis, & Donti, 2012).

Self-esteem refers to a global sense of self-worth and body-esteem is used to imply a sense of self-esteem in a specific area (Rattan, Kang, Thankur, & Parthi, 2006). High self-esteem and positive body image are important for preventing disordered eating and the development of body image disturbances among adolescents and children (Smolak, 2004). Why athletes might be expected to be at increased risk for developing eating disorder or abnormal eating attitudes? One of the reasons, according to Byrne and McLean (2001) is because athletes are considered as subjects feeling sociocultural pressure to conform to a lean body ideal as well as to an ideal body shape. Also athletes, more likely elite athletes, exhibit certain psychological characteristics as perfectionism, goal-orientation (specifically ego-orientation) and concerns with performance that are often described as risk factors for eating problems (Gomez, Martins, & Silva, 2011). It cannot be denied that in some sports which are characterized as lean, body image is indeed important, as weight or appearance are important for success. Body esteem is a concept referring to self-evaluation of someone's appearance, a concept of self-appraisal of one's own body (Mendelson & White, 1985). Body esteem consists feelings about one's weight, feelings about one's general appearance and opinions attributed to others concerning one's appearance (Mendelson, Mendelson, & White, 2001). Adolescence is a period during which body dissatisfaction starts increasing for girls (Bearman, Presnell, Martinez, & Stice, 2006) and is also the age during which RG athletes train intensively, since the selection of gymnasts for the national teams take place by that age (Balyi, 2001; Cupisti, D' Alessandro, Castrogiovanni, Barale, & Morelli, 2000).

Eating disorders are a serious and modern health problem. During adolescence and early adulthood the onset of eating disorders typically occurs (Byrne & McLean, 2002; Halmi, 2009). Participating in competitive sports is considered as an important risk factor for developing eating disorders (Sundgot-Borgen & Torstveit, 2004), although there are also few studies that have shown more disordered eating in non-athletes (e.g., Michou & Costarelli, 2011). There are sports emphasizing leanness, thinness and aesthetic aspects and rhythmic gymnastics is such a sport (de Oliveira Coelho, da Silva Gomes, Ribeiro, & de Abreu Soares, 2014). Athletes competing in sports in which low body fat and low body weight are required for reasons of performance or appearance, may be under intense pressure in this regard (Sundgot-Borgen, 1993). So, athletes appear to be somewhat more at risk for eating problems than non athletes, more over elite athletes in sports emphasizing thinness (Smolak, Mumen, & Ruble, 2000).

Garner and Garfinkel (1979) in order to identify people who will possible have eating disturbances developed the Eating Attitudes Test (EAT). EAT is an objective, self report measure of the symptoms of anorexia nervosa. A short-version of EAT is the EAT-26 which derived from the original questionnaire and examining whether someone is possible to have eating disorders (not only anorexia nervosa) (Garner, Olmsted, Bohr, & Garfinkel, 1982). Although the EAT-26 consists of subscales (5 or 3) it is also used as a single scale (Garner et al., 1982). Several studies have examined eating disorders and eating attitudes in several populations, as athletes (Doninger, Enders, & Burnett, 2005; Ferrand, Champely, & Filaire, 2009; Filaire, Rouveix, Pannafieux, & Ferrand, 2007), female and male athletes and non athletes (Fortes, Kakeshita, Almeida, Gomes, & Ferreira, 2014), athletes in aesthetic and lean sports (Ferrand, et al., 2009), and dancers (Arcelus, Witcomb, & Mitchell, 2014). It seems that the prevalence in western countries of abnormal eating attitudes range from 8.3% among college students, young adults, in Switzerland (Buddeberg-Fisher, Bernet, Sieber, Scmid, & Buddeberg, 1996) to 26% among college age women in the USA (Graber, Tyrka, & Brooks-Gunn, 2003). More specifically in gymnastics Theodorakou and Donti (2013) found that 30% female elite rhythmic and artistic gymnasts had abnormal eating attitudes. In their study, age and BMI were highly correlated to eating attitudes. Their findings were similar to Douka's study (Douka, Grammatopoulou, Skordilis, & Koutsouki, 2009). There are few studies trying whether to predict global eating attitudes score from dimensions of body esteem (Rouveix, Bouget, Pannafieux, Champely, & Filaire, 2006), or to predict a dimension of eating attitude scale, Dieting, from body esteem dimensions (Ferrand, Magnan, & Philippe, 2005). No study so far has used global eating attitude scale and global body esteem scale, examining their possible relation, although body esteem can be considered as an evaluation in higher level of generality that can affect attitudes and behaviors.

The belief among athletes and coaches that a reduction in weight or body fat could enhance athletic performance can also increase athlete's risk in prevalence of eating disturbances (Thompson & Sherman, 1999). This pressure to be thin is a fact in gymnastics, artistic and rhythmic, by coaches, parents and judges (Theodorakou & Donti, 2013; Salbach, Klinowski, Pfeiffer, Lehmkuhl, & Korte, 2007). There seems to be a trend toward gymnasts with lower height and weight in competitive gymnastics because it is more appealing to the eye, it is easier for the gymnast to perform flight skills and to have more speed and agility (Sample, 2000). Perceived pressure to be thin predicts subsequent increases in body satisfaction (eg. Stice & Shaw, 2002; Stice & Whitenton, 2002). Stice and Shaw (2002) also depicted graphical the putative precursors and consequences of body dissatisfaction where perceived pressure to be thin was affected by body mass and in turn it affected body dissatisfaction.

Purpose of the present study was to examine whether global body esteem could be predicted by eating attitudes, pressure to be thin by coaches, parents or friends, Body Mass Index (BMI) and training age in rhythmic gymnastics athletes. Body esteem is a more global concept, which affects attitudes. Also, the study examined the possible differences between former and current RG athletes in body esteem, eating attitudes, pressure to be thin by coaches, parents and friends. Body esteem and self reported BMI would be negatively related, as in other studies with typical female population (Mendelson, Mendelson, & Andrews, 2000). There would not be found significant differences between current and former athletes as it is supposed that involvement in sports leads to common positive changes in variables, as physical self-esteem, independently to the level of sport participation (Findlay & Bowker, 2009).

METHODS

Participants

In the present study participated 83 Greek rhythmic gymnastics athletes, former (N= 34) and current (N= 49). Their mean age was 17.45 years (±6.97). Former athletes' mean age was 25.03 years (±4.45) and current athletes' mean age was 12.35 years (±1.67). Their training age was 7.76 (±2.72). Former athletes' mean training age was 9.70 years (±2.05) and current athletes' mean training age was 6.45 years (±2.31).

Instruments

Self reported questionnaires were used assessing demographic and personal characteristics (age, competitive experience, being a current or a former athlete, body height and weight for calculating Body Mass Index [kgr/m^2]), eating attitudes, body esteem, and pressure for thin body by coaches, parents and friends.

Body esteem (BES)

A validated Greek version (Karamitziou, 2008) of the Body–Esteem Scale for Adolescents and Adults (Mendelson et al., 2001) was used to assess the body esteem which includes 23 items. Body-esteem scale has three subscales: Appearance, Weight, and Attribution. Also these items compute an overall factor "Body esteem" which was used in the present study, with Cronbach's alpha .86. All responses were in a five-point Likert scale, from 0 (never) to 4 (always). Higher scores indicated a higher level of body esteem.

Eating attitudes

The validated Greek version (Varsou & Trikkas, 1991, Douka,et al. 2009) of Eating Attitudes Test-26 (Garner & Garfinkel, 1979; Garner et al., 1982) was used. Twenty six items scored using six answer options by the following scores: 0=never, rarely, or sometimes, 1= often, 2= usually, and 3=always. A total score ≥20 is indicative of symptoms and concerns about eating disorders. EAT-26 assesses global eating attitudes with Cronbach's alpha .87.

Pressure for thin body by coaches, parents and friends

It was measured by Durkin, Paxton and Wertheim's questionnaire (2005). In their study they assessed only peer and parental pressure using two items for each group ("Do you think your coach/parents/friends would like you to be thinner than you are now?", "Does you coach/parents/ friends encourage you to lose weight?"), rated from 1 (never) to 5 (very often). In the present study pressure to be thin was measured for each significant person separately (coach, parents and friends). For coaches Cronbach's alpha was .88, for parents Cronbach's alpha was .84 and for friends Cronbach's alpha was .70.

Procedure

Researchers received authorization from the Rhythmic Gymnastics clubs' Directors, the parents and the coaches. Before the athletes completed the questionnaires, they were assured their participation was voluntary and that there were no wrong or right answers. Researchers also assured them that their answers were confidential and anonymous and that coaches and parents would not be permitted to see their responses. Most of the athletes took approximately 15-20 min to complete. Former athletes were contacted by personal.

Statistical analyses

Descriptive statistics (M, SD) were examined for training age, BMI, eating attitudes, body esteem and pressure to be thin, for all participants and separately for former and current athletes. Correlations between measures were examined with Pearson r criterion. To examine the possible differences between current and former RG athletes in eating attitudes, BMI and body esteem independent t-tests were used. A repeated measures ANOVA was conducted to compare the differences in pressure to be thin by three groups of significant persons (DVs: by coaches, by parents and by friends) between RG athletes (IV: current-former athletes). Hierarchical regression analysis was used to examine the prediction of body esteem from eating attitudes, pressure to be thin from coaches, parents of friends, BMI and training age for all participants. The analyses were conducted with SPSS 20.0 for Windows, adopting a level of significance of 5%.

RESULTS

Descriptive statistics and Correlations

Table 1 indicates means (M) and standard deviation (SD) values for all variables for all participants, for former and current athletes. Correlations among measures are shown in Table 2. Results indicated significant correlations between BMI and pressure to be thin by coaches, between body esteem and eating attitudes, pressure to be thin by coaches and parents, between eating attitudes and pressure to be thin by parents and friends. Finally, there were significant correlation between pressure to be thin by every signifant person.

Differences between current and former athletes

There was a significant difference in BMI between former and current athletes (t_{79}= 8.68, p<.001). Former athletes had higher BMI than current athletes (Table 1). None participant had BMI larger than 25, meaning that none was overweight. Underweight (lower than 18.5) was 61.4% (26.5% of the former athletes and 85.7% of the current athletes). There was, also, a significant difference in BES between former and current athletes (t_{80}=2.12, p<.05), with former athletes having higher body esteem.

Eighteen participants (21.7%) had eating attitudes' score higher than 20, indicating eating concerns or disorders (Garner & Garfinkel, 1979; Garner et al., 1982). There were 5 former athletes and 13 current athletes scoring higher than 20, 26.5% of the current athletes and 15.2% of the former athletes. The different percentages between current and former athletes were not significant (*chi square*=1.49, p=.17). Differences in eating attitudes between current and former rhythmic gymnastics athletes were significant (t_{80}=-2.09, p<.05). Current athletes had higher mean score on eating attitudes (M= 16.26 ± 10.40) than former athletes (M= 11.45 ± 9.97).

A repeated measures ANOVA was conducted to compare the differences in pressure to be thin by three groups of significant persons (by coaches, by parents and by friends) between RG athletes, with a Greenhouse-Geisser correction. The results determined that there was a significant effect or the pressure to be thin (Wilk's Lambda= 71.93, F (2,160) = 93.53, p< .001, eta squared= .54), and there was a significant interaction between type of RG athlete (current-former) and pressure to be thin by each significant persons (coach, parent, friend) ($F_{2,160}$= 8.34, p <001). Post hoc tests using the Bonferroni correction revealed that for current RG athletes and for former RG athletes there were significant differences between pressure by every significant other group, coach- parents-friends (Table 1). Analysis of Variance was used to examine differences between current and former RG athletes in pressure to be thin by coaches, by parents and by friends. There was a significant difference only in pressure to be thin by parents (F(1,80) = 5.10, p <.05).

Prediction of Body Esteem

In the regression analysis as dependent variable body esteem was used and as independent variables global eating attitudes, pressure to be thin by coaches, parents or friends, BMI and training age were used. In Table 3 there is a summary of hierarchical regression analysis indicating that contributed significantly only pressure to be thin by parents, training age and BMI.

Table 1
Mean (M), standard deviation (SD) and differences in training age, BMI, EAT, MES and pressure to be thin for all participants, former and current athletes.

	Total M (SD)	Former athletes M (SD)	Current athletes M (SD)
Training age	7.76 ± 2.72	9.70 ± 2.05	6.45 ± 2.31
BMI	17.44 ± 2.30	19.41 ± 1.65	16.15 ± 1.65
EAT	14.33 ± 10.44	11.45 ± 9.97	16.26 ± 10.40
BES	2.54 ± .47	2.67 ± .32	2.45 ± .53
Pressure to be thin by coaches	3.16 ± 1.40	3.50 ± 1.55	2.94 ± 1.26
Pressure to be thin by parents	1.88 ± 1.07	1.56 ± .90	2.09 ± 1.13
Pressure to be thin by friends	1.40 ± .67	1.23 ± .42	1.52 ± .78

Table 2
Correlation coefficients values (Pearson r) between variables.

	1	2	3	4	5	6	7
1.Training age	1						
2.BMI	.67**	1					
3.Body esteem (total)	.09	-.17	1				
4.EAT-26	-.12	.06	-.22*	1			
5.Pressure to be thin by parents	-.01	.03	-.45**	.34**	1		
6.Pressure to be thin by coaches	.21	.43**	-.22*	.07	.29**	1	
7.Pressure to be thin by friends	-.11	.02	-.13	.30**	.51**	.22*	1

**: p<.01 , *: p<.05

Table 3
Summary of Hierarchical Regression Analysis for Variables predicting body esteem.

	Variable	R	R^2	ΔR^2	F_{change}	*df*	*B*	*SE B*	*p-values*	*Part*
Step 1		.24	.05	.45	3.78	1. 79				
	Eat-26						-.01	.01	ns	-.21
Step 2		.29	.09	.04	3.39	1.78				
	Eat-26						-.01	.01	ns	-.20
	Pressure by coaches						-.07	.04	ns	-.20
Step 3		.46	.21	.12	12.08**	1. 77				
	Eat-26						-.00	.01	ns	-.07
	Pressure by coaches						-.03	.04		-.09
	Pressure by parents						-.17	.05	.000	-.35
Step 4		.48	.23	.02	1.67	1. 76				
	Eat-26						-.00	.01	ns	-.09
	Pressure by coaches						-.04	.04	ns	-.10
	Pressure by parents						-.20	.05	.000	-.38
	Pressure by friends						.11	.08	ns	.13
Step 5		.49	.24	.02	1.74	1. 75				
	Eat-26						-.01	.01	.000	-.10
	Pressure by coaches						-.01	.04	ns	-.03
	Pressure by parents						-.21	.05	ns	-.38
	Pressure by friends						.11	.08	ns	.13
	BMI						-.03	.02	ns	-.13
Step 6		.57	.32	.08	8.25*	1. 74				
	Eat-26						-.00	.01	ns	-.08
	Pressure by coaches						-.00	.04	ns	-.01
	Pressure by parents						-.22	.05	.000	-.41
	Pressure by friends						.14	.08	ns	.17
	BMI						-.09	.03	.01	-.28
	Training age						.07	.02	.01	.28

Note: *$p < .05$, **$p < .001$

DISCUSSION

Young girls participate in educational classes of rhythmic gymnastics or in competitive classes. Their participation takes place during fragile periods of their lives, specifically childhood and adolescence, during which their bodies change dramatically. Purpose of the present study was to examine if body esteem could be predicted by global eating attitudes, pressure to be thin by significant others, as coaches, parents and friends, BMI and training age. Former and current RG athletes participated in the study, in order to examine possible differences between them in body esteem, eating attitudes pressure to be thin and BMI. The results revealed that body esteem was predicted significantly negatively by pressure to be thin by parents and BMI, and positively by training age. Also, former athletes had more positive body esteem and eating attitudes than current athletes, and current athletes felt more pressure to be thin by their parents, than former athletes.

In the present study, body esteem was more positive (higher) for former athletes than current athletes. Self esteem changes during adolescence and body is a significant factor influencing self esteem which also changes during adolescence. During adolescence, body dissatisfaction increases, especially for girls (Bearman et al., 2006; Eisenberg et al., 2006), as females are more concerned about their body changes (Gatti, Ionio, Traficante, & Confalonieri, 2014). Participating in a lean sport, as RG, may increase even more body dissatisfaction, moreover when significant others demand athletes to be thin. As Tan, Bloodworth, McName and Hewitt (2014) mentioned adolescent gymnasts are developing their own sense of self, at a time of life where body image concerns are common, they also often compete at the very top of the sport with a need to maintain a body shape and weight optimal for elite performance. Body esteem was higher for former athletes than current athletes in the present study which probably means that after disengagement all possible negative effects disappear or revise.

Being a RG athlete, may affect body esteem. There are many reasons why that could happen. For example RG athletes must wear appropriate athletic suits which are leotards, while they are competing and practicing. Their body changes are observable to themselves and others, their coaches, their teammates, judges. A great Bulgarian RG coach, Neska Robeva, in her book "Championers' School" (Robeva & Rangelova, 1988) included a chapter by the title "The terrible war against weight". From the title of the chapter it is obvious how important weight is assumed for the sport. Training for so many hours per day, for a long period per year, is leading to a great amount of training loads. Even a small amount of change in body weight changes the effect on body and the demands from the body during practice. Joints and muscles are stressed, and injuries may happen. So, although people think that body weight change is rather an aesthetic problem, the truth is that it is mostly a problem of training loading (Robeva & Rangelova, 1988).

About eating attitudes, the results of the present study are in order to other studies. Specifically, twentysix percent of the current RG athletes who participated in the present study had abnormal eating attitudes, while Theodorakou and Donti (2013) found 30%, of female elite athletes of gymnastics (rhythmic and artistic) had abnormal eating attitudes. In their study only elite athletes from two different sports (artistic and rhythmic gymnastics) participated. In Ferrand and his colleagues' (2009) study the RG group had the highest values from all groups and also the most dispersed values. In their study 37.7% of the RG athletes had abnormal eating attitudes and it must be mentioned that their mean age was 16.2, meaning that most of the athletes were teenagers while in the present study participated also younger RG athletes. Former RG athletes had less abnormal eating attitudes (15.2%). This finding is interesting for further research. Does it mean that after sport disengagement abnormal eating attitudes become more positive?

Pressure toward athletes to be thin by coaches, parents and judges is a fact in gymnastics (Theodorakou & Donti, 2013; Salbach et al., 2007). The results of the present study revealed that pressure was higher by coaches for both current and former RG athletes. Coaches have significant role in adolescent athletes' development (Fraser-Thomas & Côté, 2009). Weight control and body esteem is a context in which coaches are involved during practice. They argue with their athletes for many years about weight change and weight control in RG. This pressure could affect athlete's body image and body esteem through both different routes of persuasion, central and peripheral (Petty & Cacioppo, 1986). According to the Elaboration Likelihood Model of persuasion (Petty & Cacioppo, 1986) a person can be persuaded to change his/her attitudes relying on the arguments of the persuader or/and by other cues than the arguments. In the first case it is the central route of persuasion and in the second it is the peripheral route of persuasion. By the central route of persuasion, athletes are weighted every single day in the gyms and coaches try to persuade them to stay as thin as possible, giving them arguments (Robeva & Rangelova, 1988). Practices coaches use, such as routines, behaviors and no verbal communication before, during or after training, can serve as cues in the peripheral routes of persuasion (Petty & Cacioppo, 1986). In many cases the recipient can rely on peripheral cues to change his/her attitude on the subject, such as when he/she is not interested in or has not enough relevant knowledge (Alba & Hutchinson, 1987). Also adolescents often use the peripheral route of persuasion as they think that some issues do not involve them, for example they think that the consequences of smoking are far away from them even if they are smokers, so far as elderly (Scott, 1996). Coaches should be aware of the ways that they can persuade RG athletes effectively, by central and peripherical route of persuasion. Perhaps nowadays curriculums at Departments of Physical Education and Sports include some lectures about subjects like communication, body image, and that's why former athletes perceived their coaches to pressure them more to be thin than current athletes. On the other hand, many coaches have athletic experience in RG, so they try not to adopt behaviors their coaches did. Appropriate educational programs should be addressed not only to coaches but to every other person is involved in RG athletes' lives (e.g., parents).

Nowadays parents are highly involved in RG athletes' carrier. Rhythmic Gymnastics is a sport in which parents have to transport athletes to and off the training centers, invest money and time, and actively participate in the sport clubs as administrators or just members. They are also responsible for athletes' diet. So, in a recent study it was found that Greek athletes in specializing years desired more praise and understanding by their parents (Giannitsopoulou, Kosmidou, & Zisi, 2010). In other words athletes desired more positive behaviors by their parents during their training years. Pressure to be thin is a negative behavior for athletes during their athletic career which needs to be minimized. By the results of the present study it was found that only pressure to be thin by parents contributed significantly to the prediction of body esteem. This revealed the importance parents plays in the development of RG athletes.

In previous studies body esteem and eating attitudes were not examined simultaneously. In the present study eating attitudes as a global variable did not contribute significantly to the prediction of body esteem. Probably it should be used sub-scales of eating attitudes, but this requires more participants for the appropriate statistical analyses, which was a limitation of the present study as will be mentioned below.

Since early '80s, in Greece many girls participate in RG clubs. Unfortunately, athletic careers in gymnastics are remarkably short-lived and according to female gymnasts there is a lack of psychological support by coaches during the biological maturation (Koukouris, 2005). After the early disengagement, former rhythmic gymnasts do not always participate as coaches or judges. Reasons are questionable and should be examined. Including former athletes in studies, may lead to conclusions concerning rhythmic gymnastics in Greece. Are the effects on body esteem and eating attitudes permanent or not? Can effects on body esteem and eating attitudes change after sport disengagement? By the results of the present study it can be assumed that after disengagement girls have positive body esteem and positive eating attitudes, so the possible effects on eating attitudes are not permanent and can be reversed after ending athletic career. This is a question to be answered.

The present study had some limitations. First of all the number of participants was not very high, although it was acceptable. Larger number of participants would allow the researchers to test more statistical models. Also, using self-reported questionnaires is a limitation that could be overcome only by using at the same time qualitative methods. Psychological issues, as body esteem, eating attitudes etc, are measures by using self- reported written questionnaires. Also, there are not many instruments that can be addressed both to adolescents and adults.

The results of the present study lead to suggestions for further future studies. For example, about body esteem there are limited studies in which former rhythmic gymnastics athletes participate and this is a direction for future studies. Probably a longitudinal study should be designed to. About eating attitudes, it is reasonable to include former athletes in order to examine how permanent are the effects of sports. Finally, programs should be designed and addressed to parents educating them, so they could be aware of the specificities of the sport and the ways they could and should help RG athletes in order to built positive body esteem.

CONCLUSION

The results of the present study can lead to several suggestions for further studies. Body esteem and eating attitudes should be examined between current and former athletes from different sports (aesthetic vs. non aesthetic, lean vs. non lean, individual vs. team), in different cultures, in different levels of sport participation (elite, recreational, non athletes). More instruments examining esteem, body and self, should be addressed in order to have more global view of body esteem in RG and sports. Not only quantitative studies should be conducted but also qualitative in order to participate younger aged athletes and observe issues as body image, body esteem and body dissatisfaction from childhood (when a girl participate for the first time in RG classes) to adulthood (years after sport disengagement).

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ANALYSIS OF LONGITUDINAL PLANTAR ARCH IN FEMALE ARTISTIC GYMNASTS

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Original article

Abstract

The aim of the study was to use plantographic measurements to analyse the condition of longitudinal plantar arch in a group of female artistic gymnasts and to find out to which characteristics of gymnasts they are related. The study group included 52 artistic gymnasts at a high performance level. Using static measurement on an Emed platform plantographs were acquired which were then evaluated by the Chippaux-Šmiřák method, the results were then scaled according to Klementa norms. In 89 measured feet out of 104 a high longitudinal foot arch was detected. Out of these 5 were slightly high, 14 were medium high and 70 were very high. The remaining 15 gymnasts had a normal longitudinal foot arch. By calculating the Pearson correlation coefficient we found out that with the duration of gymnastic practice the height of foot arch decreases (r = 0.47), these changes might also be affected by increasing BMI (r = -0.51) during growing up. Regarding the condition of preferred and non-preferred foot, no statistically significant difference was found out (p = 0.44). Based on the results we recommend compensatory exercises aiming to plantar flexors stretching to be included in artistic gymnasts' preparation.

Keywords: *Gymnastics, women, foot arch, Emed, Chippaux-Šmiřák.*

INTRODUCTION

In order to be able to compete with others at a national or international level, a gymnast should start with gymnastics at an early age. Female artistic gymnasts then perform at an elite level during adolescence. High intensity of exercise and competition loads, their amount and level of element difficulty could be in relation with the fact that there is a significant number of injuries in female high level gymnasts (Chilvers, Donahue, Nassar & Manoli, 2007). Effects of long-term specific gymnastic load on organism already from early childhood may also lead to adaptive changes in the structure of musculoskeletal system.

Despite using special mattresses, many injuries of lower extremities occur mainly during the landing phase (Mills, Pain & Yeadon, 2006, Vormittag, Calonje & Briner, 2009). Accoridng to McNitt-Gray (1991), the landings are from heights around 2 to 4 m. According to the rules, a gymnast aims to perform the landing without a loss of balance or movement of legs after the landing, while their musculoskeletal system must absorb the forces of impact. These increase the risk of ankle and feet injuries (Vormittag, Calonje & Briner, 2009).

The large forces acting on the body of the gymnast during landings in combination with high number of movement repetition are one of the main causes of injuries (Farana, Zahradník, Uchytil, & Jandačka, 2013). Caine, Russell, & Lim (2013) assume that the riskiest discipline is the floor, mainly due to the large number of take-offs and landings reflections and rebounds.

Therefore, landings are not important only as a part of gymnastic routines, but also from the point of view of injuries. Generally, stability of landing depends on balancing abilities of a gymnast and landing area characteristics. From this reason Soriano, Belloch and Alcover (2007) dealt with plantar pressure during landing and its relation to stability and perception of mattress characteristics. A statistically significant relationship between the plantar pressure and perception was found out. In the conclusion the authors summarise that even when using different types of mattresses, a high pressure repeatedly occurred on heel (785 kPa) and on a first metatarsus (352.6 kPa), approximately similar pressure on other, resting, areas (200 kPa).

Authors Slater, Campbell, Smith and Straker (2015) point out that flexion in joints of lower extremities during landings is limited by the rules of artistic gymnastics, although there are ways to decrease these forces. Using the force platform and 3D kinematic analysis of motion they measured the vertical component of force reaction of platform and angles in ankle, knee and hip joint of elite female gymnasts. Based on the results the authors suggest that the rules of artistic gymnastics should be re-evaluated as bigger flexion in joints of lower extremities during landing leads to decrease in the size of impact forces which will contribute to injury prevention.

McNitt-Gray (1991) claims that during landing are created reaction forces equivalent to ten times and more the amount of the force of gravity, which may lead to lower extremities overloading. Likewise, also Mills, Pain and Yeadon (2009) state that reaction forces of platform during landing may reach values up to 8000 N. Nevertheless, according to these authors the reduction of reaction forces of platform is not appropriate as the way of minimising the potential risk of injury because this may lead to increase of inner forces.

As mentioned above, several authors agree on the fact that the lower extremities injuries are the most frequent among gymnasts (Mills, Pain & Yeadon, 2006, Vormittag, Calonje & Briner, 2009). They assume that the reason is the high number of landings from big heights as well as landings from flight elements with rotation. Authors Kolt and Kirkby (1999) performed a 18-month-long prospective study on Australian elite female gymnasts in which they assessed the number of injuries, their anatomical localisation and type of injury in elite female gymnasts, the data were then compared to retrospectively acquired data. The most common injuries included ankle and foot injury (31.2 %), with prevailing twisted ankle (29.7 %), then stretched ankle (23.2 %) and injury of growth plates (12.3 %).

Extreme load is related to pain which is a serious problem is artistic gymnastics as it decreases the performance of a sportsman. According to Marini, Sgambati, Barni, Piazza and Monaci (2008) the pain caused by high number of hours spent on trainings may be related to injuries which are common and serious in artistic gymnastics. In agreement with previous studies they state that the most common problems in the study group affect ankles and hips, the painfully affected area was related to the training content. The results of the study proved a positive effect of preventive-compensatory movement programme already after a short-term intervention.

Musculo-skeletal changes due to overload in ankles and feet are mainly related to the character of gymnastic movements. It has been proved that the height of plantar arch is changing with age, even without any extreme overload. Forriol and Pascual (1990) state that arch index has a value of 1 in one year (the range 0.7 – 1.35), it gradually decreases to a minimum value of around 0.6

(the range 0.3 – 0.9) at the age of 12 – 14 and then increases with age to a value of around 0.8 (the range 0.3 – 1.1). It is obvious, however, that apart from the ontogenetic changes the activity of certain feet muscles may increase the plantar arch height, the activity of other muscles decrease the height. Some authors dealt with the influence of gymnastic exercises on the changes of these structures.

The aim of the research by Aydog et al. (2005) was to evaluate the relationship between the force of muscles of ankle joint and the structure of foot in gymnasts aged 18 – 30 years. The condition of plantar arch was assessed using a podoscope, the force of plantar and dorsal flexion and inversion and eversion in ankle joint was measured using Biodex 3 dynamometer. Both arch indexes were significantly lower in gymnasts compared to the control group. Also, the measurements proved a significant correlation between the values of these indexes for the right and left foot both in gymnasts and the control group. Regarding the force characteristics, a lower force of dorsiflexion in ankle joints was found in gymnasts compared to the control group. As already mentioned above, the active performance of dorsal flexion in ankle joint is not a usual intended movement in gymnasts. Muscles participating in the flexion, i.e. musculus tibialis anterior, musculus extensor hallucis longus, musculus peroneus tertius a musculus extensor digitorum longus (Bernaciková, Kalichová & Beránková, 2010), are not exercised enough in comparison with other muscle groups. Also in a study by Aydog et al. (2005) in gymnasts a correlation between the force in ankle joint during foot eversion (with participating musculus peroneus longus, musculus peroneus brevis, musculus extensor digitorumlongus and musculus peroneus tertius) and the plantar arch height was found. Based on the results the authors recommend to perform a prospective study which would better clarify the relationship between training and adaptive changes. It would be beneficial to find out how high plantar arch and weaker dorsiflexion in ankle joint are related and how these characteristics affect foot stabilisation which is a significant factor influencing the performance. Authors summarise that foot muscles influence the development of plantar arch and therefore it can be assumed that exercising of muscles connected to ankle joint will have effect of plantar arch condition.

When comparing condition of plantar arch of gymnasts with other sportsmen, such as handball players, weightlifters, footballers and wrestlers, it was found out that gymnasts have lower values of arch indexes, i.e. higher plantar arch (Aydog, Tetik, Demirel & Doral, 2005). High plantar arch (pes cavus) as well as flat foot (pes planus) may be, according to some authors (Simkin et al., 1989, Cowan, Jones & Robinson, 1993) a cause of fractures of femur, tibia, metatarsal bones and other parts of lower extremities.

Insufficient activity of certain muscles, unbalanced exercising or stretching of given muscle groups may lead to changes in plantar arch condition. In artistic gymnastics gymnasts constantly aim to have their toes point, according to the rules, so that the aesthetics of movement is preserved. Actively performed plantar flexion by concentric activity of related muscles is a condition for a dynamic take-off from the kinesiologic point of view. Eccentric contraction of plantar flexors is necessary for stable and coordinated rebound when a gymnast places the foot from fingers to the whole sole. A direct effect of the dynamic movements as well as static positions performed within the ankle joint and foot (mainly plantar flexion) on the changes of these structures is not yet clarified, therefore we would like to contribute to knowledge in this field.

In our research we focused only on a group of female gymnasts, as mechanical load of movement apparatus is different in men. Regarding foot, there are differences in parameters of shape and dimensions between men and women (Hong, Wang, Xu & Li, 2011), therefore it is advisable to deal with this issue for each sex separately.

The aim of the paper is to analyze the condition of longitudinal plantar arch and its characteristics, in female artistic gymnasts of high performance of Czech Republic. Based on the aim we formulated the following research questions: How is plantar arch height related to duration of gymnastic practice? How is BMI value related to condition of plantar arch? Is there a difference between preferred and non-preferred foot in condition of longitudinal plantar arch?

METHODS

Participants

With respect to the defined aim the tested group was created by an intended selection of female artistic gymnasts of various age categories, all being at a high performance level. It means that all of this group are included in the elite competition program of the Czech Republic.

As the research group included 52 artistic gymnasts with a range of age from 8 to 28 years old, we divided them according to categories in which they compete – minor: from age 8 to 12 (N = 19), junior: from age 13 to 15 (N = 18) and women: from age 16 to 28 (N = 15). The tested persons underwent the measurements at the Championship of the Czech Republic which took place in Brno in 2015, which met our requirements that the tested persons should at a high performance level. A questionnaire and basic measurements were used to acquire the overview of essential characteristics of individual gymnasts. These were processed into a table 1 according to age categories - minors, juniors and women. It is observed that with the increasing age height and weight changes. We can see that BMI increases from 15.8 in minors to 18.5 and then 21.4 in women. With increasing age also increases the duration of gymnastic practise which is understood as a period of continuous specialised gymnastic preparation during a number of years. The number of training units per week does not increase with the duration of practice, the biggest training load was found in juniors who train 21.7 hours a week in average. From the total number of tested gymnasts 29 use right leg as a preferred take-off leg, 23 use left leg as preferred.

Table 1

Basic characteristics of the research group, DTP = duration of training practice in years, T/h/t = number of training hours a week, pref. = lower extremity preferred as a take-off leg, R = right, L = left.

	age	height/m	weight/kg	BMI	DTP/years	T / h/t	pref.
Minor N = 19	10.74 ± 1.21	1.36 ± 0.10	29.43 ± 4.96	15.83 ± 0.97	5.58 ± 0.99	18.00 ± 1.30	13R : 6L
Junior N = 18	14.28 ± 0.80	1.55 ± 0.07	44.24 ± 6.49	18.46 ± 1.74	9.61 ± 1.46	21.72 ± 1.41	8R : 10L
Women N = 15	19.40 ± 3.28	1.62 ± 0.04	56.00 ± 5.87	21.39 ± 1.94	13.27 ± 2.95	20.23 ± 1.69	8R : 7L

Instruments

The emed-at system belongs to the family of Novel pedography measurement platforms. This system functions as all the scientific emed platforms with calibrated capacitive sensors. The sensor area is 360x190 mm^2, number of sensors 1377, pressure range 10 – 990 kPa, accuracy 7 % ZAS, hysteresis less than 3 %. The frame rate used was 50 Hz.

The features works with Windows 2000 and XP operating systems and measure foot pressure in static and dynamic mode accurately. The system starts recording automatically when the subject´s foot touches the platform. The emed-at software collects and displays the plantar pressure measurement from the emed-at platform. (Novel, 2008)

Procedures

The measurement itself was performed during a single day at Sokol Brno 1 in a reserved room. In order to acquire correct results, the area around the platform was levelled into the same level as the platform using accessory pads. The system enables both static and dynamic measurements, considering our topic we decided for a static mode, measurement in standing position. Right and left feet were measured individually. A proband stepped on the accessory pad with a non-measured foot and after the measurement started he stepped on the measuring platform with the second foot. The proband remains in this standing astride position with parallelly positioned feet and weight distributed equally between legs for 20 seconds. If the proband overstepped or significantly transferred weight to one foot, the measurement was repeated.

Data analysis

Data from paper questionnaires were transferred to Excel tables, BMI (body mass index) was calculated.

Data acquired by Emed system were processed as follows. In order to gain precise data, only 10s from the 20 seconds-long-recordings were used, so that it does not include data when the proband was stepping onto the platform or was balancing his position. From these 10 seconds an average plantograph was exported, average values of forces between the measured foot and platform, average plantar pressure as well as average area of contact between foot and platform. These data were exported into excel. The acquired plantographs were then processed in a graphic programme Microsoft Visio 2013 in which all necessary lines and dimensions were measured. The method Chippaux-Šmiřák was used to evaluate the data. This method is considered appropriate mainly due to a fact that other methods focus on evaluation of flat plantar arch, while Chippaux-Šmirák method differentiates among three grades of high plantar arch. The measured parameters were then evaluated according to norms according to Klementa (1987) who differentiates three grades of flat arch, three grades of normal arch and three grades of high plantar arch.

The study group in this research consisted of female gymnasts aged 8 to 28 years, therefore the lengths of feet differed also due to age differences. When determining the type of plantar arch, Chippaux-Šmiřák method is based on ratio of two dimensions, therefore different foot lengths do not influence the results. In order to be able to compare high plantar arches also with different foot lengths in gymnasts of different ages, we calculated relative sizes of gaps between the front and back parts of plantographs with regard to length of foot. As we dealt with this problem during data processing, the standard data about gymnasts´ feet length was not available. From this reason we determined foot length from plantographs, a distance from a dorsal part of heel print and a print from the area of second metatarsus was measured. Fingers could not be used for calculations as in some probands these were not printed.

Statistical analysis

The acquired data were evaluated using mathematics-statistical methods in *Microsoft Excel* and *Statistica 12* programmes. For individual variables basic statistical characteristics were calculated. The normality of acquired data was tested using Kolmogorov-Smirnov test ($p = 0.05$), therefore Person correlation coefficient ($p = 0.05$) was used for other calculations. Values of correlation coefficients were interpreted according to Gerylovová and Holčík (1990). In order to verify other relations, analysis of variance was calculated with a following post-hoc Scheffe test (p = 0.05).

RESULTS

Plantar arch height

Several data were evaluated for analysis of plantar arch. We measured the necessary dimensions of plantographs using Chippaux-Šmirák method and obtained indexes which were then evaluated according to norms by Klementa (1987). In the following tables 2, 3 and 4 are listed the measured distances between the frontal and dorsal area of foot in contact with platform (dist/cm), in normal feet also indexes calculated from the measured distances (i), for each foot therefore a single numeral data. Then, the tables include word evaluation of plantar foot arch by Klementa norms (1987) according to calculated indexes - flat foot (L), normal foot (N), slightly high foot (SH), middle high foot (MH) or very high (VH). In attempt to precisely compare condition of plantar arch among individual gymnasts, mainly in high arch, the data about the length of the gap were converted into relative distances with regard to the length of foot (length). The length of foot was measured in cm as a distance of dorsal print of heel and print of foot in area of second metatarsus.

Category of schoolgirls - minors

Table 2 shows foot parameters in schoolgirl gymnasts. For total number of 19 schoolgirls we measured 38 feet in which no flat foot (pes planus) was found, 1 foot had normal longitudinal foot arch, 37 feet had high plantar arch, out of which 5 were middle high and 32 were very high plantar arch. In high feet the average distance between the areas of contact with platform was 4.7 cm in preferred foot and 4.3 in non-preferred foot. After converting the distances to relative distances we got 0.39 for preferred foot and 0.36 for non-preferred foot. The last two columns of tables 2 - 4 include the relative length of gap, resp. distance with regard to foot length for preferred (PREF dist/length) and non-preferred foot (N PREF dist/length).

Table 2

Metric data on foot in a group of schoolgirls gymnasts - minors (average, SD, min and max are in columns listing distance included only in high feet).

MINORS (N = 19)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	4.656	4.305	11.779	12.005	0.391	0.357
SD	1.137	1.187	0.895	0.930	0.082	0.088
min	1.800	2.200	10.000	10.000	0.158	0.182
max	6.200	6.200	13.400	13.700	0.480	0.463

Juniors

In juniors from the total of 36 measured feet were 2 normal feet, 1 slightly high foot, 5 middle high and 28 very high plantar foot arches (tab. 3). In high feet the average distance between the areas of contact with platform was 4.2 cm in preferred foot and 4.6 in non-preferred foot. The average length of preferred and non-preferred feet was, as assumed, almost the same - 12.9 cm and 13 cm. Relative value of distance was in average 0.33 in preferred and 0.35 in non-preferred foot.

Table 3
Metric data on foot in a group of junior gymnasts (average, SD, min and max are in columns listing distance included only in high feet).

JUNIORS (N = 18)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	4.235	4.612	12.906	12.956	0.329	0.357
SD	1.621	1.273	0.638	0.638	0.125	0.094
min	1.000	1.600	11.800	11.900	0.077	0.131
max	6.200	6.100	13.900	13.900	0.488	0.462

Category of women

Number of feet measured in this category was 30 (tab. 4). Out of the 30, 12 feet had normal arch, 4 had slightly high arch, 4 middle high and 10 very high foot arch. The relative distance in the limited number of high feet was 3.3 in preferred and 3.8 in non-preferred foot. The average length of the whole group was almost the same in preferred and non-preferred foot - 13.2 and 13.1 cm. Relative length on the gap was the same for both feet - 0.27.

Table 4
Metric data on foot in a group of gymnasts - women (average, SD, min and max are in columns listing distance included only in high feet).

WOMEN (N = 15)	PREF distance [cm]	N PREF distance [cm]	PREF length [cm]	N PREF length [cm]	PREF dist/length	N PREF dist/length
average	3.330	3.788	13.227	13.140	0.267	0.271
SD	1.095	1.355	0.584	0.448	0.092	0.094
min	1.200	1.500	11.800	12.100	0.102	0.124
max	4.800	4.900	14.100	13.900	0.384	0.386

The above listed data are supplemented with an overview table 5 with the share of individual types of plantar arches in minors, juniors and women competing is artistic gymnastics.

Table 5
Share of types of longitudinal plantar arches in individual categories of gymnasts according to Klementa norms, PREF = preffered leg, N PREF = non preffered leg, N = normal foot, SH = slightly high foot, MH = middle high foot, VH = very high foot.

	MINOR N = 19		JUNIOR N = 18		WOMEN N = 15	
	PREF/ Klem	N PREF/ Klem	PREF/ Klem	N PREF/ Klem	PREF/ Klem	N PREF/ Klem
N	1	0	1	1	5	7
SH	0	0	1	0	2	2
MH	2	3	3	2	3	1
VH	16	16	13	15	5	5

Results of static measurements

In the following part we present the results of static measurements in a standing astride position with one foot placed on a platform in which we recorded the average force by which the foot acted on a platform, average pressure and average size of area which was in contact with platform.

Table 6 presents an overview of average values and standard deviations of these parameters. This table is complemented by a graph (fig. 1) showing how increasing age, i.e. Change in category, changes the individual parameters.

Table 6
Results of statistical measurements.

		PREF F [N]	N PREF F [N]	PREF p [kPa]	N PREF p [kPa]	PREF S [cm^2]	N PREF S [cm^2]
MINOR	average	150.712	152.256	102.632	104.298	43.684	38.219
	SD	31.776	34.154	32.220	23.052	15.814	6.837
	MIN	102.933	77.500	60.000	66.667	29.500	23.333
	MAX	235.867	205.800	193.333	155.000	105.333	48.167
JUNIOR	average	251.383	241.589	155.278	164.167	51.676	49.269
	SD	44.165	38.652	40.240	49.242	9.189	7.753
	MIN	171.033	178.500	73.333	95.000	29.167	39.000
	MAX	319.433	298.200	251.667	268.333	66.000	66.833
SENIOR	average	315.198	319.284	130.778	135.444	65.733	64.055
	SD	33.215	53.790	30.562	33.602	7.762	8.673
	MIN	253.167	247.300	78.333	88.333	51.500	48.500
	MAX	363.633	449.267	205.000	206.667	77.000	80.333

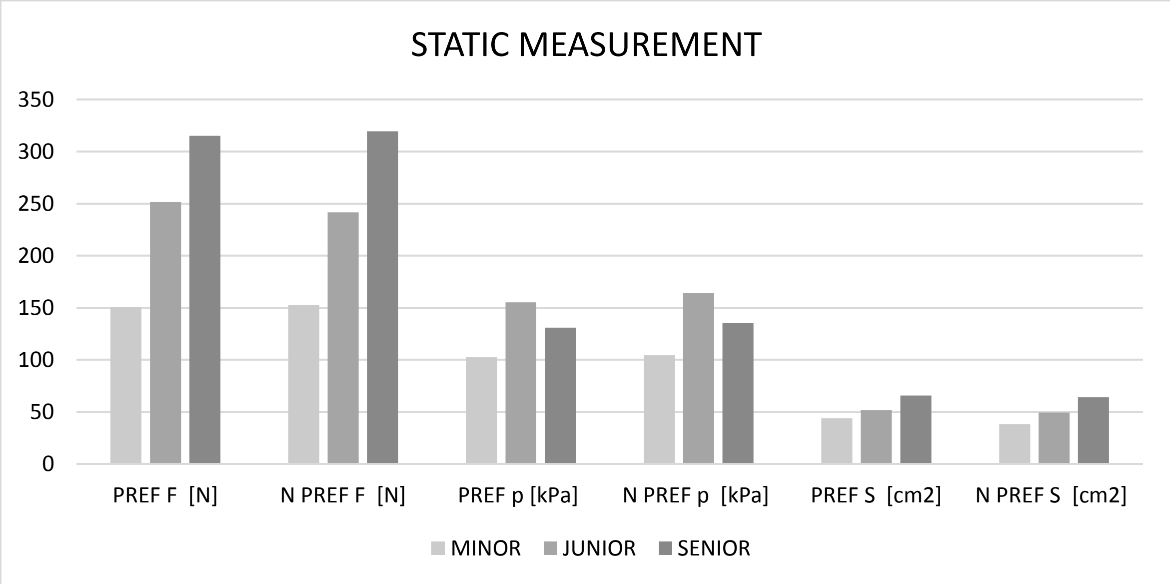

Figure 1. Comparison of results of static measurements among age groups.

With regard to measured values of force in the category of women it should be noted that with increasing forces acting on platform compared to younger categories standard deviation does not increase directly. From the point of view of this parameter women appeared as more homogeneous group. With the increasing age increases also the force acting on platform as well as size of area of foot which is in contact with platform. Different situation is with pressure which increases from minors to juniors, but decreases in women to its lowest values. From the relationship p = F / S it can be derived that if with growing force increases also area, pressure will not increase so much as the acting force is not concentrated into small area, it is dispersed. The results prove this assumption, values of pressure in women (131 kPa and 135 kPa) are lower compared to category of juniors (155 kPa and 164 kPa).

DISCUSSION

In most gymnasts, more specifically in 89 measured feet out of 104, which is in 86 %, high foot arch was found. Out of these 5 were slightly high, 14 were medium high and 70 were very high. Using Pearson correlation coefficient (p = 0.05) a statistically significant relation (r = - 0.47) was found between the length of gymnastic practice and longitudinal foot arch height, which can be interpreted as a medium dependency (Gerylovová & Holčík, 2009). This research was not conceived as a longitudinal study, therefore we don't know "departure values" for the older gymnasts. However, the statistical result points to a tendency to decrease the longitudinal foot arch height with the increasing duration of intensive regular specific exercise of lower extremities, which should be verified in further studies.

In order to clarify the calculated medium strong dependency we calculated the analysis of variance and post-hoc Scheffe test (p = 0.05) which was used to compare how big will be the difference between foot arch height among individual categories which strongly correlate with duration of gymnastic practice (r = 0.85). As shown in table 7, statistically significant difference in foot arch height was proved only between the group of minors and women (p = 0.000).

Table 7
Scheffe test for a variable "foot arch height" transformed into a scale according to Klementa.

	Scheffe test; variable:scale (group characteristics) Highlighted diferrences are significant on a level p < .050		
Prom1	{1} (M=6,790)	{2} (M=6,778)	{3} (M=5,400)
minor {1}		0.998	0.000
junior {2}	0.998		0.000
women {3}	0.000	0.000	

The results show that with the increasing duration of gymnastic practice the foot arch height decreases, these changes, however, are not too significant and rapid as significant difference was proved only between the youngest and oldest groups of gymnasts, i.e. between minors and women.

Regarding the second research question we investigated the relationship between BMI and longitudinal foot arch condition. Due the fact that indexes for normal and high foot arch cannot be calculated together as they depend on different dimensions, we transformed the resulting indexes Chippaux-Šmiřák into a scale norms according to Klementa. For the relationship between BMI and condition of foot arch according to the scale a correlation coefficient of r = - 0.51 was found, i.e. medium strong relation between the variables. However, the data transformation means loss of data, therefore we performed one more calculation of Pearson correlation coefficient (p = 0.05) in which only high foot arch data were included. A close relationship between BMI and relative distance in high feet arch was not proved (r = -0.3). This value is statistically significant, however, we cannot consider it explicitly conclusive from the factually-logical point of view. The results can be explained in a way that with increasing BMI foot arch is decreasing (r = - 0.51), however, the relationship is not sufficiently strong, smaller differences between indexes of foot arch feet are not significant enough to correlate with BMI changes.

We were also interested in differences between parameters of preferred and non-preferred leg. As shown in Table 8, there was no statistically significant difference proved between parameters of preferred and non-preferred foot based on T test of variables (p = 0.005) either in parameter "foot arch height transformed into the scale" (p = 0.44), nor when we included only high foot arch data and compared "relative distance of areas of contact of foot with platform" (p = 0.91). The only statistically significant difference was found only in parameter "average areas of contact of foot with platform" (p = 0.03).

Table 8
Evaluation of differences between parameters of preferred and non-preferred leg.

	T-test for dependant variables (group characteristics) Highlighted parameters are significant on a level of p < ,0500									
Variable	Average	SD	N	Difference	SD of the difference	t	sv	p	Int. of reliability (-95.000%)	Int. of reliability (+95.000%)
Distance/length pref	4.364	1.406								
Distance/length non-pref	4.386	1.238	42	-0.021	1.261	-0.110	41	0.913	-0.415	0.372
Scale pref	6.423	1.017								
Scale non-pref	6.346	1.118	52	0.077	0.710	0.782	51	0.438	-0.121	0.275
Area pref	52.811	14.876								
Area non-pref	49.497	13.057	52	3.314	10.846	2.203	51	0.032	0.294	6.334

Another calculation of Pearson correlation coefficient r = 0.55 proves a medium strong relationship between area of contact of foot with platform and foot arch height expressed by scale. If we take into consideration only high foot arch data, for relationship between area of contact and relative distance of contact areas we get correlation coefficient r = - 0.31. However, as stated above, in one parameter there was a difference between preferred and non-preferred leg and in the second one there was no difference, as shown in graphs fig. 2 and fig. 3.

We performed qualitative assessment of acquired plantographs in order to find out why there is no decrease in foot arch height, or distance between contact areas, with increasing contact area in preferred legs compared to non-preferred legs. We found out that contact area in preferred legs is bigger compared to non-preferred legs mainly due to bigger contact area of fingers and wider contact area of metatarsal region. We did not observe any significant increase in contact area within longitudinal foot axis, which explains the fact that with change in size of contact area of foot the foot arch height does not proportionally change. We are of opinion that frequent use of one leg as a preferred leg results in bigger involvement of fingers participating in plantar flexion during take-off phase compared to non-preferred foot.

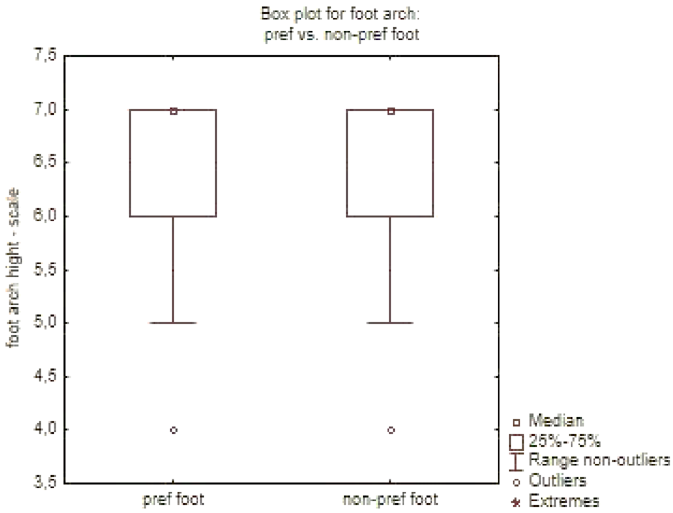

Figure 2. Box diagrams for foot arch height in preferred and non-preferred leg.

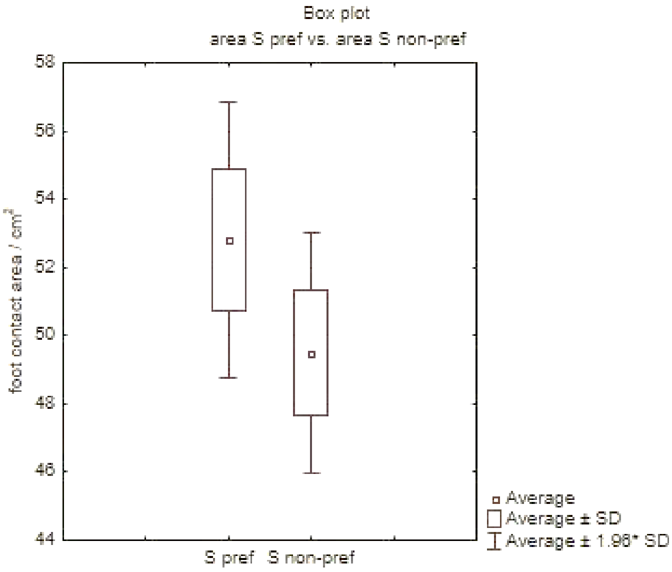

Figure 3. Box diagrams for contact area in preferred and non-preferred leg.

The results show that female gymnasts mostly have high longitudinal foot arch. This finding is in agreement with the results of previous studies (Aydog et al., 2005; Aydog, Tetik, Demirel & Doral, 2005) in which the authors found out that foot arch height in gymnasts is significantly higher compared to the control group which included handballer players, weightlifters, football players and wrestlers. It seems that high foot arch is formed already during childhood based on gymnastic load of lower extremities as it can be observed already in the youngest age category. Forriol a Pascual (1990) state that in normal population aged 12 - 14 foot arch is at its highest, then its height decreases. This decrease can be observed also in our research group when with increase in BMI during adolescence foot arch height decreases. Regarding the fact that the work was not framed as an experiment, we can state that it is the influence of gymnastic training and BMI changes that influences changes of foot arch. Changes in foot arch condition can be observed also in normal population without any extreme load (Forriol & Pascual, 1990). However, we can state that high foot arch is a frequent condition in female artistic gymnasts.

Similarly as Aydog et al. (2005) state that foot muscles affect development of foot arch, also we think that frequently actively performed plantar flexion within gymnastic exercises influence musculoskeletal structure of foot. As obvious, muscles performing plantar flexion are considered muscles that are responsible for foot arch support. As stated in Čihák (2001), these are muscles supporting longitudinal foot arch: musculus tibialis posterior which supports the heighest place of arch, musculus flexor digitorum longus, musculus flexor hallucis longus and superficial short muscles of foot. There is also superficial ligamentous layer of a tendinous character (aponeurosis plantaris), which is grown into musculus flexor digitorum brevis, and a tendinous stirrup which is used by musculus tibialis anterior to strain the edge of foot upwards. It should be noted that during normal load (standing, walking) these muscles are not activated, they are activated and contracted during load other than walking, as shown by electromyographic studies (Dylevský, 2003). We think that load acting on foot during gymnastic exercise, mainly during landing (Soriano, Belloch & Alcover, 2007), have sufficient intensity to activate muscles supporting foot arch, which leads to high foot arch condition in gymnasts. Similarly as flat foot, also high foot may be a reason of injury, mainly fractures of lower extremities (Cowan, Jones & Robinson, 1993; Simkin et al., 1989). Exercise for both flat and high foot are based on stretching and strengthening of long extrinsic muscles and short intrinsic muscles (Rose, 1992). Therefore it is advisable to include also compensatory stretching exercises of overloaded foot arch muscles into gymnastic preparation, which may act as a prevention of injury of lower extremities which are very frequent in artistic gymnastics (Mills, Pain & Yeadon, 2006; Vormittag, Calonje & Briner, 2009 and other).

CONCLUSIONS

The results of our research has shown that the high foot arch - either of mild or severe level - was present in 86% of measured gymnasts. We suppose that this finding in measured group is important for both sport persons and their coaches, despite we have seen no statistically important dependencies between variables according to our measurements. We suggest to include a stretching of plantar flexors of foot into the training practice. These compensatory exercises should serve among other purposes also as a prevention of injury of lower extremities.

We suggest to perform also a longitudinal study, in which repeated measurements would be performed over time in order to measure foot arch in gymnasts and control group to prove the influence of gymnastic load on these musculoskeletal changes. These measurements could also be performed in younger gymnasts, because our youngest tested gymnasts - juniors already have very high foot arch.

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ACUTE EFFECTS OF PROLONGED STATIC STRETCHING ON JUMPING PERFORMANCE AND RANGE OF MOTION IN YOUNG FEMALE GYMNASTS

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Original article

Abstract
This study examined changes in countermovement jump (CMJ) height and hip and knee joint range of motion (ROM), after an acute bout of prolonged static stretching. Nineteen, female "Gymnastics for All" gymnasts (age: 9.8±0.5 years, training experience: 2.5±1.5 years, height: 135.0±7.3cm, body mass: 33.4±6.9 kg) performed 90s of quadriceps stretching. A single-leg stretching and jumping design was used, with the contra-lateral limb serving as control. One-leg CMJ performance for the stretched and the control leg and two-legs CMJ were measured after warm-up, and 2 min post-stretching. ROM of the stretched leg was measured before and after stretching. One-leg CMJ height remained unchanged for both the stretched (pre: 7.4±1.7, post: 6.9±1.8 cm) and the control leg (pre: 7.0±1.7, post: 6.7±2.1 cm), as shown by the lack of main effects for time (pre vs. post: p= 0.278), leg (stretched vs. non-stretched leg: p= 0.207), and interaction (p= 0.444). Two-legs CMJ also remained unchanged (pre: 16.9±3.1, post: 16.3±3.4 cm, p=0.186). Hip joint ROM increased after stretching (pre: 16.3±3.7, post: 18.2±4.2^{o}, p=0.002), while knee joint ROM remained unchanged (pre: 26.6±2.7, post: 25.9±3.0^{o}, p= 0.218). Prolonged static stretching increases ROM, but has no negative effect on CMJ performance in very young, flexibility-trained female gymnasts.

Key words: *youth sports, flexibility, muscle power, warm-up, gymnastics.*

INTRODUCTION

The aim of a warm-up prior to training and competition is to optimize subsequent performance and prevent injuries (Chaouachi et al., 2010; Haff, 2006). Warm-up is typically composed of a submaximal aerobic activity, stretching of major muscle groups, and sport-specific exercises (Taylor, Sheppard, Lee, & Plummer, 2009). Stretching, following submaximal aerobic activity, has been shown to further increase range of motion (Magnusson & Renström, 2006) and to enhance performance (Young & Behm, 2002) while recent research has shown that pre-activity stretching may also be beneficial for injury prevention (Behm, Blazevich, Kay, & Mc Hugh, 2015).

A large number of previous studies in adults, demonstrated that prolonged static stretching (total duration > 45 s) may acutely reduce the ability of the stretched muscles to generate power output (Behm & Chaouachi, 2011; Kay & Blazevich, 2012). This stretch-induced power loss has been attributed to neuromuscular inhibition (Magnusson, 1998), and increased muscle-tendon compliance (Kay, Husbands-Beasley, & Blazevich, 2015; Morse, Degens, Seynnes, Maganaris, & Jones, 2008). Nevertheless, the negative effect of static stretching on muscle power is transient and largely depends on the stretching protocol characteristics (e.g. duration and intensity of each stretch, stretch position and muscle group) (Apostolopoulos, Metsios, Flouris, Koutedakis, & Wyon, 2015; Bogdanis, Donti, Tsolakis, Smilios, & Bishop, 2017; Lima et al., 2016). Some authors reported that the negative effect of static stretching is restored in a short-time following stretching. For example, Mizuno, Matsumoto and Umemura (2013) examined maximal voluntary contractions immediately, 5, 10, 15 and 30 min following 5 min of static stretching in adult, female participants. The authors reported decreased maximal voluntary contraction torque immediately after, and 5 min post-stretching however, this decrement recovered 10 min post-stretch.

Flexibility, is a performance determinant in sports requiring the ability to move in a ‘fluid’ and unconstrained manner through a large range of motion (ROM), like gymnastics and dance (Sands, 2002). Childhood is a key time to develop flexibility, with the age range between 6 to 11 years proposed as a sensitive period for morphological changes (Malina, Bouchard, & Bar-Or, 2004). However, data on stretching interventions in youth sports are limited (Donti et al., 2017; Kinser et al., 2008; Sands et al., 2016). Some studies that examined the acute effect of static stretching on jumping performance in adolescent athletes reported muscle power reduction following stretching (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; Di Cagcno et al., 2010; McNeal & Sands, 2003; Sands, McNeal, & Stone, 2009). A previous study that examined the acute effect of static stretching on muscle power, in child-gymnasts (Siatras, Papadopoulos, Mameletzi, Gerodimos, & Kellis, 2003) reported that 2 x 30 s of lower limb static stretching, decreased mean running speed for a handspring vault in young male gymnasts (9.8 ± 0.8 years).

For young gymnasts, the ability to generate muscle power is essential for executing acrobatic flight elements on all the apparatuses (Arkaev & Sutsilin, 2004). Increased joint ROM is equally important for technical execution (Karpenko et al., 2003) and prolonged static stretching bouts (60-90 s or more) are typically used before training or competition to enhance joint ROM (Karpenko et al., 2003; Matsuo et al., 2013). However, prolonged stretching may temporarily decrease muscle power and thus, the conflicting effects of prolonged stretching during warm-up for practice or competition, (i.e. increase in ROM and reduction in power), need to be further examined in young gymnasts. Thus, the purpose of the present study was to examine changes in one and two-legs countermovement jump (CMJ) performance and hip and knee joint range of motion (ROM), 2 min after an acute 90 s bout of static stretching, in 9-11 years old female gymnasts.

METHODS

Nineteen “Gymnastics for All”, female gymnasts, (age: 9.8±0.5 years, training experience: 2.5±1.5 years, height: 135.0±7.3 cm, body mass: 33.4±6.9 kg), were assessed for eligibility. The eligibility criteria were: training experience (1-3 y) and no history of lower limb injuries for the past six months. Gymnasts trained three times a week for 90-min each time. Gymnastics training involved general and special physical conditioning, as well as technical preparation on the apparatuses. The physical conditioning part was aimed to improve strength and power, flexibility and muscular endurance. This part contained, exercises using body weight, strength oriented gymnastic skills and combinations of skills. During this time, the gymnasts also competed in order to qualify for the gold, silver or bronze team, according to the International Gymnastics Federation Gymnastics for All Rules and Regulations (2009). Before participating in the study, the subjects and their parents were fully informed about the testing procedures to be used, the purpose and risks of this study, confidentiality, anonymity, and the right to terminate participation at will. In addition, written parental consent was obtained for each participant. The procedures of the study were approved by the local Institutional Ethics Committee and complied with the ethical standards for research involving human participants set by the Declaration of Helsinki.

The current study required the participants to complete two testing sessions at their training facilities, performed two days apart. Twenty-four hours prior to performing the main testing sessions, the gymnasts were asked to avoid any strenuous activity. The first testing session included anthropometric measures and familiarization with the testing procedures. At the end of the familiarization session, two efforts of the CMJs and hip joint ROM were recorded to calculate intra-class correlation coefficients. At the start of the second session, and following 5 min jogging at a moderate intensity (50-60% of age-predicted maximal heart rate), gymnasts underwent a series of tests in the following order: one-leg CMJ height, two-leg CMJ height, baseline hip and knee joint ROM measurement, 90 s of continuous static stretching, post-stretching hip and knee joint ROM measurement, and, 2 min after stretching, one-leg CMJ height and two leg CMJ height (Figure 1). During the 2-min recovery time following stretching, the gymnasts remained standing, and inactive. The assignment of the “stretched” and “control” leg was random and counterbalanced.

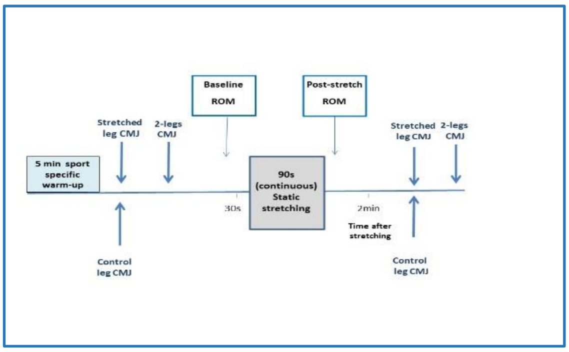

Figure 1. Schematic representation of the study protocol.

Anthropometry was assessed in the familiarization session. Standing height was measured to the nearest 0.1 cm with the use of a stadiometer and body mass was measured to the nearest 0.1 kg with a calibrated digital scale (Seca 208 and Seca 710, Hamburg, Germany).

The gymnasts performed 90 s of continuous static stretching of the quadriceps of one leg. This total stretch duration was chosen on the basis of its effectiveness on ROM enhancement (Magnusson, Simonsen, Aagaard, Sørensen & Kjaer, 1996) and its widespread use in the training practice of gymnastics (Arkaev & Sutsilin, 2004).

The main testing session included 90 s of continuous static stretching of one leg (stretched leg) while the other leg served as control and received no stretching treatment (control leg). The assignment of the gymnasts’ legs to “stretched” and “control” was done in a random and counterbalanced manner so that half of the subjects performed the stretching protocol on their left leg and the rest on their right leg.

The prone quadriceps stretch (hip extension combined with knee flexion while lying on a prone position on a mat), with force applied by an investigator to the point of discomfort, was the movement used to stretch the hip flexors and knee extensor muscles of the one leg. Gymnasts were familiar with this stretching manoeuver, as they performed it regularly in their training sessions (Figure 2).

During testing, participants laid face down on the floor and flexed their knee. At the point of maximum knee flexion, an experienced investigator pushed their heel towards their hips, and their thigh upwards while keeping the gymnasts' hips firmly down on the floor to avoid pelvic tilt (Figure 2). The stretch intensity was determined based on the feedback from the subjects to ensure that stretch achieved the point of discomfort (rating 90 to 100, indicated by the gymnast on a visual analogue scale of 0-100). Based on the same procedure used in prior investigations (Behm & Kibele, 2007) the gymnasts were informed that 0 represented "no stretch discomfort at all" and 100 represented "maximal stretch discomfort". Stretching of the one leg took 90 s and 2 min after, the athletes performed one- and two-legs CMJ (in total ~ 4 min between jumps).

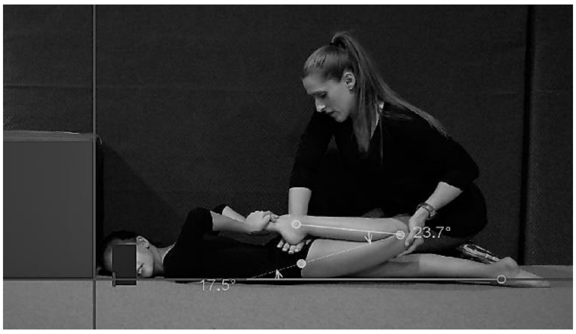

Figure 2. Prone quadriceps stretch manoeuvre.

Range of motion was measured using reflective motion analysis markers placed on the following anatomical marks: hip (trochanterion), knee (femur-tibia joint line) and ankle (lateral malleolus). The position of the markers was recorded using a digital camera (Casio Exilim Pro EX-F1) placed perpendicular to the plane of motion of the leg, and hip and knee angles were calculated using free software (Tracker 4.91 © 2016 Douglas Brown). Hip joint ROM was defined as the angle between horizontal and the line joining the hip and knee markers. Knee joint ROM was defined as the angle between the line joining the hip and knee markers and the line joining the knee and ankle markers (Figure 2).

In all the testing sessions CMJ height was assessed using an electronic contact mat (Boscosystem® Chronojump) for the stretched and the control leg and the two-leg jump immediately (10-15 s) after warm-up, and 2 min post stretching (Fig. 1). Two efforts were given for each jump after warm-up, and the best value was recorded for further analysis. Two minutes post-stretching, only one attempt was permitted for each jump. The order of the jumps was balanced so that half of the athletes performed the one-leg CMJ with the stretched and the other half with the control leg first. The subjects were instructed to perform a maximum effort and 'jump as high as possible' with their hands on their hips and while keeping the free leg hanging parallel to the jumping leg and flexed on the knee throughout the jump. For the one- and two-legs countermovement jump, subjects performed a countermovement until their knees were bent at approximately 90°, and then immediately jumped up. Body configuration was required to be the same during take-off and landing. Three criteria were adopted for a valid jump: a) correct body posture during flight, b) jumping straight up with no side to side or forward movement, and c) soft landing, including toe to heel rocking and progressive bent of the knees.

Statistical analyses were carried out using SPSS (IBM SPSS Statistics Version 22.0). The normality of data distribution was checked with the Shapiro Wilk's test. The acute effect of the stretching protocol on one leg CMJ height was examined by 2-way ANOVA with repeated measures on both factors (leg x pre-post) and a Tukey HSD test. Paired *t*-test examined pre- and post-stretching changes in hip joint ROM and two-legs CMJ height. Effect sizes (ES) for the ANOVA were determined by partial eta squared (η^2) (small: 0.01 to 0.059, moderate: 0.06 to 0.137, large >0.138). For pairwise comparisons, ES was determined by Cohen's d (trivial: 0–0.19, small: 0.20–0.49, medium: 0.50–0.79 and large: 0.80 and greater) (Cohen, 1992). The intra-class correlation coefficient (ICC) was used as a measure of test-retest reliability (Hopkins, Marshall, Batterman, & Hanin, 2009), for the variables examined in this study, and was determined by using a 2-way mixed model. Additionally, the standard error of measurement (SEM) was calculated as the square root of the mean square error term from the ANOVA and was expressed both as an absolute value and as a percentage of the participants' mean scores (coefficient of variation) (Weir, 2005).

Statistical significance was accepted at $p<0.05$.

RESULTS

Test-retest reliability for the one-leg CMJ and knee joint ROM was high (ICC=0.79, p<0.01; SEM=2.3 cm; CV=0.23%, and ICC=0.84, p<0.01; SEM=2.5° CV=0.9%, respectively). For the two-leg CMJ and hip joint test-retest reliability was excellent (ICC=0.93, p<0.01; SEM=2.3 cm; CV=0.19%, and ICC=0.94, p<0.01; SEM=2.3°; CV=0.21%, respectively).

Table 1
One-leg and two-legs counter movement jump (CMJ) height in the stretched and control leg and hip and knee joint range of motion (ROM) pre- and post- 90 s of static stretching (n=19).

	Pre-stretching	Post-stretching	Cohen's *d*	p
One-leg CMJ (cm) Stretched leg	7.4±1.7	6.9±1.8	0.29	0.207
Control leg	7.0 ±1.7	6.7±2.1	0.16	0.278
Two-legs CMJ (cm)	16.9±3.1	16.3±3.4	0.19	0.186
Hip ROM (°) Stretched leg	16.3±3.7	18.2±4.2	0.49	0.002
Knee ROM (°) Stretched leg	26.6±2.7	25.9±3.0	0.25	0.218

One-leg CMJ height remained unchanged post stretch for both the stretched and the control leg as shown by the lack of main effects (p= 0.207, η^2=0.087 and p= 0.278, η^2=0.065 for pre-post stretch and leg, respectively) and interaction (p= 0.444, η^2=0.033) (Table 1). Two-leg CMJ also remained unchanged post stretch (p= 0.186). Hip joint ROM increased significantly post-stretching by 13%, while knee joint ROM remained unchanged (p= 0.218) (Table 1).

DISCUSSION

The aim of this study was to examine changes in one- and two-legs CMJ height and hip joint ROM, 2 min after an acute bout of 90 s of continuous static stretching in young female gymnasts. The main finding of this study was that jump height remained unchanged 2 min post-stretch for both the stretched and the control leg, as well as for the two-legs CMJ, while ROM significantly increased post stretching. The effect sizes for pre- and post-stretch changes in one-leg CMJ for the stretched and the control leg and the two-legs jumps were small (d=0.29, d=0.16, and d=0.19, respectively) indicating that in these flexibility-trained young athletes there is no negative effect of static stretching on jumping performance, despite the prolonged stretching duration.

A substantial body of research has demonstrated that prolonged static stretching (total duration > 45-60 s) may temporarily reduce maximal muscular performance in a dose dependent manner, (Behm, Blazevich, Kay, & Mc Hugh, 2015; Behm & Chaouachi, 2011; Kay & Blazevich, 2012; Trajano, Nosaka & Blazevich, 2017). In adult populations, stretch-induced force and power loss may be attributed to acute reductions in muscle and tendon stiffness (Morse et al., 2008) possibly due to the thixotropic behavior of the muscles (Axelson, 2005) and to neural changes causing an improved stretch tolerance (Magnusson, 1998, Weppler & Magnusson, 2010). However, evidence is limited on stretch-induced power loss in children and only a small number of studies examined muscle performance changes following static stretching in adolescents (Faigenbaum, Bellucci, Bernieri, Bakker, & Hoorens, 2005; Di Cagcno et al., 2010; Mc Neal & Sands, 2003). For example, Mc Neal and Sands (2003) reported significantly reduced flight time but not contact time during drop jump, following a total stretching time of ≈ 180 s in adolescent gymnasts (13.3 ±2.6 years), while Di Cagno et al. (2010) found reductions in gymnastics leaps flight time by 7%, following ≈ 10 min of static stretching (4 different lower body exercises x 3 times x 30 s), in 38 adolescent rhythmic gymnasts (14.1 ± 3.2 years).

Interestingly, all these studies, examined gymnasts' jumping performance immediately post-stretching, and to date there was no evidence about the magnitude and the duration of muscle power decrements following an acute bout of prolonged static stretching. The results of the present study, found no power deficit in the stretched leg, 2 min post-stretching, suggesting that a possible negative effect of static stretching is abolished shortly after the cessation of the stretching manoeuver. This suggestion is supported by the findings of Mizuno et al. (2013) who found decreased maximal voluntary contraction torque immediately after, and 5 min post-stretching, which was however, recovered 10 min post-stretch. In other studies where performance tests were conducted more than 10 min following stretching, performance decrements were small, unless extreme stretching duration protocols had been used (Behm, Blazevich, Kay, & Mc Hugh, 2015). For example, Power et al. (2004) found 9.5% and 5.4% decrements in quadriceps maximal voluntary and evoked force following 270 s of static stretching. In that study, force remained significantly decreased for 120 min (10.4%), while range of motion was increased (6%) (Power et al., 2004). The results of the present study showed an almost two-fold higher improvement in ROM (13%, *d*=0.49), while leg muscle power was not significantly changed (Table 1). This improvement in ROM with no negative effect on power output may be important for young gymnasts who train and compete after performing prolonged static stretching routines. In contrast, knee joint ROM remained unchanged post-stretching (p=0.218) probably because of the nature of the stretching movement: gymnasts' heel was touching their hips, before the upwards movement of the thigh.

The lack of stretch-induced jumping decrements in the present study may also be explained by the fact that these young gymnasts regularly applied stretching protocols of this duration during training. Previous studies in trained athletes, failed to detect impairments in muscle performance after static stretching (Chaouachi et al., 2010; Egan et al., 2006), or even reported enhancement of muscle work at longer muscle lengths and/or, if the duration of the stretching bouts was brief (≤30 s) (Bogdanis et al., 2017; Godges, Macrae, Longdon, & Tinberg, 1989). Therefore, it is proposed that flexibility trained athletes might be less susceptible to stretch-induced deficits than their unaccustomed counterparts (Chaouachi et al., 2010; Donti, Tsolakis, & Bogdanis, 2014; Egan, Cramer, Massey, & Marek, 2006). In addition, preadolescent children may be less susceptible to stretch-induced muscle power loss than adults or adolescents due to their decreased neuromuscular activation (Dotan, Mitchell, Klentrou, Gabriel, & Falk, 2012) and to the increased pliability of the musculotendinous tissue during childhood (Rumpf, Cronin, Oliver, & Hughes, 2013). For example, Rumpf, Cronin, Oliver, and Hughes, (2013) found that prepubertal athletes have more pliable musculotendinous tissue than older athletes and this may reduce the negative effects of stretching, while positively affecting the energy storage in slow stretch shortening cycle movements, such as a one-leg CMJ (Komi, 1999). Similarly, Kubo, Kanehisha, Kawakami and Fukunaga (2001), reported that the tendons of younger boys (10.8 ± 0.9 years) were more compliant than those of older boys (14.8 ± 0.3 years) and adults (24.7 ± 1.6 years).

A few previous studies have shown contralateral effects of stretching on the unstretched limb (Chaouachi, Padulo, Kasmi, Othmen, Chatra. Behm, 2017; Cramer et al., 2005). For example, Chaouachi et al (2017) reported similar increases in hip flexion in the stretched and the non-stretched limb (*d*=0.91 and *d*=0.69, respectively) following eight repetitions of 30 s of static stretching. In another study, Cramer et al., (2005) reported decreases in muscle activation from pre to post-stretch in both the stretched and the unstretched leg extensors, suggesting that the stretch-induced muscle power deficit could be related to a central nervous system inhibitory mechanism. However, in the present study, hip and knee joint ROM were not measured in the control leg as it was thought that any stretching maneuver and ROM measurement may affect subsequent jump height. Nevertheless, jumping height in the control leg was not changed from pre- to post intervention (p=0.278).

In the present study, a single stretching exercise of an important muscle group for jumping (i.e. knee extensors) was performed in order to examine changes in one-leg CMJ performance. The use of the other leg as a control allowed for the calculation of the net effect of static stretching on jumping performance. As the knee extensors contribute significantly (≈25-30%) to the total power output during jumping (Van Soest et al., 1985; Wong et al., 2016), any influence of stretching these muscles on vertical jump performance would be evident. In contrast with several studies that use a series of stretching exercises (e.g. quadriceps, hamstrings, calf muscles etc) with one or more sets for each leg separately, it was decided to use only one stretching exercise and perform single leg performance testing. This allows to assess the immediate effect of stretching a muscle group on muscle power in a movement that it has a significant contribution. In the case of stretching multiple muscle groups (e.g. quadriceps, hamstrings, calf muscles) in both legs with one or more sets for each, there is a long period between stretching of one muscle group (e.g. the quadriceps, if they are stretched first) and performance testing, while the order of stretching also influences the outcome. Thus, the effects of stretching one muscle on performance may diminish due to the time lapse between stretching and performance testing. Although the protocol used in the present study has the limitation of not stretching the hip and ankle extensors, which are major power generators during single leg jumping (Van Soest et al., 1985; Wong et al., 2016), it allows for a controlled timing of stretching and testing an important muscle group.

CONCLUSIONS

The results of this study demonstrated that an acute bout of continuous static stretching of 90 s increased hip joint ROM, but had no statistically significant effect on jumping height 2 min post stretch. Probably the long-term flexibility training and the increased musculotendinous pliability of young gymnasts may have contributed to prevent the transient decrease in strength and power typically seen after prolonged static stretching. Further research should examine the combination of static with dynamic stretching and/or potentiating exercises in preadolescent athletes in the context of a real-life training and competition setting.

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RELATIVE AND ABSOLUTE RELIABILITY OF ISOMETRIC AND ISOKINETIC SHOULDER MAXIMAL MOMENT AND FLEXION/EXTENSION RATIOS IN GYMNASTS

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Original article

Abstract

Shoulder strength is essential for gymnasts in order to succeed in their sport, but little research has examined isometric and isokinetic shoulder moment and flexion/extension ratios. The purpose of this study was to evaluate the relative and absolute reliability of isometric and isokinetic shoulder moment and shoulder flexion/extension ratios. Fifteen international level male gymnasts (age: 19.3 ± 2.3 years) participated in the study. Two identical measurements with one week interval were applied using the isokinetic Humac Norm 770 dynamometer at three angles (45º, 90º, and 135º) for isometric and at three angular velocities (60º/s, 180º/s, and 300º/s) for concentric and eccentric action modes. All measurements were conducted in a range of motion of 10º to 180º, in supine position, bilaterally, with the elbows fully extended. Notwithstanding a small systematic bias (due to testing/learning) from measurement 1 to measurement 2 significant in four parameters, the results supported the reliability of the measurements. Relative (a) and absolute (b) reliability values were ranged as follows: (a) intraclass correlation coefficient (ICC) 0.73 to 0.96 and (b) standard error of measurement (SEM)(%) (calculated using ICC) 3.4 to 11.2%, minimum detectable change (MDC)(%) 10.7 to 31.1%, SEM_e(%) (calculated using mean square error) 0.1 to 23.4%, MDC_e(%) 1.6 to 48.8%, and coefficient of variation (CV)(%) 8.6 to 17.8%. Bland-Altman analysis showed that the bias was lower than 10% and limits of agreement (LOAs) were lower than 35%. SEM_e(%) and MDC_e(%) were considered as more important and meaningful to detect any significant change between two measurements, or to detect muscle imbalances. Considering the limitations of the study, results from the present study provided assessment methods and normative data that could be very helpful for researchers and practitioners to evaluate the effectiveness of intervention programs aiming at the development of shoulder muscle strength.

Keywords: *Reliability, shoulder, isokinetics, flexion/extension ratio, gymnastics.*

INTRODUCTION

The shoulder joint plays a vital role in artistic gymnastics. Shoulder strength and flexibility are essential for gymnasts in order to achieve a safe performance with a high degree of aesthetic and technical mastery. Gymnasts use their arms extensively during their sport activity (Caine, 2003). During the execution of gymnastic skills, gymnasts use their arms in low angular velocities (e.g., flexion-extension of the shoulder during the swings in frontal position on the parallel bars) and high angular velocities (e.g., rapid shoulder flexion during the rise to the handstand during the upswing in a clear hip circle, rapid shoulder flexion during the first jumping back phase of the back handspring). The safe and effective execution of weight bearing skills requires supplementary strength of the arm muscles and stability of all contributing joints (Caine, 2003). Contrary to overhead throwing athletes who use their arms in an open kinetic chain, gymnasts use their upper extremities very often in closed kinetic chain skills with the hand supported on a floor, balance beam, or pommel horse (Cools, Geerooms, Van den Berghe, Cambier, &Witvrouw, 2007).

Isokinetic dynamometers make it possible to evaluate with good reliability muscle strength in the concentric or eccentric mode across a wide range of angular velocities (Ellenbecker & Davies, 2000; Mikesky, Edwards, Wigglesworth, & Kunkel, 1995; Walmsley & Pentland, 1993). Furthermore, isokinetic dynamometers can be used to assess the agonist-antagonist strength balance (conventional and dynamic control ratio), a significant index in terms of shoulder function and predisposition to shoulder pathology (Bak & Magnusson, 1997). However, some researchers have provided concerns about the reliability of isokinetic assessment of the shoulder, due to its complex kinematics and its relatively extensive mobility (Mayer, Horstmann, Kranenberg, Röcker, & Dickhuth, 1994; Plotnikoff & MacIntyre, 2002).

Over the past few decades, isokinetic muscle strength at the shoulder joint has been widely studied in muscle imbalance studies in swimming (e.g., Bak & Magnusson, 1997) baseball (e.g., Mikesky et al., 1995), water polo (e.g., McMaster, Long, & Caiozzo, 1992), and other overhead sports (e.g., Yildiz et al., 2006). Compared with other athletes, gymnasts use a unique kinetic chain during the execution of specific gymnastic skills, including specific muscle activation of the upper extremities. Adaptations in the shoulder muscles may influence the quality of the performance and the risk of injuries due to overuse (Cools et al., 2007). Because of the relevance of the kinetic chain during the execution of gymnastic skills using flexion-extension of the shoulder, isokinetic dynamometers provide the ability to reproduce and evaluate these functions of the shoulder. However, only few studies have assessed the performance of the shoulder muscles in gymnasts (Cools et al., 2007; Siatras, Douka, & Milosis, 2010; Zhou, Liu, Cheng, & Jiang, 2014) and no research has been reported in literature regarding the evaluation of isometric and isokinetic (concentric and eccentric) shoulder strength of flexors and extensors and flexion-extension ratios in gymnastics with bilateral arm activation.

The aim of the present study was to determine the relative and absolute reliability of the flexion and extension isometric (FLisom, EXisom), flexion and extension concentric (FLcon, EXcon) and eccentric (FLecc, EXecc) peak moment (PM) of gymnasts, when performing shoulder maximum flexion-extension with both upper arms in supine position. An additional aim was to analyze the relative and absolute reliability of moment ratios such as flexion concentric/extension concentric (FLcon/EXcon) and flexion eccentric/extension concentric (FLecc/EXcon) ratios (conventional) and extension eccentric/flexion concentric (EXecc/FLcon) ratios (dynamic control). It has been suggested, that for a more complete picture of the strength balances for dynamic and static muscle actions, an evaluation of a combination of these dynamic control ratios is needed (Aagaard, Simonsen, Magnusson, Larsson, & Dyhre-Poulsen, 1998). It was hypothesized that (a) all the measurements would show acceptable relative and absolute reliability and (b) that based on the literature the conventional ratios obtained from the present study would provide important clues for the balanced development of highly competitive gymnasts' shoulder strength.

METHODS

Participants

The sample size was calculated using MedCalc software to achieve a power of 0.90 for an intraclass correlation coefficient (ICC) under the following assumptions: alpha = 0.05; ICC > 0.80, considered an ICC over 0.90 as high, between 0.80 and 0.90 as moderate and below 0.80 as low (Atkinson & Nevill, 1998; Hopkins, 2000). A minimum of 12 subjects was required for the measurements. However, in order to account for potential study dropouts, some additional subjects were allocated to participate in the measurements. Thus, fifteen male gymnasts (age: 19.3 ± 2.3 years, height: 169.6 ± 6.3 cm, mass: 67.2 ± 6.5 kg) with no previous experience in isokinetic measurements volunteered to participate in the study. All of them were mature/senior gymnasts who take part in international competitions, with more than 10 years of intensive training, and with a minimum of 18 hours of training per week. The majority of the athletes were competed in all gymnastics apparatus and four of them specialized in still rings. All gymnasts were right-hand dominant (the hand preferred for writing), without prior orthopedic problems as regards the shoulder joint. According to the Ethical Committee of the Aristotle University, all the subjects and their coaches were informed about the objectives of the study and the possible difficulties or risks in the implementation of the protocols. Before participating, all subjects gave their written informed consent. Signed parental consent was obtained for the two gymnasts who were under the age of 18 years. Approval of the study was obtained from the Laboratory of Exercise Physiology-Ergometry. The measurements were performed in a pre-competition period.

Measures

Shoulder muscle strength was evaluated using an isokinetic dynamometer (Humac Norm 770) calibrated according to the manufacturer's instructions (Humac Norm manual; Computer Sports Medicine, Inc.; CSMI, 2006). A second handgrip rotation was inserted on the elbow/shoulder adapter assembly (Figure 1). The starting position (10º) was set by the subjects fully extended arms near their hips and the full flexion (180º) was set by the subjects fully extended arms in the extension of the body. The compromised axis of rotation of the moment arm passed through the shoulder joint center when the shoulder was at 90 degrees flexion, to ensure the minimum displacement of the center of rotation in the range of motion for each measurement. The alignment between the dynamometer rotational axis and the shoulder joint rotation axis was checked for each subject at the beginning of each trial.

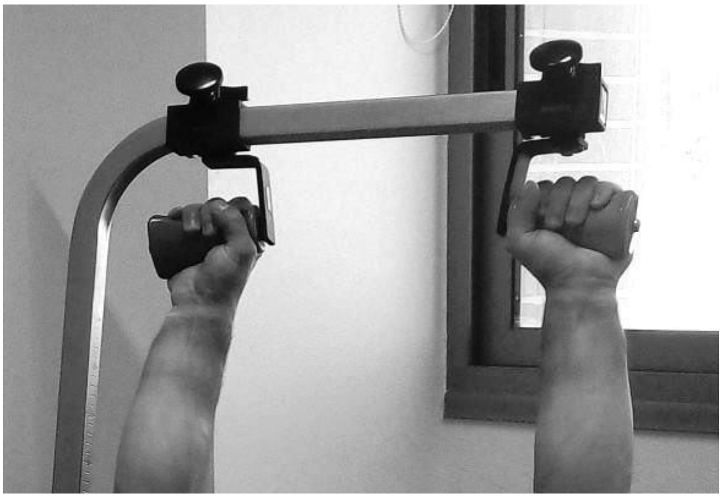

Figure 1. Customized elbow/shoulder adapter assembly.

Two identical measurements with a one-week interval were performed to determine intersession variability (test-retest). All measurements were recorded by the same investigator in order to eliminate inter-tester variability. All measurements were done according to a standardized protocol: measurements were done in a supine position; subjects were strapped down with two Velcro straps across the chest, one across the pelvis and one across the thigh. Subjects performed all measurements holding and pressing the elbow/shoulder adapter assembly with the arms fully extended in the elbow joint in overhand (dorsal) grip (usually performed in a variety of gymnastics skills) (Figure 1). Gravity correction was performed according to the recommendations of the CSMI (Humac Norm manual; Computer Sports Medicine, Inc.; CSMI, 2006).

The same standardized procedure was followed by all the participants. Subjects were asked to refrain from strenuous exercise 24 hours prior to the day of testing. After the anthropometric measurements, the subjects warmed-up for six minutes on an arm-cycle ergometer (MONARK 881; in forward and backward rotation) with progressively increased load, and for three minutes performing shoulder flexion-extension with an elastic band, followed by three minutes of shoulder muscles' stretching. After that, subjects were placed in the dynamometer chair. Before the recording of the measurements, subjects performed 5 submaximal consecutive isokinetic concentric extension-flexion warm-up repetitions at 60º/s and 3 repetitions at 180º/s so as to familiarize with doing so over the full range of motion. Subjects performed for practice one submaximal repetition prior to each test for each contraction mode and angle or angular velocity.

Isometric measurements were performed first at 45º, 90º, and 135º of shoulder flexion. One isometric contraction of shoulder extensor and flexor muscles was performed and recorded for each angle. Subjects were consistently instructed to produce their maximal force rapidly (as fast and forceful as possible) and to maintain the contraction for 6 s so to ensure that the maximum moment value was obtained (Moudgil & Karpovich, 1969). According to literature, isokinetic concentric and eccentric movements consisted of three consecutive reciprocal shoulder contractions (extension-flexion for concentric and flexion-extension for eccentric) performed at three angular velocities; 60º/s (low), 180º/s (moderate), and 300º/s (high) (Ayala, Sainz de Baranda, De Ste Croix, & Santonja, 2013). Taking into consideration the recommendation of Mayer et al. (2001) that at 300º/s a range of at least 60º is required to obtain an isokinetic contraction, this angular velocity was included as suitable and feasible due to the wide range of motion (10º to 180º) of the measurements of the present study. For both concentric and eccentric repetitions, subjects were exhorted to push⁄pull as hard and fast as possible and to complete the full range of motion. Subjects were allowed to recover passively for 30 s between sets and for 60 s between different measurements. On-line visual feedback of the instantaneous moment was provided graphically to the subjects on a computer screen. Furthermore, the subjects were given standardized verbal encouragement by the investigator.

Analysis

Statistical analysis was performed with SPSS, Microsoft Excel and MedCalc software. The level of significance was set at $P < 0.05$. Mean and standard deviation (SD) values PM for each isometric contraction and the average PM of the three repetitions for concentric and eccentric contraction at different angular velocities were calculated. PM is the strength parameter that has received the most attention in the study of its reliability (Ayala et al., 2013). Conventional (FLisom/EXisom, FLcon/EXcon, and FLecc/EXecc) and dynamic control ratios

(FLecc/EXcon and EXecc/FLcon) were calculated for the three angles and the three angular velocities. Normality of the data was tested using the Shapiro-Wilks test. Homogeneity of variance between the two measurements was tested with the Levene's test. A repeated-measures ANOVA was performed to primarily test whether the two sets of scores were significantly different from each other (detection of systematic biases) (Atkinson & Nevill, 1998; Weir, 2005). Heteroscedasticity was examined, by plotting the residual versus predicted values and calculating the Pearson's correlation (Atkinson & Nevill, 1998).

Following the recommendations of Atkinson and Nevill (1998) for sports clinicians and researchers, a number of statistical methods for assessing reliability were applied and interpreted in the present study. Relative reliability as regards the degree to which individuals maintain their rank order in a sample with repeated measurements was evaluated using the intraclass correlation coefficient $(ICC)_{(2,1)}$ (Atkinson & Nevill, 1998; Hopkins, 2000; Weir, 2005). Absolute reliability is the degree to which repeated measurements vary for a given population (Hopkins, 2000; Weir, 2005). One indicator of absolute reliability is the 'standard error of measurement' (SEM) (Thomas & Nelson, 1990).

The SEM was calculated by the equation: $SEM = SD \times \sqrt{1 - ICC}$ (Baumgarter, 1989; Thomas & Nelson, 1990). However, this way of calculation has been criticized as not a true indicator of absolute reliability because it is sensitive to population heterogeneity (Atkinson & Nevill, 1998) and is affected by the form of ICC (Weir, 2005).

Thus, the SEM was also estimated as the square root of the mean square error (MSE) term in a repeated measurement ANOVA: $SEM_e = \sqrt{MSE}$ (Bland & Altman, 1996; Hopkins, 2000; Weir, 2005). This type of SEM (SEM_e) is largely independent of the population from which it was determined and thus, is not affected by between-subjects variability as is the ICC (Weir, 2005). For the better interpretation of the results the SEM and SEM_e were calculated and presented as a percentage of the mean value of the PM: $SEM(\%) = \frac{SEM}{mean\ of\ 2\ sessions} \times 100$ and $SEM_e(\%) = \frac{SEM_e}{mean\ of\ 2\ sessions} \times 100$.

In order to achieve a better practical interpretation of the reliability results, the 95% limits of agreement for the determination of the minimum detectable change (MDC) (or smallest real difference), were calculated from the SEM. MDC reflects the smallest amount of change in score which is outside an error and which is due to a real change in score and not due to the error in measurement (Atkinson & Nevill, 1998; Hopkins, 2000; Impellizzeri et al., 2008; Weir, 2005). MDC estimation is based on SEM and expressed in original units of measurement: $MDC = \pm 1.96 \times \sqrt{2} \times SEM$ and $MDC_e = \pm 1.96 \times \sqrt{2} \times SEM_e$. The 1.96 value in the equation is the z score associated with a 95% CI and represents the difference between the measured value and the 'true' one for 95% of observations. The multiplier square root of 2 is included because of the two measurements per subject considered. MDC index approximates to the limits of agreement statistic (95% LOA). For the better interpretation of the results the MDC and MDC_e were calculated and presented as a percentage of the mean value of the PM: $MDC\ (\%) = \frac{MDC}{mean\ of\ 2\ sessions} \times 100$ and $MDC_e\ (\%) = \frac{MDC_e}{mean\ of\ 2\ sessions} \times 100$.

The use of a dimensionless statistic like the coefficient of variation (CV) was also calculated, because as stated by Fetz and Miller (1996) the reliability of different measurement tools can be compared. Furthermore, as a ratio statistic, the CV is useful if heteroscedasticity is present in the data (Atkinson & Nevill, 1998). The CV was calculated by the equation: $CV(\%) = 100 \times (SD \times \sqrt{2}) \times (Average1 + Average2)$ (Portney & Watkins, 2000).

Finally, Bland-Altman plots were conducted to visualize the repeatability of the measurements. The proportion of scores at two standard deviations of the mean difference between test-retest values was taken as a parameter of agreement. According to Bland and Altman recommendations, 95% of the data points should lie within ± 2s of the mean difference (Bland & Altman, 1996).

RESULTS

Tables 1 and 2 present the Mean ± SD, ICC, SEM(%), MDC(%), SEM_e(%), MDC_e(%), and CV(%) of shoulder strength and shoulder strength imbalance (conventional and dynamic control) ratios respectively, obtained for the two measurements. All variables presented normal distribution according to the Shapiro-Wilks test. Homogeneity of variance between the two measurements was confirmed by Levene's test. Analysis of systematic biases by repeated measures ANOVA found no significant differences except for FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s. The Pearson's correlation coefficient of the absolute differences between test measurements 1 and 2 and the mean of the two test measurements was not significant except for the FLcon at 300º/s, FLecc/EXcon at 300º/s and FLecc/EXcon at 180º/s. After the logarithmic data transformation, Pearson's correlation coefficient was still significant, thus results from original data were presented.

Isometric shoulder PM ranged from 194.73 to 146.87 Nm (flexion) and from 229.40 to 257.07 Nm (extension) at 45º, 90º, and 135º for the two measurements. Isokinetic concentric PM ranged from 159.53 to 94.80 Nm (flexion) and from 201.13 to 118.33 Nm (extension), while eccentric PM ranged from 180.27 to 204.40 Nm (flexion) and from 194.40 to 276.27 Nm (extension) at 60º/s, 180º/s, and 300º/s for the two measurements. Conventional ratios ranged from 0.84 to 0.59 for isometric shoulder strength, from 0.79 to 0.85 for concentric, and from 0.74 to 0.78 for eccentric isokinetic strength at 60º/s, 180º/s, and 300º/s. Dynamic control ratios ranged from 0.98 to 1.74 for FLecc/EXcon, and from 1.69 to 2.87 for EXecc/FLcon isokinetic strength at 60º/s, 180º/s, and 300º/s.

In the present study, ICC values for shoulder strength indices ranged from 0.73 to 0.96 were considered low in 3 cases, moderate in 4 cases and high in 9 cases. Correspondingly, ICC values for shoulder strength conventional ratios ranged from 0.81 to 0.93, were considered moderate in 6 cases, and high in 3 cases and for dynamic control ratios ranged from 0.74 to 0.89 (except FLecc/EXcon at 60º/s; 0.46), were considered low in one case and moderate in 4 cases (Tables 1, 2).

SEM(%) values (calculated using ICC) for shoulder strength indices ranged from 3.4 to 7.9% and MDC(%) values ranged from 9.4 to 21.8%. SEM(%) values (calculated using ICC) ranged from 3.9 to 7.1% for shoulder strength conventional ratios and from 7.2 to 11.2% for dynamic control ratios. MDC(%) values ranged from 10.7 to 19.8% for shoulder strength conventional ratios and from 20.1 to 31.1% for dynamic control ratios. SEM_e(%) values for shoulder strength indices ranged from 5.3 to 23.4% and MDC_e(%) values ranged from 1.6 to 48.8%. SEM_e(%) values ranged from 2.5 to 15.7% for shoulder strength conventional ratios and from 0.1 to 15.9% for dynamic control ratios. MDC_e(%) values ranged from 5.6 to 26.3% for conventional ratios and from 0.3 to 44% for dynamic control ratios. The CVs(%) ranged from 8.6 to 15.6% for shoulder strength indices, from 10.4 to 15.2% for shoulder strength conventional ratios, and from 10.8 to 17.8% for dynamic control ratios (Tables 1, 2).

Table 1
Reliability of the shoulder strength indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Mean ± SD		Change in mean	Main effect *P*-value	$ICC_{(2,1)}$	95% CI Lower-Upper	Absolute Reliability				
	Measurement 1 (Nm)	Measurement 2 (Nm)					SEM (%)	MDC (%)	SEM_e (%)	MDC_e (%)	CV (%)
FLisom at 45º	189.60 ± 36.54	194.73 ± 41.21	+5.13	0.288	0.94	0.83-0.98	5.0	13.7	7.3	20.3	14.3
EXisom at 45º	229.40 ± 35.17	238.33 ± 34.36	+8.93	0.098	0.91	0.75-0.97	4.5	12.4	10.5	29.0	10.5
FLisom at 90º	184.53 ± 29.48	185.27 ± 33.42	+0.74	0.869	0.92	0.77-0.97	4.8	13.3	1.1	3.0	12.0
EXisom at 90º	250.00 ± 41.82	256.47 ± 44.08	+6.47	0.151	0.96	0.89-0.99	3.4	9.4	7.0	19.4	12.0
FLisom at 135º	146.87 ± 22.38	151.87 ± 23.83	+5.00	0.289	0.83	0.50-0.94	6.4	17.7	9.2	25.4	10.9
EXisom at 135º	257.07 ± 51.28	252.13 ± 57.84	-4.94	0.465	0.94	0.83-0.98	5.2	14.5	5.3	14.7	15.2
FLcon at 60º/s	156.27 ± 27.89	159.53 ± 30.95	+3.26	0.434	0.92	0.77-0.97	5.3	14.6	5.7	15.7	13.2
EXcon at 60º/s	199.13 ± 24.63	201.13 ± 35.59	+2.00	0.740	0.84	0.52-0.95	6.2	17.1	2.7	7.6	10.9
FLcon at 180º/s	120.73 ± 23.80	131.53 ± 25.37	+10.80	0.008	0.92	0.75-0.97	5.5	15.3	23.4	65.0	13.8
EXcon at 180º/s	146.07 ± 24.69	155.93 ± 27.95	+9.86	0.011	0.94	0.81-0.98	4.3	11.8	17.9	49.6	12.3
FLcon at 300º/s	94.80 ± 19.94	99.80 ± 22.90	+5.00	0.074	0.94	0.83-0.98	5.4	14.9	14.1	39.0	15.6
EXcon at 300º/s	118.33 ± 24.72	126.47 ± 27.74	+8.14	0.008	0.96	0.88-0.99	4.3	11.9	18.2	50.4	15.2
FLecc at 60º/s	194.80 ± 30.54	194.40 ± 28.32	-0.40	0.955	0.73	0.20-0.91	7.9	21.8	0.6	1.6	10.7
EXecc at 60º/s	258.87 ± 43.99	265.80 ± 50.95	+6.93	0.428	0.86	0.60-0.95	6.9	19.1	7.2	20.1	13.0
FLecc at 180º/s	180.27 ± 22.18	183.80 ± 23.34	+3.53	0.503	0.76	0.29-0.92	6.3	17.4	5.3	14.7	9.1
EXecc at 180º/s	239.07 ± 23.85	248.67 ± 30.84	+9.60	0.143	0.77	0.31-0.92	5.9	16.2	10.8	29.9	8.6
FLecc at 300º/s	197.73 ± 31.13	204.40 ± 30.35	+6.67	0.243	0.87	0.60-0.96	5.5	15.3	9.1	25.2	10.8
EXecc at 300º/s	257.27 ± 34.20	276.27 ± 44.28	+19.00	0.008	0.90	0.70-0.97	5.0	13.8	17.6	48.8	11.1

Abbreviations: FL, flexion; EX, extension; isom, isometric; con, concentric; ecc, eccentric; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurements based on ICC; MDC, minimal detectable change based on ICC; SEM_e, standard error of measurements based on random error; MDC_e, minimal detectable change based on random error; CV, coefficient of variation.

Table 2
Reliability of the shoulder strength imbalance indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Mean ± SD		Change in mean	Main effect *P*-value	$ICC_{(2,1)}$	95% CI Lower-Upper	Absolute Reliability				
	Measurement 1 (ratio)	Measurement 2 (ratio)					SEM (%)	MDC (%)	SEM_e (%)	MDC_e (%)	CV (%)
Conventional ratios											
FLisom/EXisom at 45º	0.84 ± 0.17	0.82 ± 0.15	-0.02	0.479	0.89	0.68-0.96	6.4	17.7	6.6	15.2	13.6
FLisom/EXisom at 90º	0.75 ± 0.14	0.73 ± 0.12	-0.02	0.331	0.91	0.73-0.97	5.3	14.6	7.4	15.2	12.4
FLisom/EXisom at 135º	0.59 ± 0.12	0.62 ± 0.13	+0.03	0.117	0.89	0.68-0.96	7.1	19.7	15.7	26.3	15.2
FLcon/EXcon at 60º/s	0.79 ± 0.11	0.80 ± 0.13	+0.01	0.431	0.92	0.73-0.97	4.3	11.9	5.3	11.6	10.7
FLcon/EXcon at 180º/s	0.83 ± 0.13	0.85 ± 0.14	+0.02	0.470	0.81	0.42-0.94	7.0	19.4	6.7	15.7	11.3
FLcon/EXcon at 300º/s	0.81 ± 0.11	0.80 ± 0.16	-0.01	0.787	0.83	0.49-0.94	6.9	19.1	2.5	5.6	11.8
FLecc/EXecc at 60º/s	0.76 ± 0.13	0.75 ± 0.12	-0.01	0.454	0.84	0.53-0.95	7.1	19.8	6.8	14.2	12.6
FLecc/EXecc at 180º/s	0.76 ± 0.10	0.74 ± 0.09	-0.02	0.256	0.93	0.80-0.98	3.9	10.7	5.3	11.1	10.4
FLecc/EXecc at 300º/s	0.78 ± 0.13	0.75 ± 0.12	-0.03	0.183	0.87	0.67-0.96	6.8	19.0	10.0	21.3	13.4
Dynamic ratios											
FLecc/EXcon at 60º/s	0.98 ± 0.15	0.98 ± 0.14	0.00	0.894	0.46	-0.62-0.82	11.2	31.1	0.1	0.3	10.8
FLecc/EXcon at 180º/s	1.27 ± 0.30	1.21 ± 0.24	-0.06	0.267	0.84	0.51-0.95	8.7	24.1	13.7	37.9	15.4
FLecc/EXcon at 300º/s	1.74 ± 0.49	1.67 ± 0.36	-0.07	0.489	0.85	0.64-0.96	9.8	27.0	10.6	29.3	17.8
EXecc/FLcon at 60º/s	1.69 ± 0.34	1.70 ± 0.33	+0.01	0.889	0.87	0.32-0.92	7.2	20.1	0.5	2.6	14.2
EXecc/FLcon at 180º/s	2.05 ± 0.42	1.93 ± 0.29	-0.12	0.211	0.74	0.33-0.92	10.0	27.7	15.9	44.0	13.9
EXecc/FLcon at 300º/s	2.80 ± 0.60	2.87 ± 0.67	+0.07	0.663	0.89	0.68-0.96	7.6	21.1	6.6	18.4	16.2

Abbreviations: FL, flexion; EX, extension; isom, isometric; con, concentric; ecc, eccentric; ICC, intraclass correlation coefficient; CI, confidence interval; SEM, standard error of measurements based on ICC; MDC, minimal detectable change based on ICC; SEM_e, standard error of measurements based on random error; MDC_e, minimal detectable change based on random error; CV, coefficient of variation.

Tables 3 and 4 present the average of the differences between the two measurements (bias), the standard deviation of the measurements, the lower limit, the upper limit, and the confidence intervals (CI). Furthermore, Figure 2 shows indicative Bland-Altman percent plots with the bias line, the limits of agreement for the 2 measurements, and 95% confidence interval of the parameters showed the lower [FLcon at 180º/s; Figure 2(a)] and the higher [(FLecc at 60º/s; Figure 2(b) and FLecc/EXcon at 60º/s; Figure 2(c)] absolute reliability according to SEM_e(%) values.

Table 3
Bland and Altman plot statistics of the shoulder strength indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Difference mean ($\bar{d}$)	SD(s)	95% CI of mean difference		95% CI of agreement limits			
			$\bar{d}$ - 1.96s	$\bar{d}$ + 1.96s	Lower limit From	Lower limit to	Upper limit From	Upper limit to
FLisom at 45º	-2.15	9.19	-20.16	15.86	-29.06	-11.26	6.96	24.75
EXisom at 45º	-3.92	8.58	-20.73	12.89	-29.03	-12.43	4.58	21.20
FLisom at 90º	-0.11	8.99	-17.72	17.50	-26.42	-9.02	8.80	26.20
EXisom at 90º	-2.51	6.49	-15.24	10.22	-21.52	-8.95	3.93	16.51
FLisom at 135º	-3.16	11.42	-25.54	19.22	-36.60	-14.48	8.16	30.28
EXisom at 135º	2.34	11.79	-20.57	25.64	-31.99	-9.15	14.22	37.06
FLcon at 60º/s	-1.69	10.50	-22.27	18.88	-32.43	-12.10	8.71	29.04
EXcon at 60º/s	-0.11	12.30	-24.22	24.00	-36.14	-12.39	12.09	35.91
FLcon at 180º/s	-8.66	11.76	-31.70	14.39	-43.08	-20.31	3.00	25.77
EXcon at 180º/s	-6.38	9.03	-24.08	11.31	-32.52	-15.34	2.57	20.05
FLcon at 300º/s	-4.92	9.61	-23.76	13.91	-33.25	-15.45	2.78	20.59
EXcon at 300º/s	-6.33	9.19	-24.35	11.69	-34.39	-14.95	4.95	24.39
FLecc at 60º/s	-0.06	13.36	-26.23	26.12	-39.16	-13.30	13.19	39.05
EXecc at 60º/s	-2.30	12.85	-27.48	22.89	-39.93	-15.04	10.45	35.34
FLecc at 180º/s	-1.88	10.83	-23.10	19.34	-33.59	-12.62	8.85	29.83
EXecc at 180º/s	-3.73	9.42	-22.20	14.73	-31.32	-13.07	5.61	23.85
FLecc at 300º/s	-3.50	9.79	-22.69	15.69	-22.17	-13.21	6.21	25.17
EXecc at 300º/s	-6.70	8.47	-23.30	9.91	-31.50	-15.09	1.71	18.12

Abbreviations: Difference mean ($\bar{d}$), the average of the differences between the two measurements (bias); SD(s), the standard deviation of the measurements; $\bar{d}$ - 1.96s, the lower limit; $\bar{d}$ + 1.96s, the upper limit; CI, Confidence Intervals.

Table 4
Bland and Altman plot statistics of the shoulder imbalance indices obtained during the isokinetic tests on Humac Norm dynamometer.

Parameters	Difference mean ($\bar{d}$)	SD(s)	95% CI of mean difference		95% CI of agreement limits			
			$\bar{d}$ - 1.96s	$\bar{d}$ + 1.96s	Lower limit		Upper limit	
					From	to	From	to
Conventional ratios								
FLisom/EXisom at 45º	1.76	11.88	-21.53	25.05	-33.04	-10.02	13.55	36.56
FLisom/EXisom at 90º	2.45	9.77	-16.70	21.60	-26.17	-7.24	12.13	31.06
FLisom/EXisom at 135º	-5.59	12.59	-30.26	19.10	-42.46	-18.07	6.90	31.29
FLcon/EXcon at 60º/s	-1.77	8.46	-18.35	14.80	-26.54	-10.16	6.61	22.99
FLcon/EXcon at 180º/s	-2.30	13.11	-27.99	23.39	-40.63	-15.30	10.70	36.08
FLcon/EXcon at 300º/s	1.78	13.17	-24.04	27.59	-36.79	-11.28	14.83	40.33
FLecc/EXecc at 60º/s	2.48	13.00	-23.00	27.96	-35.58	-10.41	15.37	40.55
FLecc/EXecc at 180º/s	1.91	6.17	-10.18	14.00	-16.16	-4.21	8.03	19.98
FLecc/EXecc at 300º/s	3.50	9.68	-15.26	22.47	-24.83	-6.09	13.10	31.84
Dynamic ratios								
FLecc/EXcon at 60º/s	-0.03	17.90	-35.11	35.05	-52.44	-17.78	17.72	52.39
FLecc/EXcon at 180º/s	4.47	15.22	-25.36	34.30	-40.10	-10.62	19.56	49.03
FLecc/EXcon at 300º/s	2.73	14.93	-26.54	31.99	-40.99	-12.08	17.53	46.45
EXecc/FLcon at 60º/s	-0.55	17.76	-35.36	34.26	-52.56	-18.16	17.08	51.46
EXecc/FLcon at 180º/s	4.98	14.70	-23.83	33.79	-38.07	-9.60	19.55	48.02
EXecc/FLcon at 300º/s	-1.71	14.86	-30.83	27.43	-45.22	-16.44	13.04	41.82

Abbreviations: Difference mean ($\bar{d}$), the average of the differences between the two measurements (bias); SD(s), the standard deviation of the measurements; $\bar{d}$ - 1.96s, the lower limit; $\bar{d}$ + 1.96s, the upper limit; CI, Confidence Intervals.

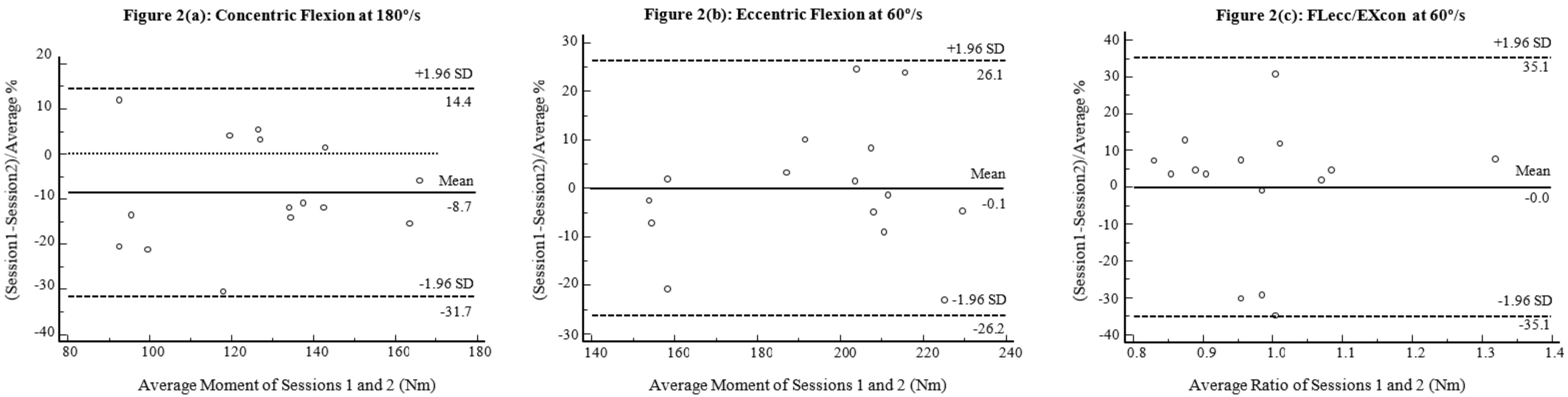

Figure 2. Bland-Altman plots of differences between session 1 and session 2, expressed as percentages of the values on the axis [(session 1-session 2)/average%)] against the mean of the two measurements. The bias line (mean absolute agreement), random error (upper and lower) and lines forming the 95% limits of agreement are presented on the plot.

According to the Bland-Altman analysis, PM showed mean of differences of less than 10%. The mean of differences (bias) for PM was non-significant at session 1 and 2. Furthermore, the LOAs were low (LOAs < 28%) for the majority of the variables. However, the LOAs were higher (LOAs < 35%), for the variables Flcon at 180º/s, FLisom/EXisom at 135º/s, FLcon/EXcon at 60º/s, FLcon/EXcon at 180º/s, FLcon/EXcon at 300º/s, EXecc/FLcon at 60º/s, EXecc/FLcon at 180º/s, and EXecc/FLcon at 300º/s.

DISCUSSION

The present study analyzed the relative and absolute reliability of international level gymnasts' isometric and isokinetic shoulder flexion and extension PM and conventional and dynamic control ratios. The main findings of this study were: (a) the PM and ratios values were comparable with those presented in the literature, (b) the relative and absolute reliability for both shoulder PM and conventional and dynamic control ratios was acceptable to excellent, showing critical results for only a few measurements as evaluated by SEM_e(%) and MDC_e(%).

In the present study, systematic bias was detected only for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s. Atkinson and Nevill (1998) supported that there might be a trend for a retest to be higher than a prior test due to a learning effect. It could be supported that subjects of the present study as novices in isokinetic measurements, familiarized much easier with the isometric and isokinetic contractions in low and moderate (eccentric) angular velocities, after the practicing trials according to the adapted protocol. Conversely, the systematic error detected in the present study may be explained by the participants' familiarization (learning effect) of the measurements in high angular velocities after the completion of the first measurement (more trials). Therefore, for high angular velocities, it is recommended to design a measurement protocol that removes the learning effect from the test. For example, it could include more familiarization trials before the implementation of the measurement, increase the time between repeated measurements (Baumgarter, 1989), or perform more measurements (re-tests) (Atkinson & Nevill, 1998; Streiner & Norman, 1996).

Isometric and isokinetic (concentric and eccentric) shoulder PM values measured in the present study were comparable to the measurements of other studies (Cahalan, Johnson, & Chao, 1991), considering the differences in the design of the studies (e.g., protocol, participants). In the present study, the isometric flexion PM decreased as the angle increased (45º, 90º, 135º), while the opposite occurred for the extension PM. In agreement with previous research findings (Bassa, Michailidis, Kotzamanidis, Siatras, & Chatzikotoulas, 2002; Cahalan et al., 1991; Mameletzi, Siatras, Tsalis, & Kellis, 2003), isokinetic concentric flexion and extension PM values decreased as angular velocity increased. Conversely the isokinetic eccentric PM values decreased at 180º/s compared to the values at 60º/s, and increased at 300º/s compared to the values at 60º/s and at 180º/s, partially confirming the notion that as angular velocity increases the eccentric force remains the same or increases (Bassa et al., 2002; Greenfield, Donatelli, Wooden, & Wilkes, 1990). Conventional ratios values for the isometric shoulder strength decreased as the angle increased, while they were almost stable for the isokinetic contraction for the three different angular velocities. Finally, in agreement with the findings of other studies (Scoville, Arciero, Taylor, & Stoneman, 1990), values for the dynamic control ratios increased as angular velocity increased, for both the FLecc/EXcon and the EXecc/FLcon.

It has been supported that due to their greater muscle mass, the shoulder extensors would be expected to produce greater moment than the shoulder flexors muscles (Cahalan et al., 1991; Cook, Gray, Savinar-Nogue, & Medeiros, 1987; Siatras et al., 2010; Zhou et al., 2014). Previous investigations showed conventional ratios of 0.80 for normal volunteers (Ivey, Calhoun, Rusche, & Bierschenk, 1985), 0.70 to 0.81 for pitchers and 0.76 to 0.99 for non-pitchers (Cook et al., 1987) and 0.75 to 0.80 for adult tennis players (Ellenbecker, 1991). Considering the differences that existed in the design of the studies, the shoulder conventional ratios estimated in the present study are in line with those reported above (isometric 0.59 to 0.84, isokinetic concentric 0.75 to 0.85, and isokinetic eccentric 0.74 to 0.78). Based on these findings it could be concluded that highly competitive gymnasts do not have muscle imbalances regarding the shoulder flexors' and extensors' strength. However, some studies found lower conventional ratios as for example 0.48 for high school and college-aged pitchers (Alderink & Kuck, 1986), 0.63 for high school wrestlers (Housh et al., 1990), and 0.46 to 0.53 for normal volunteers varying by age (Hughes, Johnson, O'Driscoll, & Kai-Nan An, 1999), indicating some disagreement among these investigations. However, reviewing the literature no research data have been found regarding the gymnasts' shoulder dynamic control ratios. The results of the present study provided novel data for these parameters.

In the present study, results from ICC measurements showed strong reproducibility of shoulder flexion and extension at all angles and angular velocities in line with results from previews studies (Atkinson & Nevill, 1998; Cools et al., 2002; Hopkins, 2000). Correspondingly, ICC values for shoulder strength conventional ratios were considered moderate in 6 cases, and high in 3 cases and as for dynamic control ratios they were considered low in one case and moderate in 4 cases. Researchers have reported low reliability for muscle balance ratios and they suggested that shoulder strength assessments are more reliable when they are based on measurements of PM (Nm) than when based on balance ratios (%) (e.g., Codine, Bernard, Sablayrolles, & Herrison, 2005). The lower reliability for the evaluation of strength ratios compared to the PM values, it is probably due to the fact that they are a composite of two absolute scores, each possibly varying in the same or a different direction with re-evaluation, resulting in error reproduction (Iga, George, Lees, & Reilly, 2006). In the present study, a low ICC compared to all other ICCs was presented only for the dynamic ratio FLecc/EXcon at 60º/s. This result could be attributed to the low levels of between-subjects variability for this parameter, which according to Atkinson and Nevill (1998) depress the ICC even if the differences between subjects' scores across test conditions are small. It is becoming clear that the use of ICCs only, for the analyses of reliability is not sufficient because they influenced by the between-subject variability and the heterogeneity of the sample (Atkinson & Nevill, 1998; Hopkins, 2000). Thus, although the test for reliability of tools and protocols for the measurement of isokinetic muscle strength with correlation methods showed strong reproducibility (Perrin, 1993), it has been supported that the repeatability of these measurements is relatively poor at faster isokinetic angular velocities (Atkinson, Greeves, Reilly, & Cable, 1995). By examining the reliability of 23 common measurement tools in sport and exercise science research, Nevill and Atkinson (1997) found that using an absolute measurement of reliability emerged considerable differences in reliability between measurement tools. These notions were confirmed in the present study in which relative and different absolute measurements of reliability were used. For example, while the ICCs for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s (in which systematic bias was detected) showed strong reliability, the absolute reliability indices (with the exception of SEM based on ICC) were indicators of low reliability.

Furthermore, SEM(%) and MDC(%) based on the ICC showed high reliability for all shoulder strength and imbalance measurements according to the recommendations of Lund et al. (2005). However, there was a disagreement in some cases with the SEM_e(%) and MDC_e(%) indices in which the reliability was not strongly supported (e.g., for the parameters FLcon and EXcon at 180º/s, EXcon at 300º/s, and EXecc at 300º/s in which systematic bias was detected). On the other hand, CV(%) values with an analytical goal of 15% or below were considered as acceptable for almost all the parameters. These findings provide support to the arguments of Lund et al. (2005) and Atkinson and Nevill (1998) that the interpretation of the reliability of a measurement is a complex procedure and the acceptance of the reliability levels for a specific measurement depends on the analytical goals.

According to their review of literature, Edouard et al. (2011) reported that PM isokinetic strength parameters seem to present a moderate-high absolute reliability (SEM < 10%). This tendency was present regardless of the muscle contraction (concentric and eccentric), angular velocity (low, moderate and high) and joint movement (knee flexion and extension). On the other hand, Ayala et al. (2013) based on their review, reported that concentric muscle contraction presents lower intersession variability, compared to eccentric contraction (5.9 and 10.4% of SEM for concentric and eccentric contractions, respectively). In addition, the same review does not support the notion that higher angular velocities generate higher variability if the results are obtained in comparison to low and moderate velocities (low: 7.7% SEM; moderate: 8.6% SEM; and high: 8.2% SEM). However, it is important to take into account that these studies concerned mainly low to moderate angular velocities for the joint of the knee. Another important factor which must be taken into account is the type of absolute reliability index used.

Compared to the above findings, the results of the present study provided some trends (not so clear in some cases) for the intersession variability of the measurements of isometric and isokinetic shoulder strength parameters based mainly on the SEM_e(%) and MDC_e(%) indices: (a) isometric contractions and their conventional ratios presented lower intersession variability at the moderate angle (90º), (b) the intersession variability of isokinetic contractions presented to be lower at the angular velocity of 60º/s, while conventional ratios for concentric contractions presented lower intersession variability at the angular velocity of 300º/s and at the angular velocity of 180º/s for eccentric contractions (c) the intersession variability of flexion contractions were presented to be lower compared to extension contractions; and (d) dynamic control ratios (FLecc/EXcon and EXecc/FLcon) presented lower intersession variability at the angular velocity of 60º/s (Tables 1 and 2).

Results from the Bland-Altman analysis of the present study provided support for the equivalence of the two measurements (Tables 3 and 4; Figure 1). More specifically, the average discrepancy between the two measurements (the bias) was small and not statistically significant in all cases and the LOAs were narrow in most cases. This finding was in line with that of previous studies of isokinetic dynamometry. Reviewing the literature, Ayala et al. (2013) reported that the PM strength parameter presents a value of variability that range from 5.9% to 33.0%.

The present study had some limitations. In this study, specific shoulder strength parameters of fifteen highly competitive male gymnasts having some interpersonal variability as regards their personal characteristics (e.g., age, weight, competitive level) of one mid-sized city, were tested by one investigator. Although the size of the sample is considered adequate for the evaluation of reliability, and statistical analyses confirmed the normality of the data and the homogeneity of variance between the two measurements, larger sample sizes have been suggested by some researchers to form a practically useful 95% MDC and MDC(%) and LOAs

(Hopkins, 2000). Furthermore, a small systematic bias demonstrated an increase in four parameters from measurement 1 to measurement 2, was observed in the present study.

Therefore, extreme care should be taken before extending the inference of this study. More research is needed to develop more sensitive assessment methods to evaluate the training efficacy oriented towards the improvement of the shoulder force in gymnastics. A more extensively familiarizing procedure and additional investigators should be included in further evaluations in order to increase the generalizability of such results. Furthermore, it is suggested to evaluate the reliability of other aspects of strength except PM (e.g., time to PM, total work, power) and other movements of the shoulder joint (e.g., external, internal rotation), in a larger sample of gymnastics athletes and non-athletes, using relative measures (e.g., PM/body weight) in order to eliminate the possible effects of interpersonal variability. By examining and validating the relationships between these parameters, sufficient evidence to support extrapolation of the data at different test protocols for different sports, physical, and daily activities could be provided.

The evaluation of the absolute reliability of these parameters relevant to gymnastics movements and performance provided ecological validity to the results of the present study. Specifically, gymnastics trainers could use the assessment methods suggested above and the normative data provided by such methods to evaluate the improvement of shoulder flexion and extension strength after the implementations of training programs or the deterioration over time. Furthermore, such reliable measurements could provide information about the progress of gymnasts over time and could be useful for guiding the training for the achievement of difficult gymnastics skills as for example (a) static elements (e.g., “Hanging scale”, “Manna”, “Support lever”, “Swallow”), (b) strength elements (e.g., “Press to handstand with bend or straight body and straight arms”, “From hanging scale rear ways press to swallow or to support scale”), and (c) elements which require rapid flexion or extension of shoulder (e.g., “Salto backwards stretched”, “Scissor to handstand”, “Back kip to support scale at ring height”, “Forward handspring”, “Basket to handstand”).

CONCLUSION

Considering the limitations of the present study, the results supported the reliability of the shoulder flexion and extension measurements for different contraction modes, angles and angular velocities. All the indices used in the study (relative and absolute) provided acceptable reproducibility of the measurements and seem to be appropriate if there is a need for a detection of large strength differences (e.g., elite athletes vs. non-athletes, males vs. females, adult vs. adolescents, after rehabilitation programmes). However, to detect any significant change between two measurements for elite athletes or for the same athlete after the implementation of different strength training programmes, or to detect muscle imbalances, SEM_e(%) and MDC_e(%) are more important and meaningful. Furthermore, in order to eliminate differences due to interpersonal variability of the participants, the use of relative measures (e.g., PM/body weight) instead of PM is suggested. Future studies, using the methods provided above should examine the relationships of objective and dynamic control shoulder strength values with the performance of gymnasts in difficult gymnastics skills as described above.

The present study contributed to the establishment of normative data, to determine a functional-strength profile of the shoulder flexion and extension muscles for highly competitive gymnasts, for isometric (in specific angles) and isokinetic concentric and eccentric (in low, moderate, and high angular velocities) contractions. Furthermore, the results of the present study could also be very helpful for practitioners (e.g., trainers, therapists) and researchers of the physical activity, sports, exercises and daily activities or jobs requiring bilateral hand coordination, since it could reflect objective and dynamic control shoulder strength values. Considering the limitations of the study, such measurements could be very useful to detect important changes after interventions or deterioration over time. Moreover, although the balance of flexibility and strength of the rotator cuff muscles play the central role in the stability of the shoulder joint, proper balance of the muscles which act in shoulder flexion and extension as for example pectoralis major and deltoid is also necessary for the good function of the shoulder and the prevention of injury.

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MOVEMENT PROTOTYPES IN THE PERFORMANCE OF THE HANDSPRING ON VAULT

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Original article

Abstract

Most research concerning the kinematic analysis of gymnastics skills only deals with selected variables, thereby often ignoring the holistic nature of the analyzed skills. Therefore, the goal of this study was to develop an innovative approach to analyze the front handspring on vault. To gain comprehensive insight into the aforementioned motor skill, different skill prototypes should be detected and their variant and invariant characteristics should be investigated. The digitized video sequences of 60 handspring trials from ten female gymnasts were used for kinematic analysis. Time courses of six joints were analyzed by means of a hierarchical cluster analysis. In addition, the coefficients of variation were calculated. Results revealed that four distinct prototypical movement patterns could be identified for the handspring on vault in female near-expert gymnasts. The movement patterns within each prototype are thereby more similar to each other than the movement patterns between the four prototypes. The four different prototypes can be distinguished by certain variant and invariant characteristics, that become obvious when inspecting the time courses of the hip and shoulder angles, as well as the time course of the coefficient of variation. In light of the training process in gymnastics, the study provides further evidence for strongly considering gymnasts' individual movement patterns when it comes to motor skill acquisition and optimization.

Keywords: *kinematic analysis, cluster analysis, prototypical movement patterns, variant and invariant characteristics.*

INTRODUCTION

Artistic Gymnastics involves very complex and technically demanding sequences of elements requiring maximal effort and a high level of functional ability such as agility and coordination (Arkaev & Suchilin, 2004). There is a large number of studies in the field of sport science and gymnastics investigating biomechanical aspects of different gymnastics elements (Prassas, Kwon, & Sands, 2006). However, the evaluation of gymnastics performances during training and competition mainly relies on observation by coaches or judges, and is therefore influenced by their respective perception of different kinematic characteristics (Bradshaw & Sparrow, 2001; Farana, Uchytil, Zahradník, & Jandacka, 2015; Farana & Vaverka, 2012). Due to the presence of the high amount of degrees of freedom in the human motor system, movements can be performed in many different ways (Bernstein, 1967; Latash, Scholz, & Schöner, 2002). Because humans perceive movement in a holistic way (Davids et al., 2014; Jeraj, Hennig, & Heinen, 2015; Johansson, 1973), the interrelation of movement characteristics with the evaluation can only take place when a movement is taken into account as a whole, and not as a collection of individual parameters. The goal of this study was to identify different prototypes and their variant and invariant characteristics by means of an innovative approach that allows to analyze gymnastics skills in a holistic fashion.

Theoretical Background

When engaged in a goal-directed activity, like a handspring on vault, performers develop different coordination states through learning and practice (Davids, Button, & Bennett, 2008). Those coordination states are not constantly stable but contain a particular amount of variability leading to distinguishable movement options that could be described by a specific composition of biomechanical parameters (Latash et al., 2002). Gymnastics skills can be seen as complex systems. Complex systems consist of many components, which interact among themselves and as a whole with the environment. These interactions change depending on the constraints embedded within the complex system and without being previously developed and imposed on the systems behavior (Davids et al., 2014). The functional role of movement variability in human motor behavior was emphasized in the works of Bernstein (1967) and Higgins (1977) and through nonlinear statistical models in the study of human movement systems (Thompson & Stewart, 2002). It is thought that variation in the structure or function of complex biological systems, interacting with different constraints provided by the task, the environment or psychological factors, leads to movement variability (Davids et al., 2008; Higgins, 1977).

There is recent evidence from empirical research that movement variability is an essential feature of human motor behavior. It affords the necessary flexibility and adaptability to operate proficiently in a variety of performances in fine and gross motor skills (Fitzpatrick, Schmidt, & Lockman 1996; Kelso, 1995; Li, van den Bogert, Caldwell, van Emmerik, & Hamill, 1999), and also for complex skills in gymnastics comprising whole-body rotations (Hiley, Wangler, & Predescu, 2009; Williams, Irwin, Kerwin, & Newell, 2015). This movement variability and the resulting coordination dynamics in complex systems have a tendency to form patterned behavior (synergies) which have time-dependent characteristics (Davids et al., 2014).

Nowadays a large amount of kinematic and kinetic data is available to describe human movement. However, sports scientists usually identify, measure, and interpret selected variables, especially on the basis of time discrete values of selected variables (Federolf, Reid, Gilgien, Haugen, & Smith, 2014; Young & Reinkensmeyer, 2014). Schöllhorn, Chow, Glazier, and Button (2014) illustrated the difference between time discrete and time continuous movement with the following analogy:

If we see a known person far away standing still, it is often difficult to identify that person. Once he/she starts to walk, our visual system receives additional information that increases the likelihood of recognizing that person." (Schöllhorn et al., 2014, pp. 145).

Perception appears to be a complex process with a holistic character that takes into consideration hints and cues that are distributed over the whole time and space, in which the movement is performed and which is carried both by movement-mediated structural information and by pure dynamics (Troje, 2002). There is further evidence that the perception of biological movement relies on relative movement rather than absolute movement characteristics (Johansson, 1973). Especially in gymnastics, movement is described by coaches, judges, and athletes in terms of specific body postures and movement components (Jeraj et al., 2015). Nevertheless, the challenge is to find an appropriate approach to analyze the holistic nature of gymnastics skills.

Quantitative technique analysis seems not suitable for establishing the characteristics of the whole skill, but methods, such as cluster analysis or principal component analysis may be able to overcome this limitation (Davids et al., 2014; Lees, 2002). Plausible criteria for a classification of objects seem to be their relative similarity or proximity of movement characteristics. The simplest procedure of classifying objects is to quantify certain characteristics of all objects and to determine the relative distance of these quantities. Joint and body angles seem to be such characteristics because they can be used to describe gymnastics skills in a holistic way, and other kinematic characteristics can easily be computed from these values (Enoka, 2002).

Hence, qualities can be compared by means of their relative size or vector distance. A commonly used measure for mathematical comparisons is the euclidean distance, which represents the mathematical distance between two objects. Cluster analysis then deals with the quantitative sorting of these euclidean distances (Everitt & Dunn, 2001). If for example the euclidean distance between the knee angles of two participants, performing a handspring on vault, is smaller than the euclidean distance relative to a third participant, the first two participants would be assigned to one cluster and the third participant to another cluster. Thus, clustering aims to find groups of objects with a high degree of structural similarity to each other, which can be visualized in a tree diagram. Given the natural variation of objects in relation to their analyzed qualities, the different clusters contain a certain degree of variability (Troje, 2002). In this study, the goal was the identification of prototypical movement patterns of the handspring on vault by means of a cluster analysis. A prototype is thereby defined by the average angle-time courses of all trials which are assigned to one cluster.

Objectives and Hypothesis

It can be stated that for a better understanding of complex gymnastics performances it is not only relevant to analyze isolated parameters, but to analyze gymnastics skills in a holistic way. Relevant criteria for a classification of objects seem to be their relative similarity or proximity of kinematic characteristics like particular joint and body angles. Until now, there is a lack of gymnastics research, which deals with analyzing gymnastics skills holistically. Thus, the purpose of this study was to examine gymnastics performance in a holistic way based on an explorative approach of analyzing time continuous data. Special interest was on two topics: (a) to identify prototypes of a gymnastics skill, and (b) to explore the structure of a gymnastics skill in terms of its variant and invariant characteristics.

In a first step, the angle-time courses of separate trials of one specific gymnastics skill (handspring on vault) were mathematically analyzed with a cluster analysis. It was hypothesized that some trials are more similar than others. The cluster analysis should reveal patterns of similarity, leading to a particular number of distinguishable clusters (i.e. *prototypes*). In a second step the variant and invariant characteristics were investigated qualitatively by analyzing the angle-time courses in relation to the different prototypes and the different movement phases. It was hypothesized that the prototypes differ in their variant and invariant characteristics in specific movement phases.

METHODS

Participants

Ten female gymnasts participated in this study (age: M = 11.50, SD = 1.43; body size: M = 143.00 cm, SD = 11.36 cm). The gymnasts reported an average training amount of 26 hours per week. They were able to perform the experimental task of this study with a high degree of consistency in training and competition (handspring on vault; see Motor task section).

Motor task

The motor task was a handspring on vault (Čuk & Karácsony, 2004). The vaulting table was arranged according to the competition guidelines of the International Gymnastics Federation for women's artistic gymnastics (FIG, 2017). There was a running track in front of the table, landing mats (0.20 m high) behind the table, and a certified springboard (1.20 m long and 0.60 m wide) in front of the table. The vaulting table was adjusted to a height of 1.25 m.

The handspring on vault can be subdivided into six movement phases: approach run and hurdle, take-off phase, first flight phase, repulsion phase, second flight phase, and landing phase (Brüggemann, 1994). From a standing position at the beginning of the running track, the gymnast performs an accelerated run-up towards the vault apparatus. A hurdle motion at the end of the run-up precedes a reactive leap on the springboard, which in turn precedes the first flight phase to support on both hands on the vaulting table. During support, the gymnast pushes of the vaulting table, and performs a whole-body rotation about the somersault axis during the subsequent flight phase. The handspring ends with a landing on both feet in upright body posture. Gymnasts were asked to perform handsprings on vault as they would do in a regular competition. In particular they were asked to perform handsprings with the highest movement quality they were capable of at the time of the study.

Movement Analysis

The performance of the gymnasts was videotaped with a digital video camera (240 Hz, 1920 x 1080 pixel) which was placed at a distance of about 15 m from the vaulting table in order to compensate for lens distortion. The camera videotaped gymnasts' performance orthogonal to the movement direction, simulating the judge's perspective. For the kinematic analysis, the recorded video sequences were used. The horizontal and vertical coordinates of 18 points (body landmarks) were digitized for each frame using the movement analysis software Simi Motion®. Thus each one of the 18 body landmarks was represented by a two-dimensional time series $[x_j(t); y_j(t)]$ with j = 1, 2, 3, …, j (t = time, j = frame number). The 18 body landmarks defined a 17-segment model of the human body (Enoka, 2002). A software built-in digital filter was applied for data smoothing. For each trial, the time series of each body landmark was time normalized and rescaled to the interval [0; 1000]. Kinematic angular data were calculated from the time-normalized position data of the body landmarks for all handspring trials (Jaitner, Mendoza, & Schöllhorn, 2001). The calculated joint angles (knee, hip, shoulder) were specified with regard to the frontal horizontal body axis, thereby reflecting flexion and extension movement (Behnke, 2001).

Procedure

The study was conducted in three phases. In the first phase the gymnast arrived at the gymnasium. She was informed about the general procedure of the study. In particular, the gymnast was told that she takes part in a study on kinematic analysis of the handspring on vault. The study was conducted in compliance with the Helsinki Declaration and the International Principles governing research on humans, as well as in line with the ethical guidelines of the local ethics committee. The gymnast gave her informed consent, and was given a 20-minute warm-up period. After warm-up, the gymnast was allowed one familiarization trial. In the second phase, the gymnast performed ten handsprings on vault. She was allowed to take breaks as requested and there was no time pressure. In the third phase, and after completing the ten handsprings on vault, the gymnast was debriefed and dismissed into an individual cool-down period.

Data Processing and Analysis

The free statistic software R (R Core Team, 2017) was used for further data processing and analysis. The further data analysis comprised two steps: In a first step, the prototypical movements of the handspring on vault were identified by means of a hierarchical cluster analysis. Therefore, euclidean distances were calculated for each time course of joint angles (see equation 1: *x* and *y* denote a corresponding joint angle between a pair of two handsprings and *i* denotes a point in the rescaled time interval [0;1000]). The resulting values were summed up to form one euclidean distance value for each pair of two handspring trials. Thereby a value of zero would have indicated an exact identical course of two handspring trials whereas the larger the resulting value, the more dissimilar two trials were.

Equation 1: $d(x,y) = \sqrt{\sum_{i=1}^{n}(x_i - y_i)^2}$

The resulting euclidean distance values were recorded to a distance matrix, indicating the similarity between each pair of two handspring trials. In order to classify all trials by means of their similarity, the euclidean distance matrix was evaluated quantitatively by a hierarchical cluster analysis using Ward's hierarchical clustering method (Ward, 1963). It was decided to use Ward's method because this is an agglomerative clustering method that is based on a classical sum-of-squares criterion, producing groups that minimize within-group dispersion at each fusion step (Murtagh & Legendre, 2014). The classification result was represented by a two-dimensional tree diagram illustrating the fusions or divisions made at each stage of the analysis. The number of clusters was determined by inspecting the scree plot in terms of the elbow criterion (Everitt & Dunn, 2001). In a second step and in order to characterize each of the prototypes, the time courses of the joint angles were averaged over the corresponding trials in each cluster. In addition, the time courses of the coefficient of variation were calculated for all joint angles of each prototype, indicating the relative extend of variability of a particular prototype along its time course (Stergiou, 2004).

RESULTS

Figure 1 presents the result of the hierarchical cluster analysis. Four subgroups (i.e., clusters) could be distinguished from each other following the inspection of the scree plot of the cluster analysis. Each of the four clusters thus comprised handspring trials that were more similar to trials within a particular cluster, but which were more dissimilar to handspring trials in the other clusters. Therefore, each cluster characterized a particular handspring prototype within the sample of all analyzed handspring trials. Inspecting the individual clusters revealed that prototype #a comprised 17 handspring trials (28.33%), and prototype #b comprised 15 (25%) handspring trials. Prototype #c contained 7 handspring trials (11.67%), and prototype #d contained 21 handspring trials (35%). A subsequent Chi-square test revealed a statistical trend that the amount of handspring trials was not distributed equally between the four clusters, $\chi^2 = 6.93$, $p = .07$, indicating that some handspring prototypes appear more frequently in gymnasts, such as prototype #d, while other prototypes appear less frequently, such as prototype #c.

Prototype 1

In cluster #a, 17 trials were grouped together. A picture sequence of an exemplary trial can be seen in Figure 3a. Exemplary time courses of hip and shoulder joints can be found in Figure 2a and 2b. A typical handspring trial from cluster #a comprised the following characteristics: 1) slightly inclined trunk with open shoulder angle during touch-down on springboard, 2) inclined trunk, slightly flexed hip joint and open shoulder angle during take-off from the springboard, 3) slightly flexed hip joint, open shoulder angle and trunk orientation close to 45° during touch-down on the vaulting table, 4) slightly overarched back, and stretched hip and shoulder joints during take-off from the vaulting table, and 5) straight back with slightly flexed hip and knee joints and open shoulder angle during touch-down on the landing mat. There was a rather small coefficient of variation for the hip joint and the knee angle over the time course (0 - 0.1). For the shoulder angle, the coefficient of variation was about 0.2 at the take-off phase which decrease to 0.1 during the first flight phase. Exemplary time courses of the coefficient of variation of hip and shoulder joints for the four prototypes can be found in Figure 2c and 2d.

Prototype 2

In cluster #b, 15 trials were grouped together. A picture sequence of an exemplary trial can be seen in Figure 3b. Exemplary time courses of hip and shoulder joints can be found in Figure 2a and 2b. A typical handspring trial from cluster #b comprised the following characteristics: 1) upright trunk orientation with shoulder angle slightly larger than 90° during touch-down on springboard, 2) inclined trunk, slightly flexed hip joint and open shoulder angle during take-off from the springboard, 3) slightly extended hip joint, slightly flexed shoulder joint and trunk orientation close to 45° during touch-down on the vaulting table, 4) considerable overarched back, stretched hip and shoulder joints during take-off from the vaulting table, and 5) straight back with slightly flexed hip and knee joints and open shoulder angle during touch-down on the landing mat. There is a small coefficient of variation for the hip angle and the knee angle over the whole movement (below 0.1). The shoulder angle showed a larger coefficient of variation (about 0.15) at the take-off phase, the beginning of the first flight phase, the end of the second flight phase and the landing phase and a coefficient of variation about 0.1 at the rest of the movement. Exemplary time courses of the coefficient of variation of hip and shoulder joints for the four prototypes can be found in Figure 2c and 2d.

Prototype 3

In cluster #c, 7 trials were grouped together. A picture sequence of an exemplary trial can be seen in Figure 3c. Exemplary time courses of hip and shoulder joints can be found in Figure 2a and 2b. A typical handspring trial from cluster #c comprised the following characteristics: 1) upright trunk orientation with shoulder angle less than 90° during touch-down on springboard, 2) inclined trunk, slightly flexed hip joint and shoulder angle greater than or equal to 90° during take-off from the springboard, 3) slightly flexed hip joint, flexed shoulder angle and trunk orientation angle smaller than 45° during touch-down on the vaulting table, 4) considerable overarched back, stretched hip and flexed shoulder joints during take-off from the vaulting table, and 5) slightly overarched back with stretched hip and knee joints and open shoulder angle during touch-down on the landing mat. In terms of the variation of the movement for the different trials, there is a low coefficient of variation for all joint angles over the time course (0 - 0.1). Exemplary time courses of the coefficient of variation of hip and shoulder joints for the four prototypes can be found in Figure 2c and 2d.

Prototype 4

Finally, in cluster #d, 21 trials were grouped together. A picture sequence of an exemplary trial can be seen in Figure 3d. Exemplary time courses of hip and shoulder joints can be found in Figure 2a and 2b. A typical handspring trial from cluster #d comprised the following characteristics: 1) upright trunk orientation with shoulder angle larger than 90° during touch-down on springboard, 2) inclined trunk, slightly flexed hip joint and shoulder angle greater than 90° during take-off from the springboard, 3) slightly flexed hip joint, open shoulder angle and trunk orientation slightly greater than 45° during touch-down on the vaulting table, 4) straight back, trunk orientation about +10° from vertical, stretched hip and shoulder joints during take-off from the vaulting table, and 5) straight back with slightly flexed hip and knee joints and open shoulder angle during touch-down on the landing mat. In terms of the variation of the movement for the different prototypes, the knee angle shows a coefficient of variation of 0.2 at the take-off which decreased until nearly zero at the end of the first flight phase. There was a small coefficient of variation for the hip angle(0 - 0.1) over the time-course. For the shoulder angle, the coefficient of variation was about 0.2 at the take-off phase and decreased to 0.1 during the first flight phase. Exemplary time courses of the coefficient of variation of hip and shoulder joints for the four prototypes can be found in Figure 2c and 2d.

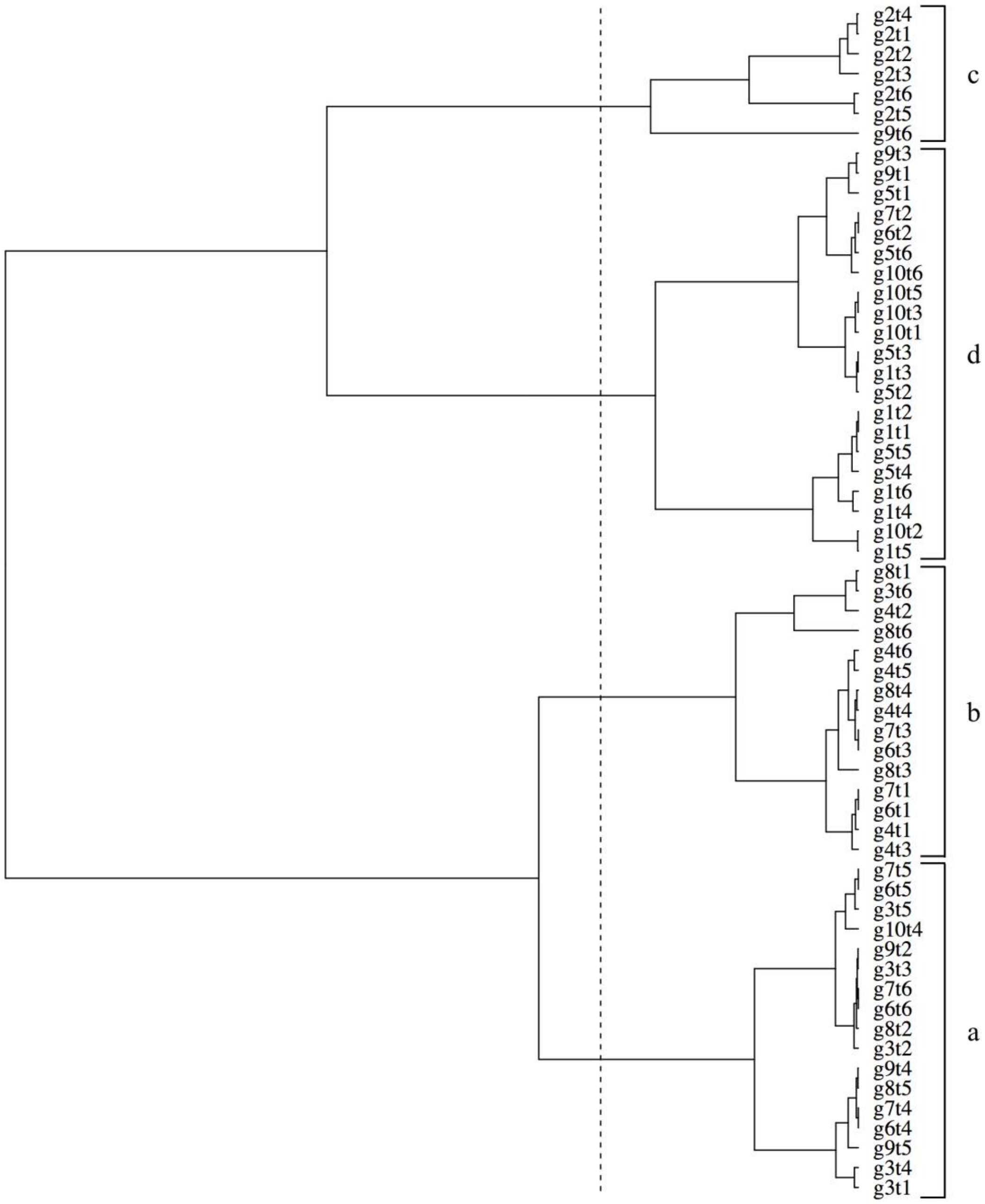

Figure 1. Tree diagram resulting from a cluster analysis using Wards' clustering algorithm. Horizontal lines indicate the level of the distance at which the respective handspring trials are grouped into one cluster. *Notes:* The dashed line represents the euclidean distance below which the clusters are identified. The letters "a)" to "d)" correspond to the four clusters, containing the different prototypical movement patterns of the handspring on vault. *g1t1* to *g10t6* represent the analyzed handspring trials.

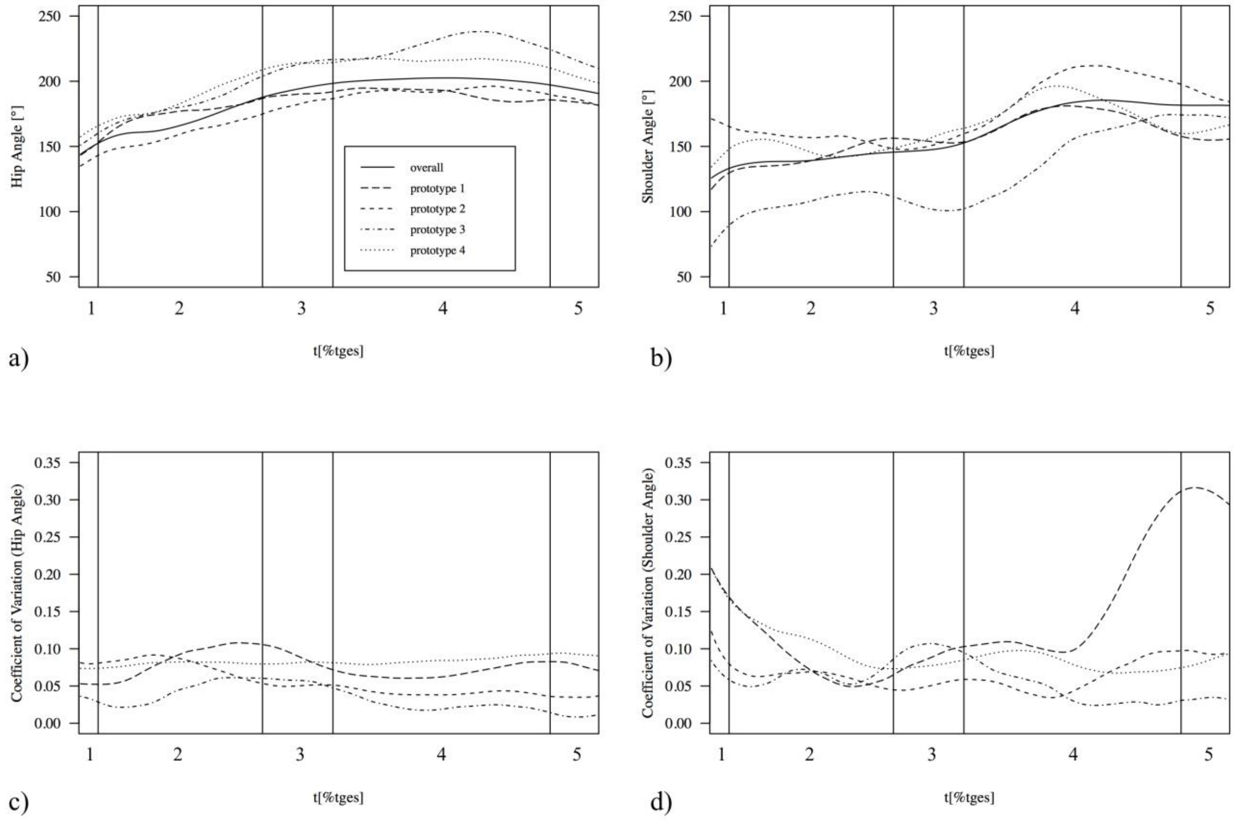

Figure 2. Illustration of time-normalized angle-time plots for the prototypical courses of the shoulder angle (a) and hip angle (b), as well as time courses of the corresponding coefficients of variation for the different prototypes (c, d). *Note:* 1 = take-off phase from springboard, 2 = first flight phase, 3 = repulsion phase, 4 = second flight phase, 5 = landing phase.

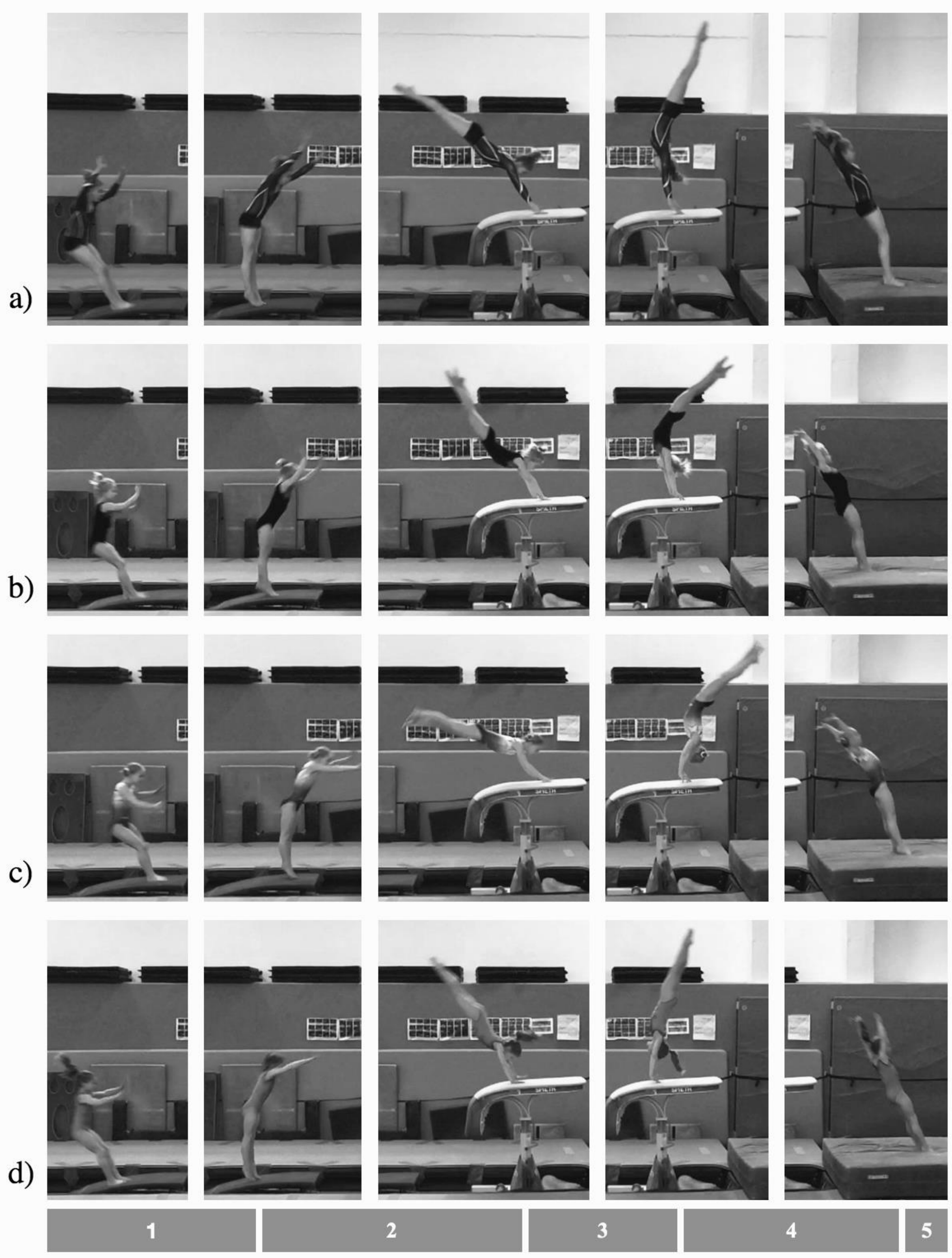

Figure 3. Illustration of the four handspring prototypes (see also Figures 1 and 2). a) Prototype #1, b) Prototype #2, c) Prototype #3, d) Prototype #4. *Note:* Each picture sequence shows one exemplary handspring trial of each prototype cluster. The letters “a)” to “d)” correspond to the four clusters in Figure 1. The number “1” to “5” correspond to the movement phases of the handspring (see Figure 2).

DISCUSSION

Most of the research concerning the kinematic analysis of gymnastics skills deals with selected variables. Because humans perceive movement in a holistic way, the goal of this study was to develop a method to analyze a front handspring on vault in a holistic fashion. To gain insight into a complex motor skill like the handspring on vault, different prototypes of the movements should be quantitatively detected and its variant and invariant characteristics should be qualitatively investigated. The results of this study revealed that for near-expert gymnasts four prototypical movement patterns could be identified. The four different prototypes can be differentiated by certain variant and invariant characteristics such as the time courses of the different joint angles and their coefficient of variation.

Concerning the assignments of the trials to one prototype one can see that the trials from one person are not assigned consistently to the four prototypes but rather most of them. This highlights that the pattern of movement characteristics stays similar over a high amount of trials, thus that there are structural similarities in space and time (Troje, 2002). When engaged in a goal-directed activity, like a handspring on vault, performers exhibit different coordination states. Those coordination states are not stable but contain variability leading to a set of movement options that could be described by a specific composition of biomechanical parameters (Latash et al., 2002). This instability might explain why not all trials of one gymnast are assigned to one prototype. Variations in the movement patterns are carried out through an interaction of the body as complex biological system with different constraints provided by the task, the environment or psychological factors leading to movement variability (Higgins, 1977).

Comparing the description of the four prototypes with the Code of Points (FIG, 2017), there are prototypes which meet the criteria for a high scoring and prototypes which might get deductions. According to the Code of Points (FIG, 2017), there are deductions for a poor technique regarding the hip, the shoulder and the knees. Out of the identified four prototypes, the movement patterns of prototype #a and prototype #d might meet the criteria the most. They are characterized by extended knees and hip and an open shoulder angle. The movement patterns of prototype #b and prototype #c might get the worst scoring.

There are limitations of this study and three specific aspects should be highlighted. First, looking at the tree diagram of the cluster analysis, one might assume that the trials could also be distributed into two, five or even six clusters. When analyzing the pattern of the movement characteristics it was revealed that by distributing the trials into two prototypes, a high number of structural features would be ignored, which could improve the description of the movement. On the other side, taking five or six prototypes would not improve the description of the movement. These findings are in line with the results given by the elbow method, which looks at the percentage of variance explained as a function of the number of clusters.

Second, the study was conducted with near-experts at one point in time. For that reason, it is unclear whether the number of clusters and the distribution of the trials of one athlete to the different clusters are the same for top experts or novices and how the distribution to the different clusters change over time. One might assume that training leads to a change of the distribution of the movement execution to the different clusters. Either the movement patterns become restructured, which would be reflected in a more reliable distribution of different skill executions to one cluster. Or the distribution of the skill executions of one athlete moves to a different cluster, which would be reflected in a less reliable distribution of different skill executions to one cluster.

Third, there should be some effort to study other gymnastic movements and their prototypical movement structures as well as how they appear in the variant and invariant features. This is relevant particularly in gymnastics because of the varying environmental constraints due to the different gymnastic apparatuses. The handspring is not only performed on vault, but it is also part of floor routines. The same fundamental movement has to be carried out in different ways, dependent on the features of the gymnastic apparatuses.

Furthermore, it would be interesting to investigate the relations between movement characteristics and the evaluation of the performance. It should be investigated whether the different prototypes are scored differently and how the movement characteristics, especially their variant and invariant features, find expression in observers' gaze behavior and when judging and evaluating the corresponding prototypes.

The current approach opens up interesting practical applications. With regard to gymnastics training, this study provides further evidence for the demand of individuality in training in terms of an optimal organization of the complex functional movement system to solve the movement task. By an adjustment of the skill execution of one athlete with the different prototypes, the skill level of the athlete could be easily determined and a specific training could be implemented. Depending on the similarity of the skill executions of one athlete to one specific prototype, different instructions in the training process might be beneficial.

CONCLUSION

Overall, the approach utilized in this study allows one to identify structural characteristics of movement patterns of a complex gymnastics skill. Therefore, this approach seems to be an appropriate and promising tool, not only for the analysis of gymnastics skills but also for a wide range of applications in various adjacent areas. The results open up practical applications as well as further fruitful research questions.

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THE USE OF AUDIOVISUAL STIMULATION IN LEARNING GYMNASTIC ELEMENTS

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Original article

Abstract

Nowadays, more and more people are aware of the difficulty to reach imposed goals and in their craving to improve their performance they often turn to different methods that help them realize their goals. The market offers many services, methods, products and machines that guarantee and promise better results. The purpose of this research was to study the impact of audio-visual stimulation (hereinafter: AVS), followed by visualization of gymnastic elements, on the improvement in performance of those gymnastic elements. The study was conducted on 39 first year students of the Faculty of Sport in Ljubljana, which attended the classes of Gymnastics and 19 of them, who were in the experimental group, attended AVS lessons twice a week. We expected AVS and visualization sessions to effect motor learning of gymnastic elements positively. Through the students' execution of gymnastic elements it was established how much the students had improved from the first lesson to the assessment. For audio-visual stimulation, the device "Therapeut", where the participants attended an 11 minute program, that stimulated alpha and *beta waves and should leave the participants refreshed and creative. Meters to determine heart rate and blood saturation, music and questionnaires with a scale to determine well-being were used. Progress of motoric learning of gymnastic elements, heart rate decline as well as changes in saturation and well-being were monitored. No results obtained in the observed parameters showed that we had any impact on the improvement and our study did not reveal any impact of AVS on the improvement of the observed parameters.*

Keywords: *audio-visual stimulation, motor learning, imagery, heart.*

INTRODUCTION

More and more people are aware of the difficulty to reach imposed goals without good mental preparation (Kajtna & Jeromen, 2013). In their craving to improve their performance, results and to be more successful in business, private life and sports, they turn to many methods that help them reach and realize their goals (Gallucci, 2008; Harwood & Anderson, 2015). The market offers many services, methods, products and machines that guarantee and promise a quicker path towards achieving those goals. One of those methods is also audiovisual stimulation (AVS), which claims to change the functioning of a person by subjecting the person to sounds and visual patterns of frequencies, that match different brain waves (Poznik, 1990).

Alpha waves (8 - 12 Hz) are one of the more simple forms of brain activity. They are present in people who are awake, relaxed and processing information automatically (Davies, 2012). The highest amplitudes of alpha waves come from the frontal and occipital cortex. Alpha waves appear also during physical activity, but only when athletes are very focused (Ricker, 2015; Evans & Turner, 2017). Beta waves (13 Hz and higher) are present at fast and intensive brain activity, for example in people who are awake and attending to internal (mental) or external events. Beta waves are strongest in frontal cortex and indicate brain functioning on the highest level. They have high frequencies, but lower amplitude than alpha waves (Ricker, 2015). Theta waves (4 – 8 Hz) indicate that a person is in a light sleep from which he or she can be awakened easily. They can also appear shortly when a person is awake and exposed to stressful circumstances or events (Davies, 2012). Theta waves originate in hippocampus and limbic system (Ricker, 2015). Delta waves have the highest amplitudes (< 4 Hz) and indicate deep sleep or even vegetative state in which people are not aware of their surroundings. They are dominant in children up to 1 year of age (Ricker, 2015; Davies, 2012). Davies (2012) and Evans and Turner (2017) support the claim that if we create these waves in the environment, then the brain will tune in to them and start functioning in the same wave length, thus creating corresponding psychological states. For example, a person exposed to light and sound of alpha frequency will become relaxed and will process information automatically.

Motor learning is a process of acquiring new motor skills and new motor knowledge, which is reflected in new synaptic connections in the brain, i.e. central nervous system, exercise is what helps store this motor knowledge in the brain, mainly in the motoric part of the cortex (Ušaj, 2003). The more we exercise and practice a skill, the stronger are synaptic connections and the more automated the process of execution this motor skill. Motor abilities are in part innate and in part acquired during the development (Pistotnik, 1999). We differentiate the following forms of motor abilities: speed, balance, power, coordination, flexibility, precision and persistence (Videmšek, Berdajs, & Karpljuk, 2003). These abilites are limited by biological as well as psychological factors (learning requires conscious control of movement), therefore we can also categorize them as psychomotor abilities.

Martens (1997, in Kajtna & Jeromen, 2013) and Fitts and Posner (1967, in Magill, 2011) defined three phases of motor learning:

- Cognitive stage: it begins when we decide for learning and ends when we know basics of movement. Athlete understands the movement and has a correct perception of it.
- Associative stage: athletes are able to execute movement correctly, but only in known circumstances and without additional challenges. Basic movement is fluent and almost automatic, which means that the motor skill is almost completely learned and control of movement decreases. Execution of movement is becoming more and more consistent, the number of mistakes decreases. Athletes are able to detect mistakes on their own, which enables them better control of training.
- Autonomous stage: athletes execute movements accurately and precisely. Motor skill is learned – it is realiable and perfected. Movements are economic and fluent, athletes are selfconfident. Automatisation of movement enables them to focus their energy on details and their surroundings.

Another model for motor learning is the Gentile's two stage model (1987, in Magill, 2011), which stets that in the first stage of motor learning is "getting the idea of the movement", which involves getting to know the patterns of movement, learning appropriate motion, coordinating different parts of the movement… The second stage is "fixation/diversification" and it involves adapting the movement pattern to the different situations in the environment and improving the consistency of the movement. Schmidt and Lee (2011) state that mental practice (or visualization) can enhance motor learning in all stages.

The term visualization refers to the cognitive process of intentionally generating visual mental imagery of a certain movement, skill or experience, without actually executing the movement (Cox, 2012). Visualization or imagery, as it is also called, is a technique, frequently used in sport psychology to help the person learn new motor skills or prepare for an execution of movement (Williams, 2010), it is often a part of athlete's precompetitive routines (Cox, 2012). When the athlete imagines jumping, the reaction of brain, and thus nerves and muscles, is similar to that of the real jump – it creates the same pattern of brain activation, as shown by EEG, it is only smaller in amplitude (Gallucci, 2008; Karageorghis & Terry, 2011). Thus visualization is often used as a method of mental training for acquisition or improvement of motor skills, motivation, self-confidence, technical and tactical elements in sport (Kajtna & Jeromen, 2013), it can be used for problem solving, pain control and in rehabilitation (Vasundhara & Noohu, 2014).

The effectiveness of visualization was proven in an experiment by Vasundhara and Noohu (2014). They studied the effect of mental training on a group of 30 amateur basketball players. One group trained by classic methods, while other group also used mental practice, a term, which is also frequently used for visualization. The progress was more significant in second group that used also visualization, they also found that visualization and actual movement create ta similar reaction in the brain, only different in intensity (Vasundhara & Noohu, 2014). Even though they looked for effects of visualization on improvement of strength and balance in recreational basketball players, not on its effect of learning new motor skills in novice learners, they show its use in the field of improving motor abilities. Other authors found thet learning is faster when mental and physical practice are used together - McBride and Rothstein (1979) found this in precision tasks and Meacci and Price (1985) came to the same conclusion in golf. If visualization is performed regularly and in a structured manner, it can importantly improve motor skills in sports. Mental preparation, which includes visualization, also contributes to better focus and helps prevent burnout (Stankovič, Raković, Joksomović, Petkovič, & Joksomovič, 2011). Schott, Frenkel, Korbus, and Francis (2013) believe that visualization is the most effective when joined with relaxation. Visualization was used in this study in order to strengthen the memory of learned gymnastic elements, while the AVS was intended to enable frequencies of brain waves, which enable relaxation and readiness to learn, therefore Alpha and Beta waves (Davies, 2012)

Visualization is most effective when performed in a peaceful and relaxed state, which enables better focus during the training. To be relaxed means to have a calm body and a calm mind. State of relaxation can be achieved not only through physical rest, but also through activity (mental or physical). In this case people have a feeling of an easy, effortless execution and pleasant tiredness after activity, therefore even relaxation is a form of activation (Jeromen & Kajtna, 2008). Eason, Brandon, Smith, and Serpas (1986) claim that relaxation in sport helps to achieve better focus and attention, decreases anxiety, heart rate, frequency of breathing and muscle tension.

Hanafi, Hashim, and Ghosh (2011) stress two techniques of relaxation, progressive muscle relaxation (PMR) and autogenic training (AT). PMR was developed by Jacobson in the early 1920s, its purpose is to teach people relaxation by first teaching them the difference between relaxed and tense muscles (Gallucci, 2008) - it is an active method of relaxation, which is also quite adaptable to the individual using it. AT is a more passive relaxation technique and is based on autosuggestion – it's founder Schultz has shown that we start to feel what we suggest ourselves to feel (Lindemann, 1988). Hanafi et al. (2011) tested the effects of those techniques on top athletes in between two highly intensive workouts and measured several characteristics, for example: heart rate, maximum usage of oxygen during the workout ($VO2_{max}$), reaction time and subjective grade of effort. Results showed no short or long-term effects of relaxation for most of the measured characteristics, the only positive effect was seen for reaction time, indicating improvement of psychomotor abilities. Besides that the heart rate descreased during relaxation - a similar effect in children was found by Lohaus, Hebling-Klein, Vogel, and Kuhn-Hennighausen (2001). They found out that the use of relaxation techniques, such as guided fantasy, resulted in lowered heart rate in children, who also claimed they feel better after execution of relaxation techniques. In our study we used AVS to relax, as additional use of relaxation techniques would have been too time consuming for the participants.

Audio and visual stimuli in the process of AVS is represented by monotonous and rythmic sounds and flashes of light (Davies, 2012; Evans & Turner, 2017). The brain responds to the stimuli with an electrical impulse, which travels through the brain and becomes the sound/picture we hear/see. Audio visual stimulation effects people on two levels ("Audio-vizuelna stimulacija s focus-om 101", 2015):

- autonomous nervous system effects relaxation of a person - it decreases heart rate, muscle tension and blood pressure;
- central nervous system changes center of thalamus to a negative level, consequently people become more alert.

The use of AVS means that a person is subjected to sound and light impulses of a certain frequency, which is chosen according to the desired intention. If we wish to enable learning, we expose the person to the frequencies of Beta waves, if we want relaxation, to Alpha waves. The brain should then synchronize with those impulses and the hypothesized outcomes are (Poznik, 1990):

- Improved capability to stay calm in stressful situations
- Deep muscle relaxation
- Termination of negative routines
- Improvement of immune system
- Changed sleep rhythm
- Improved learning abilities
- Improved focus and visualisation

Not much research has been carried out in the field of audio-visual stimulation, however few papers that exist prove positive effects of it. Siever (2006) performed audio-visual stimulation on a group of elderly people with stimuli of 18 and 20 Hz (Beta waves) for left and 10 Hz (Alpha waves) for right brain hemisphere. Results showed significant mood improvement and significant decrease in symptoms of depression. Siever proved positive effects of AVS also in other circumstances. For example, he reports significant improvement of technique, visualisation, motor learning and results in professional golf players. Besides that Siever (2012) also proved significant improvement of memorisation, focus and grades in students after AVS.

Budzynski and Budzynski (2001) report significant improvement of mental capabilities after AVS in 75-year old male. Cruceanu and Rotarescu (2013) proved that the exposure to 30-minutes of audio-visual stimulation with the frequency of 10,2 Hz significantly improves cognitive skills. Based on their research, authors claim that people need to be exposed to AVS at least for 20 minutes in order to achieve positive effects. Even first signs of relaxation (body movements, body language, tension of face muscles) appear only after 15 minutes of exposure to AVS. Kennerely (2004) on the other hand reports about positive effects of AVS after 5 minutes of exposure. Goodin et al. (2012) claim that even shorter period of time is needed. They noticed changes in brain waves two seconds after the beginning of AVS. So even if AVS is often referred to as a method to improve learning, it is rarely tested in experimental and verifiable conditions and the purpose of our research was to do just that – to verify the effects of audio-visual stimulation on motor learning and progress in gymnastics.

In our research we focused on motor learning of gymnastic elements. Sports gymnastics is one of the basic sports, its elements are of extreme importance for motor development of an individual, as it teaches conscious control of body position and movement (Čuk, 1996). One of the most important tasks of gymnastics is therefore to enable development of basic motor skills, such as power, coordination, flexibility, balance and speed (Zajc, 1992). Learning of motor skills depends on the amount of experience, which is enabled through visualization (Cox, 2012). We wanted to see if participants would gain gymnastic skills faster by being exposed to visualization, especially as we supported this process by first establishing brain waves, which enable relaxation and readiness to learn through AVS.

Our research questions are:

- How does exposure to AVS affect motor learning of gymnastic elements? According to research of Siever (2012), Budzynski and Budzynski (2001) and Cruceanu and Rotarescu (2013) cognitive abilities and learning are improved upon exposure to AVS – is our experimental group going to be more successful in learning gymnastic elements after attending both gymnastics lessons and AVS sessions, followed by visualization than the control group, who will only attend gymnastics lessons?
- How does exposure to AVS affect heart rate and blood saturation through different time points? Kennerely (2004) and Goodin et al. (2012) mention different times to be needed for achieving desired results and we wanted to see what happens during the exposure to AVS.

Upon reviewed literature we set the following hypothesis:

H1: AVS, followed by visualization, effects motor learning of gymnastic elements positively.

H2: AVS is going to decrease heart rate.

H3: AVS is going to decrease oxygen saturation in blood.

METHODS

Participants

39 students of Faculty of Sport at the University of Ljubljana participated in the study, 20 of them (10 male and 9 female) were assigned to experimental and 19 (10 male and 10 female) to control group. The number of participants was chosen according to the size of groups in the subject at the Faculty and the small size of samples was taken into account when performing statistical procedures. All participants were students of first year of bachelor program Sports Education and had no prior knowledge of gymnastics. Participants were included in subject Sports gymnastics for the first time. We chose them based on their grades of gymnastic elements, that they performed on the first hour of subject. The sum of grades was obtained by summing up the grades they obtained in the initial evaluation of 8 gymnastic elements, which was performed by teachers of the subject.

Table 1

T test for differences in gymnastics knowledge for control and experimental group.

Variable	Status	*M*	*SD*	*t*	*p*
Sum of grades for gymnastics elements	Experimental group	26,84	2,22	0,11	0,92
	Control group	26,70	5,57		

Legend. *M* - mean, *SD* – standard deviation, *t* – t value; *p* - significance

Table 1 shows that the level of statistical significance of *t* is 0,92, which shows that there were no significant differences in expertise level of gymnastics between students of control and experimental group before the beginning of the study.

Instruments and materials

Audio-visual stimulation was carried out with a tool for stimulation called Therapeut (Poznik, 1990.) and music background. Therapeut is a device that stimulates brain waves and brain activity through usage of headphones and glasses – sound of desired frequency are emitted through headphones, while flashes of light of the same frequency appear inside the glasses. Its goal is to reach a certain frequency of brain waves (alpha, beta, theta or delta) therefore the device produces stimuli (sound and light) with a chosen frequency of brain activity. The stimuli is reproduced in peoples brains in a form of electrical impulses that have the same frequency as external stimuli from the device. Final effect of exposure to Therapeut is a psychophysical relaxation, which feels similar to state of light sleep. People's minds are still present and conscious to a certain extent, while their bodies are completely relaxed (Poznik, 1990). The use of this AVS device was selected as it is was the only one, where several people could attend the AVS programme at the same time and from the perspective of our study design this was necessary.

For the measurement of mood we used Brunel Mood Scale (Terry & Lane, 2010), where participants evaluate 24 of their feelings and moods on a scale from 0 to 4, 0 being worst and 4 being the best possible feeling. The feelings and moods are then summed up into 6 categories, examples of feelings and moods for each category are given in parenthesis: depression (unhappy), tension (panic), fatigue (sleepiness), anger (bitterness), vigor (active) and confusion (indecisive). The Slovene translation of the scale was used (Šešum, 2015).

Finally, to measure oxygen saturation and heart rate we used Oxymeter by Guandong Biologht Meditech Co. Ltd.

Gymnastics elements and routines in the research were carried out with the help of following apparatus: vault, balance beam, floor, uneven bars and rings.

Procedure

Pre-test procedure was distributing the students into two equal groups according to their knowledge of gymanstics, as evaluated by the teachers of the subject. Then the experimental group participated in AVS programme (followed by visualization) for 3 months, 2 times a week, and attended the subject Sports gymnastics, while the control group just participated in the subject without attending the AVS sessions. The experimental group attended AVS programme immediately after lessons of practical exercises of gymnastics so that as little time as possible passes between practising and then solidifying the knowledge. The control group received no treatment because we wanted to see what the progress would be like just by attending the classes and lectures of the subject at the Faculty. After 3 months of AVS and lessons of Sports gymnastics both groups of students took a practical exam of gymnastics skills, which was graded by two professors on a scale from 5 to 10 points, with differences of 0,10 point between grades. We compared control and experimental group based on grades of this practical exam. Students performed 13 gymnastic elements, which are all part of the exam:

- straddle vault
- squat vault
- connection of two rolls backwards
- round- off with 180 turn forward
- handspring forward (flip forward)
- headspring forward
- parallel bars routine
- balance beam routine,
- floor routine,
- uneven bars routine,
- horizontal bar routine,
- swinging ring routine
- still ring exercise.

For audio-visual stimulation on a device Therapeut we chose program number 4 that combines alpha and beta waves, which exchange for 11 minutes. Manual describes the chosen program as refreshing and creative. The duration of this program corresponds to the duration of frequently used relexation techniques, such as AT or PMR (Kajtna & Jeromen, 2013).

Students were in a lying position during AVS. The light in a room was slightly dimmed in order to create calm and peaceful environment. In the background we also included calm music, which was composed by K Brandstaetter fort he relaxation exercises in the book called Relaxation – my little manual (Jeromen & Kajtna, 2008). AVS lasted for 11 minutes. Throughout AVS we also measured heart rate and oxygen saturation – and checked the values before and after the conclusion of the AVS session.

After 11 minutes of AVS students visualised gymnastic skill they practiced at gymnastics that week. After every executed skill, students filled the Brunel Mood Scale and answered two open type questions about their feelings and thought during exercises. Last two questions measured focus and calmess during AVS on a scale from 1 (not at all) to 5 (very).

Besides AVS students participated at class Sports gymnastics, which contains theoretical (1 hour per week, all together 15 hours) and practical (3 hours per week, all together 45 hours) part. The purpose of this class is to inform students about characteristics and importance of gymnastics in schools and sports association (Čuk, Bolkovič, Bučar-Pajek, Turšič, & Bricelj, 2006). Lectures (theoretical part) followed didactic principles, recommended order of teaching of gymnastics skills and motor development of students.

Data analysis

Data was analyzed using SPSS 21.0 for Windows, we used descriptive statistic for checking changes in emotional states, heart rate and oxygenation after AVS and visualisation sessions and t – test for verifying the differences between the experimental and control group before the experiment began and after the conclusion of the experiment.

RESULTS

Firstly we tested differences between control and experimental group in exam grades for the previously stated gymnastic elements. Comparison of grades of each element of students in the experimental and control group and of the number of successfully completed elements show, that there were no differences in the grades for each element, but that the students in the control group successfully completed more routines at the final exam ($M = 6.10$, $SD = 1.65$) than the experimental group participants ($M = 4.47$; $SD = 2.41$) ($t = -2.44$; $p = 0.02$). Control group received better grades for execution of gymnastic skills than experimental group in 8 out of 13 elements. Experimental group executed better only 5 elements and despite described differences between control and experimental group, we need to stress that grades of control and experimental group were very similar and statistically insignificant. Groups were thus significantly different only in number of executed routines, which was higher in control group.

Furthermore, results of analyses of heart rate after audio-visual stimulation are shown in Figure 1. Figure 1 shows unsystematic heart rate change after every measurement, therefore we can not detect a specific trend of changes. We found no reference values for a similar type of research, so it's not possible to evaluate the size of the change in heart rate.

Next we focused on change in oxygen saturation after audio-visual stimulation. Results are shown in figure 2.

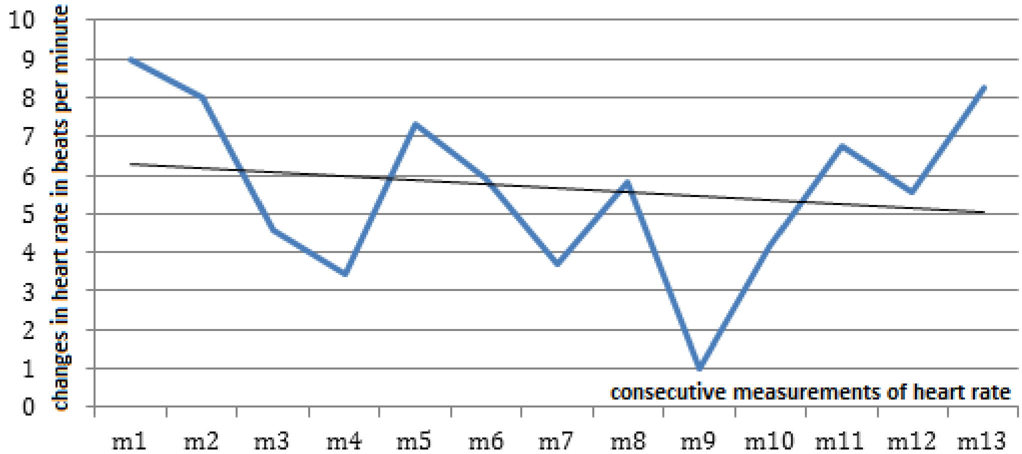

Figure 1. Mean group changes in heart rate before and after AVS and visualization sessions.

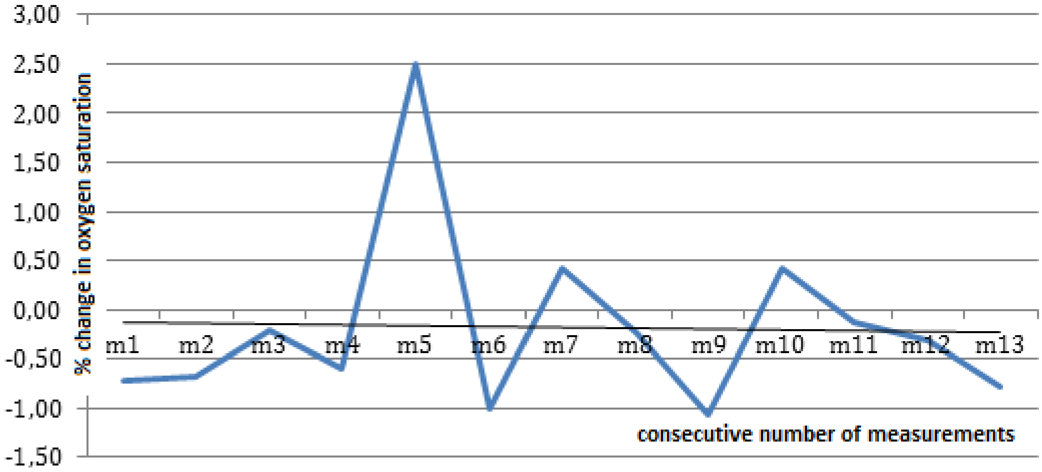

Figure 2. Mean group changes in oxygen saturation before and after AVS and visualization sessions.

Figure 2 shows that changes in oxygen saturation are not consistent or systematic, in some measurements levels dropped, while at others the levels of oxygen saturation increased. We found no reference values for a similar type of research, so it's not possible to evaluate the size of the change in oxygen saturation.

Table 2 shows results of questionnaire about mood and feelings of students after exposure to audio-visual stimulation.

Most of the feelings (depression, tension, tiredness, anger and confusion) decreased in time, while liveliness changed unsystematically in-between measurements. Moreover we examined students assessments of their focus and calmness after AVS. Results are shown in Table 3.

Table 3 shows there were no significant changes in focus and calmness of students after AVS. Students reported a medium level of calmness during AVS, similar is also true for focus.

Table 2
Grades of feelings after AVS.

Variable	m1 *M*	m1 *SD*	m2 *M*	m2 *SD*	m3 *M*	m3 *SD*	m4 *M*	m4 *SD*	m5 *M*	m5 *SD*	m6 *M*	m6 *SD*	m7 *M*	m7 *SD*
Depression	1.22	1.05	1.21	1.47	1.00	1.54	1.33	1.61	1.26	1.82	0.89	1.94	1.60	2.53
Tension	1.66	1.58	1.63	1.57	1.53	2.67	2.22	2.05	1.16	1.46	1.28	1.84	1.47	1.96
Tiredness	6.18	2.67	6.58	3.44	6.82	4.17	5.00	3.87	5.89	3.86	5.33	3.24	4.33	3.64
Anger	1.23	1.75	1.05	1.58	1.00	1.50	1.56	1.58	1.11	1.49	0.89	2.30	1.40	2.13
Liveliness	5.17	1.96	5.32	3.61	3.41	2.98	4.83	3.68	3.21	3.29	3.39	3.42	3.87	3.52
Confusion	3.68	1.89	3.84	3.13	2.18	2.40	2.17	2.48	1.95	2.15	1.44	1.89	1.87	2.00

Variable	m8 *M*	m8 *SD*	m9 *M*	m9 *SD*	m10 *M*	m10 *SD*	m11 *M*	m11 *SD*	m12 *M*	m12 *SD*	m13 *M*	m13 *SD*
Depression	1.63	2.58	0.50	1.00	1.25	2.82	0.43	0.65	0.44	1.20	0.56	1.15
Tension	1.19	2.04	0.67	0.89	1.25	2.41	0.86	1.41	1.33	2.22	0.67	1.28
Tiredness	5.00	4.86	4.33	2.81	4.69	3.40	3.57	2.74	4.39	3.15	5.28	3.75
Anger	0.88	1.75	0.25	0.62	1.31	2.70	0.36	0.84	0.28	0.75	0.78	1.52
Liveliness	3.50	3.74	5.00	3.57	3.94	3.97	3.07	3.22	3.72	3.98	2.89	3.34
Confusion	1.69	1.96	1.42	1.98	1.88	2.28	1.29	1.44	1.22	1.73	0.78	1.26

Legend. m1, m2, m3 … consecutive number of measurement; *M* - mean, *SD* – standard deviation.

Table 3
Focus and calmness after AVS.

	m1 *M*	m1 *SD*	m2 *M*	m2 *SD*	m3 *M*	m3 *SD*	m4 *M*	m4 *SD*	m5 *M*	m5 *SD*	m6 *M*	m6 *SD*	m7 *M*	m7 *SD*
How much I calmed down ?	3.85	0.77	3.79	0.71	3.88	0.78	3.22	1.26	3.74	0.87	3.61	0.70	3.73	0.80
How focused was I during AVS ?	3.97	0.51	3.95	0.85	3.53	1.12	3.50	0.99	3.53	0.90	3.56	0.86	3.67	1.11

	m8 *M*	m8 *SD*	m9 *M*	m9 *SD*	m10 *M*	m10 *SD*	m11 *M*	m11 *SD*	m12 *M*	m12 *SD*	m13 *M*	m13 *SD*
How much I calmed down ?	3.88	1.02	3.75	0.97	3.87	1.13	3.79	0.89	4.17	0.71	3.56	1.20
How focused was I during AVS ?	3.56	1.36	3.92	0.79	3.93	1.10	4.00	1.04	3.89	1.08	3.67	1.28

Legend. m1, m2, m3 … consecutive number of measurement; *M* - mean, *SD* – standard deviation.

Lastly, students answered an open question about their mood and general wellbeing during AVS. Most of the students reported feeling relaxed, nice, sleepy, exhausted or tired. Some participants stressed that they could not relax during AVS because of glasses and sound in the initial stages, but after three sessions most of theem said that they got used to disturbances and relaxed more easily at the end of our experiment. Two students reported that the sound of AVS is uncomfortable throughout the duration of the experiment. Most of the students found AVS very soothing and helpful for visualisation of gymnastic elements.

DISCUSSION

Our research was based on three goals. Firstly we wanted to analyze how exposure to AVS, followed by visualization, effects motor learning. Most of research in the field of AVS is not consistent with our findings and reports about significant positive effects of AVS. For example, Siever (2002) proved an improvement of technique and results in professional golf players after 12 minute exposure to AVS. To sum up, we cannot conclude that exposure to AVS effects motor learning, as our students in the experimental group did not do better than the control group in learning gymnastic elements after being exposed to AVS. We also have to reject our two hypotheses that AVS effects motor learning of gymnastics elements positively and that students, exposed to AVS, are going to receive significantly better grades for gymnastic elements than students in control group. As the AVS trainings were done in the same day as regular lessons of Sports gymnastics, we also cannot argue that the results were the result of some confounding variable such as loss of information due to forgetting.

One of the possible explanation for insignificant results could be length of exposure to AVS. Our participants were exposed to it for 11 minutes, while some authors (Cruceanu & Rotarescu, 2013) suggest that at least 20 minutes is needed for the positive effects to take place.

Furthermore, part of our reserach was also visualization of gymnastic skills, performed after AVS. Previous research consistently proved positive effects of visualization for motor learning (Vasundhara & Noohu, 2014), motor skills, performance and rehabiliation (Schott et al., 2013; Stankovič et al., 2011). Our results are not in agreement with these findings, since visualization did not have a significant positive effect on motor learning of students. However, we believe that the cause of ineffectiveness is not visualization as such, but lack of motivation and elaboration of students in visualization of gymnastic elements. Students participated at classes in groups of 20 to 25 people, therefore we had difficulties keeping all of the students motivated. We also could not determine whether every single participant understood instructions well enough for successful visualization.

Our second goal was to analyze, how does exposure to AVS effect heart rate and blood saturation through different time points. As brain waves are supposed to change during AVS, the response should be visible in the heart rate and oxygen saturation in order to see if there are any physical effects of the AVS. We used a program of AVS, which included Alpha and Beta brain wave frequencies, which was supposed to induce calmness, relaxation and readiness to learn. As general activation of the organism decreases when we relax, this is shown in lowered heart rate and increased oxygenation, we measured them to see if the AVS was efficient - the ideal measure would be to follow EEG, but as we were unable to measure EEG in our faculty, we resorted to heart rate and oxygen saturation. Results did not show conclusive trend of heart rate and oxygen saturation changes through time. Heart rate was highest after first measurement, which can be contributed to fear before first exposure to AVS or to expectations. In some measurements we noted decline of heart rate and oxygen saturation, while at others heart rate and blood oxygen saturation increased. We have to acknowledge that students came to AVS with different levels of energy and tiredness, which could influence their heart rate. Some of them were probably also nervous or stressed, which has an indirect effect on oxygen saturation. If students were not able to relax during AVS, because of other stressors in their life or tiredness, that influenced their heart rate and oxygen saturation. Besides that some students also claimed that the sound of AVS is unpleasant, which could also prevent relaxation and influence heart rate and blood oxygen saturation. Based on our results we have to reject our hypotheses, that AVS is going to decrease heart rate and oxygen saturation.

All in all we did not confirm positive effects of AVS for motor learning or decrease in heart rate and blood oxygen saturation. Since AVS is a form of relaxation we expected results similar to previous research on relaxation (for example Eason et al., 1986), which claims that relaxation contributes to better focus, decreased anxiety, heart rate, blood pressure and muscle tension. While heart rate in our case did decrease somewhat, the change was small. Therefore we can not confirm positive long term effect of AVS, only positive short term effects in some cases. Similar conclusion was produced also by Conte (2013), who reports about decreased heart rate only during AVS. The reason for our inconclusive results could be in number of AVS sessions. Hanafi et al. (2011) found out that even 12 sessions of relaxation are not enough to produce long term positive effects of relaxation, we had 13 sessions. On the other hand, Lohaus et at. (2001) claim that even five session should result in long term positive effects. Our results do not support their claim.

In our research students also filled out questionnaires about their feelings and mood during AVS. Results show that feelingss of liveliness and tiredness decreased with time. Also feelings of confusion decreased linearly with time, probably due to the knowledge about procedure. We noted a very small decrease in feelings of tension and depression, which we did not expect, since more sessions of relaxation were supossed to result in less tension and depression.

Lastly, we asked students to assess their focus and calmness after AVS. They reported feeling most focused between measurements 3 and 7 and 8 and 11. After measurement number 11 focus of students decreased, probably due to feelings of boredom , since students did not notice improvement of their gymnastic skills after visualisation. We have to point out that chosen sample of students had a lot of activities besides our research, therefore it is possible that thew viewed AVS and visualisation as a burden without a reward and were consequently less motivated for execution of it. Motivation is a key factor in improvement of psychomotor skills (Cucui & Cocui, 2014), which could explain lack of improvement of motor skills in our research. We noticed signs of decreased motivation in students with time. For example many students said they can not relax due to the visual and audio stimuli, in time they showed less and less interest for AVS and motor learning. We also have to stress that we had no control over how much effort students put into execution of motor skills. It is possible that some students did not try their hardest in execution of exercises. Lack of improvement in motor skills can therefore be explained also with lack of motivation and effort in students, not only with ineffectiveness of AVS. We could also discuss the stage of motor learning the participants were in – as they started out their learning was in the cognitive stage and during three months it already probably crossed into the associative stage, as stages are described by Fitts and Posner (1967, in Magill, 2011). They also state that the visualization is a very useful tool in these two stages, but we believe that this could not be a confounding variable, as all participants started out with a similar amount of knowledge of both gymanstics and visualization.

CONCLUSION

Our research is one of the first analysis of AVS in Slovenia and has contributed to knowledge of students and faculty about AVS. We recognize that we could improve our work in many ways. Firstly, in order to obtain more valid results we could include more participants into research, especially in experimental group, however then we would need to find a way to keep them motivated, as this was a problem. It would also be beneficial to offer rewards for participation in order to increase motivation of students. Furthermore, students should be better acquainted with the technique of visualization from the beginning, which would guarantee better basis for correct execution of it. Lastly it could be positive to expose students to more or longer sessions of AVS in order to obtain more valid results.

AVS is a relatively new field of research, which offers many prospects for the future. Although our research did not confirm positive effects of it for motor learning, there are many other fields where AVS could have positive effects and should be researched more extensively (for example rehabilitation, cognitive skills, health behaviors…), however we would like to emphasize that the market offers several quick solutions and fast ways to get results, AVS being amongst them and we suggest coaches and athletes be careful when deciding upon it without fist checking for scientific proofs of its validity. We can not say that AVS is a verified method, as the results of studies are controversial, therefore we rather suggest to use methods, which have continuously proven themselves to be useful, such as relaxation techniques and visualization.

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JUMPING PERFORMANCE IS NOT A STRONG PREDICTOR OF CHANGE OF DIRECTION AND SPRINTING ABILITY IN PREADOLESCENT FEMALE GYMNASTS

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Original article

Abstract

This study examined the association between jumping performance, change of direction and sprinting ability in preadolescent gymnasts. Fifty, female 'Gymnastics for All' gymnasts (age: 8.0 ± 0.7 years, training experience: 2.2 ± 0.8 years, height: 129.3± 6.6 cm, body mass: 28.1 ± 5.8 kg) performed one and two-leg counter movement jumps, drop jump, squat jump, standing long jump, 10 and 20 m sprints, and two change of direction tests: 10 m (5 + 5 m with a 180° turn) and 20 m (10 + 10 m with a 180° turn). Significant correlations were found between the examined variables, however multiple regression analyses showed that jumping performance accounted for a small amount of the variance of change of direction (18.4 to 27.1%) and sprinting ability tests (22.6 to 29.3%). Further research is needed to elucidate whether long-term training affects the association between jumping performance and various measures of change of direction and sprinting ability on male and female athletes of different ages and levels of performance.

Keywords: *children, muscle power, acceleration, gymnastics.*

INTRODUCTION

Gymnasts are among the strongest and more powerful athletes in terms of relative strength, as this is expressed per kg of body mass (Jemni, Sands, Friemel, Stone, & Cooke, 2006). Strength and power in gymnasts are developed from a very young age (7-8 years old) (Arkaev & Sutsilin, 2004), with the emphasis placed on rapid force development, i.e. the ability to apply high forces during the limited contact time with the ground or the apparatus (Prassas, Kwon, & Sands, 2006). Strength and power output of the lower limbs is considered as an important contributor to sprinting and change of direction ability tasks (Lloyd et al., 2013; Nimphius, 2014). An indirect measure to assess lower limb muscle power production in children, commonly used in youth sports mostly due to its simplicity, is vertical jump height (Harrison & Gaffney, 2001). Previous research, suggested that lower limb muscle power, is related to sprinting and change of direction ability (Hennessy & Kilty, 2001), both essential components of performance in youth sports (Nimphius, 2014). Recently, Kritikou, Donti, Bogdanis, Donti and Theodorakou, (2017) found that change of direction ability explained a significant part of the variance of the artistry scores in young competitive rhythmic gymnasts.

The physiological, neuromuscular and locomotor determinants of change of direction ability have been largely examined in adults and include speed as well as eccentric and concentric power and whole-body coordination (Hader, Palazzi, & Buchheit, 2015; Nimphius, 2014). Previous studies in adult athletes found strong associations between measures of strength and speed (Wislof, Castagna, Helgerund, Jones, & Hoff, 2004) and strength and change of direction ability (Vescovi & McGuigan, 2008). In contrast, some other studies have shown that measures of power, sprint and change of direction ability are not closely associated (Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012; Sheppard, Dawes, Jeffreys, Spiteri, & Nimphius, 2014). For example, Vescovi and Mc Guigan, (2008) reported that linear sprinting, agility and vertical jumping are independent locomotor skills in high school female athletes. Although the associations between lower limb muscle power, sprinting and change of direction ability have been examined in adults, giving controversial results, there is limited data in young athletes and especially in preadolescent gymnasts. Thus, the aim of this study was to examine whether jumping performance explains the variance of change of direction and sprinting ability in preadolescent female gymnasts.

METHODS

Participants

Fifty preadolescent Gymnastics for All gymnasts (age: 8.0 ± 0.7 years, training experience: 2.2 ± 0.8 years, height: 129.3± 6.6 cm, body mass: 28.1 ± 5.8 kg) participated in this study. Gymnasts trained 3 days a week, 90 min a day, for at least one year. Each training session involved general and special physical conditioning, as well as technical preparation on the apparatuses. The physical conditioning part aimed to improve strength and power and muscular endurance. It contained, exercises using body weight, strength oriented gymnastic skills and combinations of skills. During this time, they also competed in order to qualify for the gold, silver or bronze team, according to the International Gymnastics Federation Gymnastics for All Rules and Regulations (2009). Participants were recruited on the following eligibility criteria: training experience (1-3 years) and no history of lower limb injuries for the past 6 months. Before participating in the study, the subjects and their parents were fully informed about the training methods to be used, the purpose and risks of this study, confidentiality, anonymity, and the right to terminate participation at will. In addition, written parental consent was obtained for each participant. The procedures were approved by the Institutional Ethics Review Committee and complied with the ethical standards for research involving human participants set by the Declaration of Helsinki.

Testing procedures

The current study required the participants to complete 2 testing sessions at their training facilities, performed 2 days apart. The first testing session included anthropometric measures and familiarization with the physical fitness tests. At the start of the second session, and following a 10 min, standardized, sport-specific warm-up, gymnasts underwent a series of tests in the following order: sprint ability (10 and 20 m), two change of direction ability tests [10 m (5 + 5 m with a 180° turn) and 20 m (10 + 10 m with a 180° turn)] and jumping performance. Jumping tests included one and two-leg counter movement jumps, drop jump (20 cm), squat jump, and standing long jump. Sprint and change of direction ability tests were interspersed with 3 min of interval, and after 5 min of recovery, the gymnasts performed the jump tests. Twenty-four hours prior to each session, the gymnasts were asked to avoid any strenuous activity.

Measures

Anthropometry: Body mass, standing height and sitting height were measured with a calibrated digital scale and a stadiometer (Seca 710, and Seca 208, Hamburg, Germany). Leg length was calculated as follows:

Leg Length = Standing Height (cm) - Sitting height (cm)

The mean value of two consecutive measurements was registered for further analysis. A single researcher, experienced in kinanthropometry, performed all measures in accordance with the International Society for Advancement of Kinanthropometry, guidelines.

Maturity offset: Initially, decimal age was calculated by subtracting date of birth from date of measurement. Maturity offset was calculated according to the prediction equation of Mirwald, Baxter-Jones, Bailey, and Beunen, (2002) for girls:

Maturity offset: -9.376+0.0001882 Leg Length *Sitting Height)) + 0.0022* Age * Leg Length + 0.005841*Age*Sitting Height - 0.002658*age*weight + 0.07693*Weight by Height Ratio*

Jumping performance: Jumping performance was assessed by one and two-leg counter movement jumps, drop jump (20 cm), squat jump, and standing long jump. For all the jumps, the average value of two jumps separated by 10 s of rest was recorded for further analysis. Jump height was assessed using an electronic contact mat (Boscosystem® Chronojump) with the subjects instructed to perform a maximum effort and ‘jump as high as possible’. For the one and two-leg counter movement jumps, the drop-jump and the squat jump, subjects were instructed to keep their hands on their hips throughout the jump, to take off with the ankles and knees fully extended and to land in a similarly extended position to ensure the validity of the test. In addition, three criteria were strictly adopted: a) correct body posture b) jumping straight up with no side to side or forward movement, and c) soft landing, including toe to heel rocking and progressive bent of the knees. For the one and the two-leg counter movement jumps, gymnasts were instructed to perform a countermovement until the knees were bent at approximately 90 degrees, and then immediately jump up. ICCs for the right and left leg countermovement jumps were 0.83 ($p<0.01$) and 0.77 ($p<0.01$), respectively. For the two-leg countermovement jump, ICC was 0.89 ($p<0.01$). To execute the drop jump, gymnasts jumped down from a 20cm box onto the mat and then immediately performed a maximal vertical jump. Subjects were required to land in the same point of the take off and rebound as soon as possible with almost straight legs. The ICC for the drop jump was 0.86 ($p<0.01$). For the squat jump subjects were jumping from a semi-squatting position without countermovement. The squat jump technique required the subjects to descend to a position of 90-knee flexion, determined using a hand-held goniometer that positioned the upper thigh parallel with the ground. Gymnasts were instructed to hold this position for 3 seconds, and then jump as high as possible without prior countermovement (Gore, 2000). The ICC for the squat jump was 0.80 ($p<0.01$).

For each trial of the standing long jump, the subjects were instructed to initially stand on a standardized starting point and to bend their knees (the depth of the flexion was self-selected) and bring the arms behind the body. Then, with a powerful drive they extended their legs, moved the arms forward and jumped as far as possible. The distance from the starting point to the landing point at heel contact was used for statistical analysis. All trials were measured to the nearest 0.01 m. The ICC for the standing long jump was 0.74 ($p<0.01$).

Sprint speed (10m and 20m): The starting position was standardized for all subjects. Athletes started in a two-point crouched position with their preferred foot on the starting line and their other foot in line with the heel of the preferred foot. Two cones were placed in 10 and 20 m distance, respectively, in a gymnastics vault corridor. Participants were instructed to run as fast as possible. The total time taken to run the 10 and 20 m sprint was measured using a digital stopwatch. Gymnasts performed 2 trials for each distance interspersed by 1 min rest and the average time was recorded for further analysis. The ICCs for the 10 and 20 m sprint were 0.82 (p<0.01) and 0.90 (p<0.01) respectively.

Change of direction speed: Change of direction speed (CODs) was tested with two CODs tests: 10 m (5 + 5 m with a 180° turn) and 20 m (10 + 10 m with a 180° turn). Two cones were placed in 5 and 10 m distance, respectively, in a gymnastics vault corridor Participants were instructed to accelerate as quickly as possible along the 5 m distance, pivot 180° on the cone and return as quickly as possible through the starting cones. The same procedure was repeated for the 10 + 10 m. Athletes completed 2 trials interspersed by 1 min rest and the average time was used for further analysis. The total time taken to run the 10 m (5 + 5 m with a 180° turn) and 20 m (10 + 10 m with a 180° turn) was measured using a digital stopwatch. The ICCs for the 5 + 5 m with a 180° turn and for the 10 + 10 m with a 180° turn was 0.78 (p<0.01) and 0.75 (p<0.01) respectively.

Reactive Strength Index: Reactive Strength Index is the ratio between jump height and time spent in contact with the ground and represents an individual's ability to change quickly from an eccentric to concentric muscle action (Flanagan & Comyns, 2008). RSI was calculated from the equation of Flanagan and Comyns (2008) as follows:

RSI= jump height (millimetres)/ground contact time (milliseconds)

Eccentric Utilisation Ratio: Eccentric Utilisation Ratio is the ratio of countermovement jump (CMJ) to squat jump (SJ) performance, and has been suggested as a useful indicator of power performance in athletes (McGuigan, Doyle, Newton, & Edwards, 2006).

Statistical Analysis

Statistical analyses were carried out using SPSS (IBM SPSS Statistics Version 22.0). Data are presented as means and standard deviations for all variables. The normality of data distribution was checked with the Kolmogorov-Smirnov test. The Pearson's correlation coefficient (*r*) was used to detect linear associations among the selected variables. Multiple regression analyses were used to investigate which jumping performance test contributed most significantly to each change of direction and sprinting ability test. The intra-class correlation coefficient (ICC) was used as a measure of test-retest reliability (Hopkins, Marshall, Batterman, & Hanin, 2009) for all the variables examined in this study and was determined by using a 2-way mixed model analysis of variance. Statistical significance was accepted at $p<0.05$.

RESULTS

Baseline values of jumping performance tests, change of direction and sprinting ability tests are presented in Table 1. Jumping performance was significantly correlated with change of direction and sprinting ability tests (Table 3).

Multiple regression analyses revealed that two leg counter movement jump and drop jump accounted for 18.4% of the variance of 5+5 m CODs and standing long jump, drop jump and age accounted for 27.1% of the variance of 10+10 m CODs. Furthermore, standing long jump and drop jump accounted for 29.3% of the variance of 10 m sprint and age and drop jump accounted for 22.6% of the variance of 20 m sprint (Table 2).

Table 1. Baseline values of the tested variables. Data are means ±standard deviations

Tested variables	
Counter Movement Jump Height (cm)	17.72±3.67
Right Leg Counter Movement Jump Height (cm)	7.76±2.39
Left Leg Counter Movement Jump Height (cm)	7.08±2.35
Drop Jump Height (cm)	14.81±4.03
Drop Jump Flight Time (s)	0.34±0.06
Drop Jump Contact Time (ms)	290±70
Squat Jump Height (cm)	16.94±3.61
Standing Long Jump (cm)	110.76±15.66
Change of direction ability 5+5 (s)	3.78±0.35
Change of direction ability 10+10 (s)	5.90±0.41
Sprinting 20m (s)	4.82±0.50
Sprinting 10m (s)	2.75±0.24
Reactive Strength Index	0.53±0.20
Eccentric Utilisation Ratio	1.05±0.15

Table 2. Results of the multiple regression analyses using age and counter movement jump, standing long jump and drop jump heights as predictors of the performance of change of direction (5+5, 10+10 m) and sprint (10, 20m) abilities

Tested Variables **5+5 m Change of direction**	**Unstandardized coefficient *B***	***SEB***	**Standardized beta coefficient**	**Adjusted R^2**
				0.184*
Constant	4.608	.494**		
Counter movement jump height	-.030	.015	-.310	
Drop jump height	-.019	.014	-.214	
10+10 m Change of direction	**Unstandardized coefficient B**	***SEB***	**Standardized beta coefficient**	Adjusted R^2
				.271*
Constant	8.005	.601**		
Drop jump height	-.029	.014*	-.281*	
Age	-.099	.079	-.169	
Standing long jump	-.008	.004*	-.299*	
10m Sprint	**Unstandardized coefficient *B***	***SEB***	**Standardized beta coefficient**	**Adjusted R^2**
				.293**
Constant	3.528	.218**		
Drop jump height	-.030	.008**	-.480**	
Standing long jump	-.003	.002	-.189	
20m Sprint	**Unstandardized coefficient B**	***SEB***	**Standardized beta coefficient**	**Adjusted R^2**
				.226**
Constant	6.623	.723**		
Drop jump height	-.053	.017*	-.418*	
Age	-.126	.096	-.177	

SEB: standard error of B**;** **: $p < 0.01$, *: $p < 0.05$

Table 3. Correlations between jump performance, change of direction and sprinting ability in preadolescent gymnasts

	Training age	Age	Body mass	Height	CMJ height	R-leg CMJ height	L-leg CMJ height	Drop Jump height	Drop Jump Contact Time	Squat Jump height	Standing Long Jump	COD 5+5m	COD 10+10 m	20m sprint	10m sprint	RSI	EUR	BMI
Training Age																		
Age	.489**																	
Body Mass	-.265	-.050																
Height	-.348*	-.089	.765**															
CMJ height	.606**	.418**	-.427**	-.415**														
R-leg CMJ height	.605**	.382**	-.580**	-.410**	.788**													
L-leg CMJ height	.600**	.519**	-.451**	-.378**	.636**	.775**												
Drop Jump height	.458**	.350*	-.327*	-.371**	.564**	.615**	.531**											
Drop Jump CT	.045	.150	.144	.203	-.137	-.052	.078	-.087										
Squat Jump height	.528**	.415**	-.431**	-.304*	.792**	.802**	.739**	.613**	.005									
Standing Long Jump	.385**	.339*	-.066	-.076	.377**	.273	.350*	.307*	.127	.371**								
CODs 5+5m	-.355*	-.318*	.063	.120	-.431**	-.382**	-.391**	-.389**	.005	-.333*	-.206							
CODs 10+10 m	-.347*	-.369**	.099	.059	-.372**	-.300*	-.252	-.432**	.064	-.321*	-.442**	.489**						
20m Sprint	-.106	-.323*	.006	.061	-.363**	-.278	-.357*	-.480**	.137	-.413**	-.207	.167	.432**					
10m Sprint	-.302*	-.303*	.200	.254	-.360*	-.414**	-.426**	-.538**	.083	-.380**	-.336*	.521**	.622**	.450**				
RSI	.333*	.229	-.300*	-.383**	.458**	.459**	.335*	.763**	-.641**	.430**	.096	-.261	-.333*	-.408**	-.409**			
EUR	0.92	-.057	.036	-.164	.242	-.089	-.232	-.120	-.241	-.387**	-.088	-.111	-.017	.117	.093	.029		
BMI	-.125	-004.	.887*	.390**	-.326*	-.540**	-.399**	-.203	.060	-.405**	-.035	.018	.098	-.026	.121	-.162	.165	
Matutity offset	-.037	.370**	.786**	.724**	-.173	-.248	-.104	-.068	.157	-.152	.038	-.046	-.118	-.271	.116	-.109	-.056	.611**

Note: CMJ height=Counter movement jump height, R-leg CMJ height=Right leg counter movement jump height, L-leg CMJ height= Left-leg counter movement jump height COD=Change of direction ability, Sprint ability, RSI= Reactive strength index, EUR=Eccentric utilization ratio, BMI=Body mass index, Maturity offset
** p < 0.01, * p < 0.050.8±2.9

DISCUSSION

The aim of this study was to examine the association between jumping performance, change of direction and sprinting ability in preadolescent gymnasts. The results of this study showed that Pearson product moment correlation coefficients were statistically significant between the examined variables (Table 3). However, regression analyses showed that jumping performance accounted for a small amount of the variance of change of direction (18.4 to 27.1%) and sprinting ability tests (22.6 to 29.3%) thus being in line with previous research in adolescent female athletes (Vescovi & McGuigan, 2008).

In the present study, drop jump was the variable that showed the highest associations with change of direction and sprinting ability tests (Table 2). The drop jump is a measure of fast (<250 milisecond) stretch shortening cycle performance (Hennessy & Kilty, 2001; Schmidtbleicher, 1992). Fast stretch-shortening actions may promote greater movement speed via elastic energy usage and stretch reflex contributions (Komi & Gollhoffer, 1997). In the present study, the contact time with the ground was 290±70 ms, a time frame near the threshold of fast stretch shortening cycle activities in adults (Schmidtbleicher, 1992). Thus, the jump height those gymnasts could reach after rebound appears to be a good indicator of their performance in locomotion skills, and in particular in the measures of quickness and acceleration used in this study. In line with these results, Pettersen and Mathisen (2012) pointed out that the forceful deceleration of 10 and 20 m sprint and change of direction speed share some of the same neuromuscular characteristics as the landing phase of a drop jump. Indeed, authors have stated that the CMJ may not be the best model to examine the stretch shortening cycle mechanism, and that fast hopping or DJ may provide more insight to the relationship between the muscle-tendon complex during human locomotion (Komi, 1992). Despite a moderate correlation found in this research between drop jump height and counter movement jump height ($r = .564$, $p < 0.01$) it seems that at least to some degree they measure different explosive leg-power qualities (Cronin & Hansen, 2005).

Although it is acknowledged that Reactive Strength Index is a measure that quantifies the strain placed on the muscle-tendon unit during stretch shortening cycle actions (McClymont, 2003), in this study, Reactive Strength Index demonstrated low associations with sprinting and change of direction ability measures. Previous research with 9-15 years old boys, reported no improvement in Reactive Strength Index following 4 weeks of plyometric training in the group of 9-year old boys, and the authors assumed that age and maturational status were more important for the development of the ability to use the stretch shortening cycle than training (Lloyd, Oliver, Hughes, & Williams, 2012). Furthermore, the Eccentric Utilisation Ratio, which is an indicator of stretch shortening cycle performance in adult athletes in various sports (McGuigan, et al., 2006), was not associated with measures of change of direction and sprinting ability. It is known that in a plyometric movement, the goal is to reduce time in the amortization phase, which is defined as the time interval between the eccentric phase and the concentric phase (Voight & Dravovitch, 1991). This depends essentially on the contractile and elastic abilities of the tendomuscular system (Komi, 1992). However, volitional muscular force, motor unit activation, and agonist-antagonist synchronization in children are lower compared with adults (Dotan, et al., 2012). It seems, that for the very young gymnasts of this study, Reactive Strength Index and Eccentric Utilisation Ratio are not representing their ability to use the stretch shortening cycle. It is also reported that neural regulation of leg stiffness and Reactive Strength Index is more effective in adults that in children (Oliver & Smith, 2010) and that both measures of stretch shortening cycle increase with age (Lloyd, Oliver, Hughes, & Williams, 2011). Interestingly, in this study, age was also associated with 10+10 m CODs and 20 m sprint in the present study, despite the small age difference (~1 year) between participants.

The association of standing long jump with 10+10 change of direction speed and 10 m sprinting ability, found in the present study, is not surprising. Previous research has also shown that horizontal jumps may demonstrate higher association than vertical with sprinting ability (Meylan, McMaster, Cronin, Mohammad & Rogers, 2009).

Body mass was not associated with change of direction and sprinting ability, although previous research reported that body mass in strongly related to performance in weight-bearing activities (Bovet, Auguste, & Burdette, 2007). Probably, in normal weight children, other factors like power are more important and/or may counteract the effect of a higher body mass on locomotion. In line with this result, previous research also suggested that body mass and limb length are not related to improvements in stretch shortening cycle actions in 9 to 12 years old children boys (Lloyd, Oliver, Hughes, & Williams, 2012; Veligekas, Tsoukos, & Bogdanis, 2012).

The fact that jumping performance in general, explained a small amount of the variance of change of direction and sprinting ability tests in this study, can be attributed to a number of factors. Previous research findings on the association of lower limb jump performance and change of direction and sprinting ability tests, reported conflicting results. For example, some previous studies in adult athletes found strong associations between measures of strength and speed (Wislof, Castagna, Helgerund, Jones, & Hoff, 2004; Young, McLean, and Ardagna, 1995) and strength and change of direction tests (Vescovi & McGuigan, 2008). In contrast, some other studies have shown that measures of isokinetic power strength, power, and change of direction and sprinting ability tests are not associated (Castillo-Rodríguez, Fernández-García, Chinchilla-Minguet, & Carnero, 2012; Cronin and Hansen, 2005; Sheppard, Dawes, Jeffreys, Spiteri, & Nimphius, 2014) or that the ability of the jumps to predict change of direction ability (Buchheit, Mendez-Villanueva, Delhomel, Brughelli, & Ahmaidi, 2010) or sprint performance is limited (Meylan, McMaster, Cronin, Mohammad, & Rogers, 2009). However, the associations between measures of power and speed, and change of direction speed can only give an insight into performance components, and not a causation (Nimphius, Mc Guigan, & Newton, 2010). Other factors, like the ability to efficiently use the stretch shortening cycle in rapid movements (Markovic & Mikulic, 2010), age, training experience of the participants, and time in the training season (Nimphius, Mc Guigan, & Newton, 2010) may mediate this relationship. For example, Vescovi and Mc Guigan (2008) found that measures of counter movement jump performance explained a small amount of the variance (24-33%), for the sprint times in high school athletes (aged 15.1±1.6 years) however, the amount of variance explained was higher for the college athletes (aged 19.9±0.9 years). It should also be noted that training is considered as a critical factor determining children's muscular performance overtime. Kotzamanidis, (2006) showed that a 10-week, (twice per week), plyometric training program resulted in significantly increased 20- and 30-m sprint velocity, but not 10-m sprint velocity in 11-year-old boys compared with a control group of similar age. Buchheit et al. (2010) also found that a 10-week, 1-hour per week repeated shuttle sprints and explosive strength training produced significant improvement in 30-m sprint, but no significant improvement in 10-m sprint in adolescent male elite soccer players. In line with these results, Kums, Gapeyeva, and Pääsuke (2005) found that elite young rhythmic gymnasts demonstrated a markedly greater ability to use the stretch shortening cycle than controls during drop jump and Piazza, et al. (2014) reported an increase in lower limb muscle power of 6-7% after 6 weeks of resistance training. Thus, further research is needed to elucidate whether long-term training can change the associations between leg muscle power and various measures of change of direction and sprinting abilities, at different time points over a competitive year.

CONCLUSIONS

There is not always a consensus on the association between jump performance, change of direction and sprinting ability parameters', at different ages and performance levels. All the performance scores in this study were statistically correlated, showing that jumping performance is associated with locomotion skills performance in young gymnasts. However, only a small part of the variance in sprinting and change of direction ability are explained by jumping performance. Based on these results, it is suggested that coaches should not rely solely on a single power measurement to predict locomotion performance. Further research, needs to determine the influence of other factors to motor performance and develop assessment batteries including movement coordination, training adaptation, anthropometric and biomechanical elements that should be taken into account.

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RELATIONSHIP BETWEEN PERFORMANCE OF GYMNASTIC ELEMENTS AND NATIONAL CUP SUCCESS IN OLDER YOUTH CATEGORIES OF ALPINE SKIING

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Original article

Abstract

Competitive alpine skiing and gymnastics belong to polystructural sports disciplines. One of the differences between them are the conditions under which they are implemented. The external conditions in gymnastics are constant, in alpine skiing they vary. Due to the wide impact of gymnastics on the development of motor skills, this discipline is used as a means of physical preparation of young alpine skiers. The aim of this study was to determine whether there is a connection between the selected gymnastic elements and competitive performance of young alpine skiers, aged 14 to 15. The sample of variables consisted of eight tests about of gymnastic elements and an overall assessment. The independent variable represented the points scored in the cup for the Mercator Grand prize. The sample consisted of 34 athletes, 22 boys and 12 girls, all of them were competing that season. Considering the results, we can say that the relationship between competitive performance in alpine skiing is statistically typical for the group of boys, but not girls. In the group of boys, the statistically significant predictors of prosperity in alpine skiing were proven to be four of gymnastic elements and the total score of gymnastic elements, whereas in the group of girls only one element proved to be a statistic predictor. Differences in ranking positions influence gymnastic elements scores on performance success at competitions is statistically significant in older boys at a 5% risk level, whereas in the older girls category overall gymnastic elements do not influence total performance.

Keywords: *alpine skiing, acrobatic elements, older boys and girls.*

INTRODUCTION

Alpine skiing is one of the most attractive and exciting sports (Lešnik and Žvan, 2007). Both, recreative and competitive skiing demand a lot of agility, which must be constantly upgraded. Alpine skiing is a polystructural complex sport, which demands a child's early specialization (Lešnik and Žvan, 2010). The environment and its conditions, which can be unpredictable or even obtrusive (Pišot and Videmšek, 2004), determine the complexity of alpine skiing. A competitor must process a lot of different information so he/she can compete in severe conditions with high-risk limit (Slivnik, 2010; Hintermeister et al, 1994). The quality of skiing depends on five features of alpine skiing: speed, accuracy, punctuality,