UDC:613.25:572.087
doi: 10.5937/fizkul75-35545

BODY MASS INDEX IN DETERMINATION OF THE RELATIONSHIP BETWEEN BODY CONSTITUTION AND MOTOR ABILITIES

Zoran Pajić[1], Saša Jakovljević[1], Marija Anđelković[2], Slobodan Simović[3]

[1]Faculty of Sport and Physical Education, University of Belgrade, Serbia
[2]Sports medicine association of Serbia, Belgrade, Serbia
[3]Facylty of Physical Education and Sport, University of Banja Luka, Bosnia and Herzegovina

Abstract

The aim of this paper is to review and summarize the theoretical and empirical facts of using the *(BMI)*, *(body mass index)* in determining the relationship between body constitution and motor skills. Several key circumstances have been identified in which the body mass index can give erroneous information about the actual body composition, and especially about the amount of adipose tissue in the body. Factors such as age, sex, race, health status and muscle mass can influence the connection between *(BMI)* and body fat. Due to a relatively low coefficient of determination between *(BMI)*and percentage of body fat, one should be cautious when using *(BMI)* to evaluate body composition as a predictor of obesity or as a substitution measure in evaluating the influence of body constitution on the efficiency of motor performances. The analysis of the sources indicates that the existence of unexplained facts uses alternative measures of body composition and their limited use in research and direct training practice. Therefore, new concepts and models are necessary in order to explain the influence of body composition on the efficiency of motor performance. Apart from the necessary evaluation of variables of percentages of fatty and muscle tissues, it could be assumed that the application of two component (*BMI) = (FFMI+FMI), (Fat Free Mass Index, Fat Mass Index)* and/or *(MFR)* model (*Muscle to Fat Ratio*) would provide a better comprehension of these relations.

Key words: BODY COMPOSITION / MOTOR PERFORMANCES / MUSCLE TO FAT RATIO / FAT MASS INDEX / FAT FREE MASS INDEX

Correspondence with the author: Zoran Pajić, E – mail: zoran.pajic@dif.bg.ac.rs

INTRODUCTION

Understanding body composition of athletes was considered as an essential part of total training management process (Wilmore, 1982). Many researchers assumed that favorable anthropometric characteristics, body composition, as well as functional abilities, needed for their particular sport were required of each athlete (Singh et al., 2010; Massuca & Fragoso, 2011).

Anthropometric and kinanthropometric studies aimed at indicating how certain morphological factors, including body fat, body mass, muscle mass and body height influenced the competitive performances of athletes (Carter, 1970). Since each sport has its specific motor requirements, it could be assumed that each athlete should have specific anthropometric characteristics which correspond to his/her sports discipline. Changes in body composition and motor performances can occur on all levels, from the beginning to the end of training and competitive seasons (Silvestre et al., 2006). Therefore, the possible ideal body composition depends on a particular sport or discipline, structure of competitive activity, position in a team etc. In some contact sports such as rugby, higher body mass is an advantage, while in others such as gymnastics, marathon etc. lower body mass and high values of force/mass relation (i.e. higher relative force - production of force per one kilogram of body weight) are necessary. For example, in marathon runners the most suitable profiles and relations, necessary for achieving optimal performances were identified (Marc, Sedeaud, Guillaume et al., 2014). Calculated optimal (BMI) index for men was 19.8 kg/m^2, while for 10 best competitors of all times it was between 17.5 and 20.7 kg/m^2. Lately, (BMI) has been used intensively in anthropological researches as an indicator of body constitution of subjects. It is customary in practice that (BMI) is not only the indicator of "weight as such" but it also, through its structural component, indicates indirectly the quantity of fatty tissue, especially in the cases of extreme body masses (Malina, Bouchard & Bar-Or, 2004).

In a large number of researches (BMI) has been used as an indicator of body constitution in relation to various performances of motor activities. Many researches have clearly indicated the connection of body composition and (BMI) with the efficiency of performing motor abilities, but in other researches this connection was not established. Regarding the fact that (BMI) is a morpho-metric characteristic which mostly depends on body mass, evaluation of the relations of body mass and motor performance of moving is very up to date. Justification of doubt in the suitability of using (BMI) as a substitute measurement could be assumed in the following:

- analysis of the differences of influence on motor performances of body mass which has more muscles in comparison to fat in its structure, and vice versa;
- the fact that parts of useless fatty tissue and useful muscle tissue cannot be established from its result in the total component of body mass;
- a number of proofs that it is muscle mass, not fat mass, that is significantly positively connected with measures of physical performances.

BODY MASS INDEX AS A SUBSTITUTE MEASURE

Body mass index is often used as "a substitution measure" for body constitution and as one of the criteria in the selection of athletes, as well as persons in other fields (especially those with specific jobs, such as military and police recruits etc.). However, when certain borderline values of (BMI) are not reached or are exceeded, the problem of interpretation of results can occur. In accordance with this, there are certain circumstances in which disagreement can occur in some "substitution measurements", especially in (BMI) with actual body composition, particularly with the quantity of fat tissue within the body (Prentice & Jebb, 2001). When evaluating body fat within the body, relying on (BMI) as a substitution measure can cause inconsistencies in overall population (Cohn, 1987), which can also create an incorrect picture of exceeded body mass in athletes (Heyward & Wagner, 2004). Measuring only body mass cannot determine the quantity of body fat in an organism (Pajic, Ilic, Jakovljevic et al., 2011), since it does not differ between fat and fat free body components. Therefore, in such analyses the limitations of using (BMI) and the necessity of applying additional measuring should be pointed out. From the above mentioned, it could be implied that substitution measures could provide wrong and not quite reliable information on body composition, as well as that (BMI) is an indirect measure of body mass, not of adiposity. This creates the conditions for wrongful diagnosis of obesity and inadequate tries of reducing body mass, as well as not understanding the influence of actual body composition on motor performances of treated athletes. Therefore, the supposed unreliability of (BMI) is possible, since the quantity of useless fatty tissue and useful muscle tissue in total component of body mass cannot be established from its value.

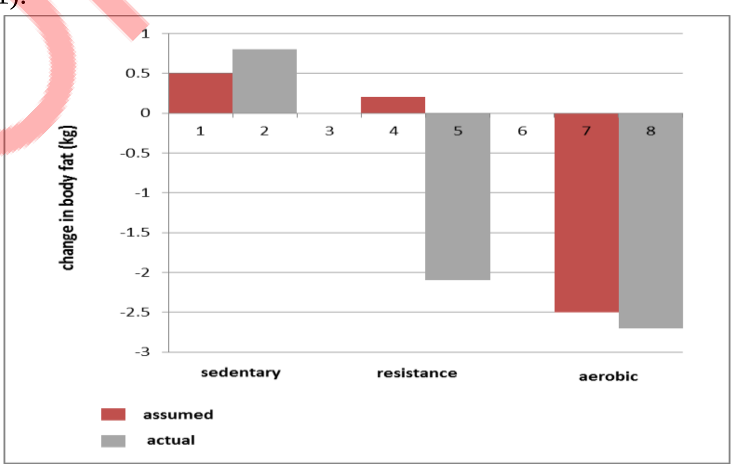
Explanations for the above assumptions must be considered through certain restrictions on the use of (BMI), as a measure of body fat, and especially in people with overweight, because, above all, (BMI) is a measure of body weight, not excess body fat. Also, (BMI) does not differ between excessive fat, muscle and bone mass, and it cannot indicate the distribution of fat in various persons. Factors such as age, sex, race, health status and muscle mass can influence the relation between (BMI) and body fat. On average, **elderly people** have more fatty tissue than the young for the same values of (BMI), (Cohn, 1987). Body mass and (BMI) cannot detect the "conversion" of fat free into fatty tissue (Cohn, 1987), which is a normal process which occurs while aging. Aging is followed by progressive increase in relation between fat and fat free body mass. This occurs even in people who manage to maintain the same values of (BMI). Therefore, the connection between (BMI) and body fat depends on a person's age. These deviations are especially prominent after middle age and during menopause in women. In contemporary sedentary world, the increase of (BMI) in most individuals is noticeable. Although these data indicate the increase of body fat in people, they still severely underestimate the true increase of body fat. There are prediction equations, which include years of change, i.e. gaining certain values of body fat from (BMI), and they are also efficient in overcoming the afore mentioned problems (Deurenberg, Weststrate & Seidell, 1991). Also, the composition of muscles changes with the increased infiltration of fat. Increase of fat infiltration in muscles with aging can be an important, if not the main aspect of sarcopenia (loss of muscle mass and muscle strength), (Roubenoff & Hughes, 2000). As for the proteins, their intake usually decreases in adults, which contributes to the loss of muscle mass and lower basal metabolism, which consequentially leads to the increase of body weight even if the energy intake remains the same (Shin, Liu, Panton & Ilich, 2014). These phenomena can be a significant predictor of the fact that (BMI) is not suitable for evaluating body constitution.

In children, (BMI) generally increases between the ages of 8 and 18 and is highly connected with fat and fat free body components in all ages. Furthermore, unlike the adults whose body height and (BMI) are generally not connected, in children they are. Yearly changes of (BMI) can be strongly caused by changes both in fat and fat free components of body composition, as well as in a child's height. Yearly increases in (BMI) during childhood are primarily led by the increase in fat free component of (BMI), especially in boys during puberty, due to fast increase of height and relatively low yearly decrease or increase in total body fat. This results in negative average fluctuations of fatty component of (BMI) (i.e. total body fat/height^2). The degree to which each component contributes to average increase of (BMI) depends partially on the age and sex of a child. The circumference of limbs as well as the quantity of muscle tissue increase through both early childhood and adolescence. At the age of 11, children are still in the period of pre-puberty and more prominent body changes are not noticeable yet. With reaching puberty (girls around 12 and boys around 13) larger and more sudden changes in body shape and composition begin to occur, which further influence (BMI) and indirectly contribute to the quality of performing motor tasks, especially demonstrating muscle strength (Malina, Bouchard & Bar-Or, 2004). This clearly illustrates the complexity of interpreted changes in (BMI) in children and stresses the fact that (BMI) is the measure of body mass, not adiposity. Although (BMI) can be useful to define obesity in adults, (BMI) in children and adolescents does not have the same characteristics. Application of (BMI) in children is complicated by its dependence on height, relative difference between the length of body and legs, fat free body mass (FFM) and the level of maturity (Siervogel, Maynard, Wisemandle et al., 2000). The degree and level of sexual maturity influence the relation between (BMI) and body fat in children (Dawkins, 1990). Because of this, height is one of the first selective characteristics in most sports, and it is used to recruit children as kinanthropometric suitable athletes.

On average, **women** have higher quantities of total body fats than man for the same values of (BMI). They have lower muscle mass, higher fat infiltration into muscles and lower muscle strength (Shin, Liu, Panton & Ilich, 2014; Visser, Harris, Langlois et al., 1998; Visser, Goodpaster, Kritchevsky et al., 2005). Women in menopause are more prone to gaining weight with fat infiltration into muscles, as well as to deposition and redistribution of fat into central, abdominal region. At the same time they suffer from loss of muscle mass, which leads to sarcopenia and loss of bone density (i.e. osteopeny or osteoporosis can occur). Both of these occur in cases of sarcopenic or osteopenic obesity.

It is well known that (BMI) does not provide valid data on body fat in people with **developed musculature**, gained through long-term exercising or due to natural muscle build (genetic heritage). Muscular persons can have high (BMI) due to increased muscle mass. Due to the fact that muscles are heavier than fat, very muscular people can have high values of (BMI), (Sum, Wang, Choo et al., 1994).

In today sedentary lifestyle, individuals who take care of their health, continue to practice both aerobic and resistance trainings, in order to stay physically fit. Many of them do not necessarily want to lose mass, but aim towards improving their condition and body composition. Others, on the other hand, consider losing fat layers as their primary aim. Changes in body mass can give deceptive impressions on thorough changes in fat, especially in resistance training, which helps build muscle mass (Prentice & Jebb, 2001), (Picture 1).

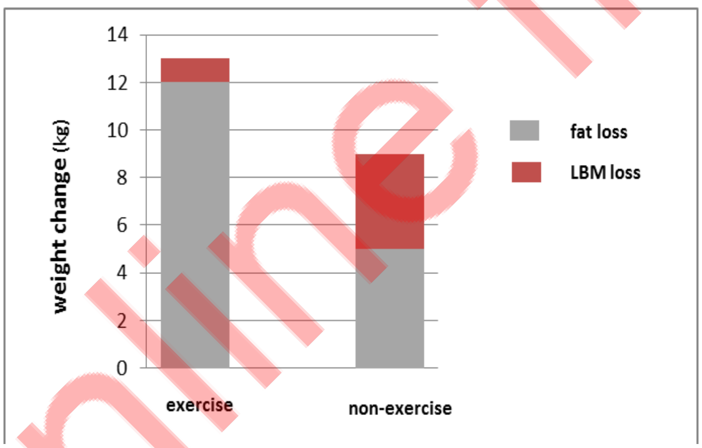


Picture 1. Assumed and real change in body fat after training, modified to Prentice & Jebb, (2001).

"The assumed" change in body fat is simply calculated as 75% of the total loss of weight, while "real" change is the directly measured loss in fat. On average, the differences are not so large in all studies, but they can have important motivational effects. For example, people who practiced training with load would assume that they did not achieve any loss in fat.

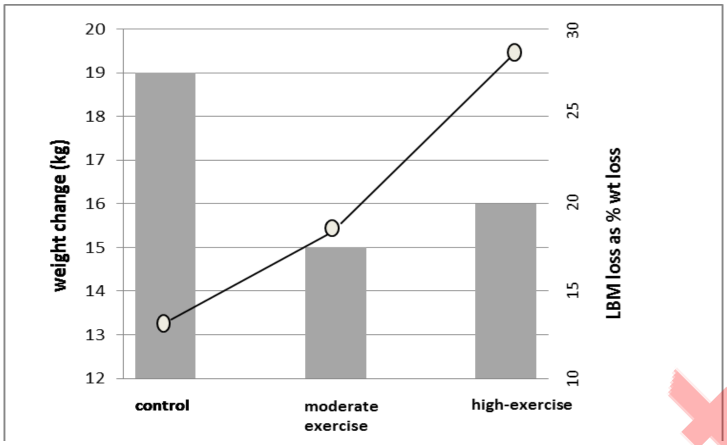
Simple measures of body mass (and therefore measures deduced from BMI) generally provide satisfactory evaluations of clinical progress in programs for losing of body weight using diets. Incorporation of exercising in the regimes of body reduction is justified due to long term results of keeping body mass after losing weight. However, under these circumstances, loss in mass does not equal the loss of fat, so body mass and (BMI) can lead to deceptive measurements of progress in losing weight.

The composition of weight loss was determined in 72 medium obese persons on which various programs for reducing body mass were applied, including physical exercise (Pavlou, Steffee, Lerman & Burrows, 1985), (Picture 2). If measuring of body composition was not available, the advantages of exercising would at first sight have been small and statistically insignificant (11.8 compared to 9.2 kg of body mass lost). Be that as it may, the analysis of body fat has indicated that the group which exercised lost 11.2 ± 1.5 kg of fat when compared to only 5.2 ± 1.6 kg in the group which has not exercised ($p<0{,}001$). This is only one of the examples of successful body mass loss, but it also points out the fact that establishing the loss of mass itself, and, with it, leaning on substitution measurements can be ill-suited.



Picture 2. Composition of losing body mass, modified to Pavlou, Steffee, Lerman & Burrows, (1985).

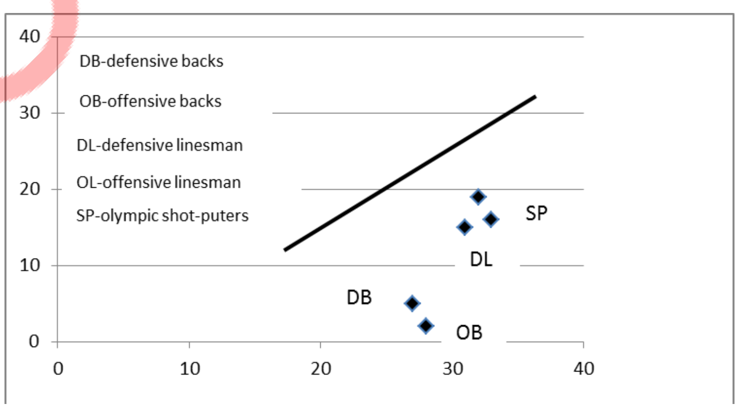
In an analogous study (Whatley, Gillespie, Honig et al., 1994), the effect of intensity of exercising on the loss of fatty tissue in obese women was analyzed and evaluated (Picture 3). It can be noticed that the proportion of body loss of fat free component was higher in the group which has not exercised (i.e. the control group) and also that the real amount of weight loss was lower. These findings indicate that the substitution measures are unsuitable and that detecting the effects of used programs by applying the analysis of body fat is important.



Picture 3. The effects of exercising on the composition of lost weight while dieting, modified to (Whatley, Gillespie, Honig et al., 1994).

In the experiment in which extremely obese persons with (BMI) > 30 followed a special diet and exercise program regime, similar results were acquired (Dikic & Andjelkovic, 2013). Average body mass at the beginning of the program was 107.2 ± 19.4 kg, (BMI) 37.1 ± 4.3 kg/m^2 and average percentage of body fat was 41.0 ± 5.7. After ninety days of program, average loss of (BM) amounted to 9.2 ± 5.4 kg (9.19% of initial (BM). (BMI) was statistically significantly lowered to 32.7 ± 3.4 from the initial average 37.1 ±4.3 kg/m^2 at the end of the ninety-day-program. Percentage of body fat was statistically significantly lowered to 36.4 ± 6.3 from average 41.0 ± 5.7 at the end of the ninety-day-program. On average, subjects have lost 7.2 kg of fatty tissue, which was statistically significant. Percentage of fat and the quantity of fatty tissue in limbs and body trunk were statistically significantly lower, which supports the idea of body remodeling. Body remodeling, segmental fat loss and loss of fatty tissue of as much as 7.2 kg could not be indicated if only (BMI) and body mass were taken into consideration, which implies their limitations in everyday work.

Be that as it may, in specific groups such as athletes, evaluations based on usage of substitution measurements, especially (BMI) can lead to systematic errors. A prominent error was the result of an attempt to evaluate body fat based on (BMI) in players of American football and hammer throwers (Katch & Katch, 1984), (Picture 4). They had a higher percent of fat free component than their (BMI) indicated. This connection can be applied to most athletes, even in very low values of (BMI).



Picture 4. Disagreement between (BMI) and percentage of body fat in athletes, modified to (Katch & Katch, 1984).

There are numerous clinical states in which disturbed hormonal status changes the usual connection between fat free and fatty tissue in which body mass and (BMI) give wrong impressions on body composition and changes in it. Huge changes in hydration of tissue can have similar effects (Vukašinović-Vesić, Anđelković, Stojmenović et al., 2015). For example, a group of patients with diagnosed sepsis lost 8 kg of mass during the first days of illness without any significant loss in body fat (Plank, Connolly & Hill, 1998). Under these and similar circumstances, direct measuring of body fat and fat free component is essential in order to follow the progress in the state of nourishment.

Due to relatively low coefficient of determination between (BMI) and percent of body fat, using (BMI) as a predictor of obesity was criticized. (BMI) is more appropriate as an index of total body fat or body fat in relation with height, then total body fat in relation to mass (Garrow & Webster, 1985). The degree of adiposity is partially predictable using (BMI), at least on the population scale, if adiposity is defined as excessive body mass per body height unit, but not as excess of body fat per body mass unit. Similar to predicting the percentage of body fat from (BMI), predicting body fat/height^2 from (BMI) is much more changeable in people with (BMI) under 30 kg/m^2.

Obesity is defined if (BMI) is at least 30 kg/m^2 or if the amount of fat is at least 25% of the total body mass for men and 30% for women (Frankenfield, Rowe, Cooney et al., 2001). However, it has been established that 30% of men and 46% of women with (BMI) under 30 kg/m^2 had increased levels of body fat. They were also obese and therefore their classification according to (BMI) was wrong. The highest variability in predicting the percentage of body fat and body mass divided by square height value (body mass/height^2) from regression equations using (BMI) was among the values of (BMI) under 30 kg/m^2. Therefore, the measuring of body fat is a much more suitable way to evaluate obesity in people with (BMI) under 30 kg/m^2.

The biggest flaw of (BMI) is that with its usage, real body composition is not taken into consideration (Schutz, Kyle & Pichard, 2002). Excess in body mass can occur due to the increase of fat tissue or due to muscle hypertrophy. On the other hand, decrease of values of (BMI) can occur due to the loss of fat free component (FFM) (i.e. sarcopenia), loss of fat tissue or combination of both.

Higher infiltration of fat into muscles with aging can be a crucial aspect of **sarcopenia** which influences the functional status in old age. Fat infiltration into muscles is positively connected with total body fat **(**Ryan & Nicklas, 1999**;** Sinha, Dufour, Petersen et al., 2002) and it can be a factor which contributes to inadequacy of applying (BMI) in the evaluation of body constitution. Although many studies support the fact that muscle mass is a strong predictor of physical function in adults, it is evident that lower fat infiltration in muscles as a measure of muscle quality, could be used as a valid predictor of better physical performance. It was additionally indicated that persons who fall into the "normal" category according to their (BMI), can have increased values of fat (FM), which indicates the need for those persons to normalize their body fat, regardless of the values of (BMI), (Schutz, Kyle & Pichard, 2002). Previous explanations illustrate several key circumstances in which (BMI)as substitution measurement of body constitution, and especially body fat can provide wrong information on real body composition of an individual, mostly due to the disagreement in usual connection between fat free (FFM) and fat (FM) components.

RELATIONSHIPS OF BODY MASS INDEX WITH MOTOR ABILITIES

In a large number of researches, *(BMI)* was used as an indicator of body constitution in relation to various performances of motor activities. Many researches clearly indicated the connection between body composition and *(BMI)* with the efficiency of performing motor abilities in all ages *(Table 1*).

Table 1. Connection of (BMI) with the efficiency of performing motor abilities

(BMI)- motor performance relationship			Source of confirmation
Inverse	Positive	No relationship	
Fundamental movement skills (FMS - running, gallop, hops & long jump); General motor skills			(28); (39); (72); (81); (88); (97).
Endurance (VO_2max), Energy consumption; Aerobic fitness, Cardiorespiratory fitness			(8); (11); (15); (55); (62); (64); (81).
Maximum runing speed			(15); (33); (34); (40); (56); (58); (64).
Accuracy - dexterity of motor skills (i.e. running)			(22); (35); (97).
Jumping efficiency			(8); (33); (34); (48); (64).
Agility	Agility		(15); (34); (56); (58); (82); (86).
Balance			(2); (75); (88).
Coordination Perceptual – motor coordination		Overall & fine coordination	(4); (7); (9); (27); (44); (50).
		Flexibility	(20); (37); (82).
		Explosive strength	(7); (20); (87).
		Precision	(22); (35); (53).

The findings acquired by using separate groups formed by dividing the sample of subjects into groups of subjects with under average, average and above average indexes of body mass (Table 2).

Table 2. Connection of different levels of BMI with the efficiency of performing motor abilities

Different *(BMI)*levels and motor performance relationship			Source of confirmation
Below average	Average	Above average	
Speed			
Agility			(36); (82); (54).
Vertical jump	Vertical jump	Vertical jump	
Muscle force			(20).
Flexibility	Flexibility	Flexibility	(20).
Strength endurance			
Balance			

This is why there is a completely reasonable doubt that it is not enough to rely on (BMI) which is not about the structure of body mass, and it can therefore be assumed that it is not a reliable indicator when explaining the relations of treated morphological characteristics and motor abilities. This is also the origin of the supposition that in many above mentioned researches the structure of body mass was not analyzed, which caused the existence or nonexistence of the connection of (BMI) with the treated motor performances. The justification for the mentioned doubt on unsuitability of (BMI) as a substitution measurement could be assumed in the analysis of the differences of influence of body mass, which in its structure has more muscles when compared to fat and vice versa (Table 3).

Table 3. Analysis of the differences in influence of body mass with larger muscle mass in comparison with fat tissue and vice versa on motor performances.

Ability	Body weight		Source of confirmation
	Muscle tissue	Fat tissue	
Speed	+	-	(3); (57); (64).
Change of direction speed		-	(41); (57).
Power, Strength	+		(1); (5); (13); (14); (24); (31); (43); (57); (64); (65); (66); (67); (69); (70); (73); (83); (85); (89); (96).
Endurance	+		(1); (16); (43); (45); (55); (57); (64); (69); (76); (89); (91).

Body mass can influence motor performances and success in various sports, but body composition and the quantity of body fat can be more precise indicators of motor efficiency than body mass (Wolinsky & Driskell, 2008). Sports in which lower quantity of body fat is an advantage (running, diving, gymnastics, skating and wrestling). Muscle mass improves sports achievement in the activities which require muscle force, strength and stamina, but also in those which require considerable aerobic ability (Ramadan & Byrd, 1987; Rico-Sanz, 1998). Body mass index does not take into consideration build and cannot illustrate the percentage of fatty tissue in relation to muscle or bone mass (Pajic, Ilic, Jakovljevic et al., 2011). Certain players with higher body mass and high (BMI) who have large content of muscle and bone mass in relation to height cannot be treated as obese (Pajic, Ilic, Jakovljevic et al., 2011)..

Several authors (Prentice & Jebb, 2001; Pajic, Ilic, Jakovljevic et al., 2011; Sporiš, Vuleta, D., Vuleta Jr, D., & Milanović, 2010) have noticed strong negative correlation between body fat and maximal speed of running. They point out that the efficiency of locomotion of players is more complex the faster their moving is. It is inversely proportional to the volume and mass of his/her body, if it is largely determined by fatty tissue. Therefore, a different influence of body mass on athletic achievement depending on body structure is noticeable. Extremely heavy football players, whose mass is determined by higher amount of fatty tissue, achieve weaker results in motor activities of maximal speed running, as well as in changing the direction of moving (Pajic, Ilic, Jakovljevic et al., 2011). Body mass can influence speed, stamina and strength of an athlete, while body composition can influence force and agility (Prentice & Jebb, 2001; Pajic, Ilic, Jakovljevic et al., 2011. Previous statements indicate that other morphological characteristics which could influence speed and the speed of changing the direction of moving should also be researched and used at the same time (Pajic, Ilic, Jakovljevic et al., 2011). Apart from body height, the following characteristics should be taken into consideration: relative length of limbs (Cronin, McNair, Peter, & Marshall, 2003), height of the center of mass (Sheppard & Young, 2006), percentage of fatty tissue etc.

Concerning the fact that in this study a morphometric characteristic, i.e. (BMI) was treated, which most of all depends on body mass, the evaluation of the relation of body mass and motor performance of movement is necessary. The influence of body mass while moving segments of the body (translocation) or whole body (transposition) can be an impeding factor of performance, considering the fact that an athlete should master his inertial characteristics, which will usually produce a fast growth of working effort in a short period of time. This is usually required during performance of speed factor or speed of changing the direction of moving (Pajic, Ilic, Jakovljevic et al., 2011). Inverted connection between motor skills and body mass with larger fat tissue is usually explained from the mechanic point of view, since excess of body fat can influence body geometry. Therefore, this useless mass (fat mass) can lead to biomechanic inefficiency of moving and can be bad for motor skill. Apart from this, detailed kinematic analysis of moving patterns in athletes with excessive body fat can provide additional information and proofs that, in motor skills which include several body segments and higher body mass quantity, confirms the "weight-bearing hypothesis" (D'Hondt, Deforche, De Bourdeaudhuij & Lenoir, 2009). An athlete with more fat in his body composition has a higher inertia of the body or separate body segments. This requires a higher production of force per kilogram of fat free mass, in order to perform certain change in speed or the direction of moving, i.e. has lower lean body mass (LBM) which can influence the required speed demands such as start, acceleration or changing of direction (Sheppard & Young, 2006). Subcutaneous fat tissue functions as ballast mass, so called "dead mass" since it decreases relative strength, i.e. the relationship between the developed strength and body mass, which is important for successful performance (Godek, S., Godek, J. & Bartolozzi & 2004). This leads to the deficit in all forms of manifested strength (start, acceleration, deceleration and reactive strength), which are (in different combinations) necessary for performing most of the required types of moving in motor activities (Pajic, Ilic, Jakovljevic et al., 2011). These are the types of moving in changed conditions in order to overcome gravity, forces of surface reaction, air resistance, as well as inertia of the body or its limbs. It has been shown that it is more difficult to move higher body mass in order to oppose gravity (Riddiford-Harland, Steele & Storlien, 2000). So, the negative influence of fat tissue of all regions of the body on the efficiency of locomotion is indisputable.

Various authors have shown that increased ballast fat in the structure of body mass, and, as a consequence, changed inertia characteristics of the body or its segments, impose limitations in certain types of movements (Table 4).

Table 4. The influence of increased ballast fat in the structure of body mass on limitation of movement

Movements	Reasons	Source of confirmation
Goal oriented (*eng. goal – directed movements*)	Negative influence on balance control	(26); (68).
Propulsion or lifting own body weight (*eng. weight – bearing activities*)	Overcoming body or limb inertia	(26); (68).
Dynamic balance maintenance	Longer duration of contact phase using one or both legs	(30); (93); (98).
Quick stop and/or turn	Overcoming body or limb inertia	(34) ; (41); (57).
Repeatedly lifting body weight vs gravity	Overcoming body or limb inertia	(51).
In which body is projected through air		(15).

Contrary to previous statements, higher quantity of muscle tissue provides better motor performance (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005). Many determinants contribute to this, first of all the ability to master and coordinate inertia forces, surface reactions, gravity etc. The consequence is, for example, greater motion economy in moving center of gravity (i.e. body mass) vertically upwards into jump after the ball and in running around the whole court area (Gorostiaga, Granados, Ibanez, & Izquierdo, 2005). While running, the forces of surface reaction and muscle strength can exceed the values of body weight i.e. are higher than body weight 2.5 to 5 times (Weyand, Sternlight, Bellizzi & Wright, 2000; Wright, S. E. T. H., & Weyand, 2001), (that is why it is dangerous to allow extremely obese persons to run, due to possible burden on their joints). Performance of such strong forces during running requires that the runners should have a relatively large quantity of muscle mass, in order to generate these forces (Hill, 1950; Nelson, Gabaldón & Roberts, 2004; Biewener, 1989). Accordingly, greater body mass of fast runners is directly connected with higher performance of force reaction which is necessary for faster running.

The autors (Chaouachi, Brughelli, Levin et al., 2009; Krustrup, Mohr, Amstrup et al., 2003) have shown that (VO_2max) correlates with fat free and fat components. This finding could be explained by the fact that fat free component represents the metabolism of fat free cell mass, which can reach and perform the main role in body metabolism. Some studies have established that fat free component creates all metabolic activity of the body, and determines the total oxygen consumption (Payette, Hanusaik, Boutier et al., 1998; Newman, Kupelian, Visser et al., 2003; Pedersen, Ovesen, Schroll et al., 2002).

NEW CONCEPTS AND MODELS IN THE EXPLICATION OF THE INFLUENCE OF BODY COMPOSITION ON THE EFFICIENCY OF MOTOR EXPRESSION

Discrepancy of all previous statements indicates that new concepts and models are necessary in explaining the influence of body composition on the efficiency of motor performance. Apart from the necessary evaluation of variables of fat tissue percentage and muscle tissue percentage, it could be supposed that the application of two-component (BMI) and (MFR) (muscle to fat ratio) models would provide a better insight into these relations. Examination of body composition aims at measuring body mass and dividing it into basic components. Some theoretical models were taken as basis for the development of methods for measuring body composition, such as: anthropometric, measuring skin folds, bioelectric impedance and NIR method (Malina, 2007). Classic models divide body mass into components as shown in Table 5.

Table.5 Theoretical models of body composition

Theoretical model	Body weight			
Two component	fat (***FM***)	Fat free (***FFM***)		
Three component		Body water	Lean (***LBM***)	
Four component			Bones	Rest

Therefore, fat tissue and fat free body mass are the components of total body mass. When height (stature) is also considered, they become fat mass index (FMI) and fat free mass index (FFMI) and represent fat and fat free components of (BMI), respectively. These indexes are defined in the following way (Schutz, Kyle & Pichard, 2002).

FFMI = fat free mass/height^2 (kg/m^2)

FMI = fat mass/height^2 (kg/m^2)

Regarding the fact that (BMI) = (FFMI + FMI), the increase or decrease of (BMI) could be explained by increase (or decrease) in one or both components. So, for certain (BMI), if (FFMI) increased, (FMI) should decrease, since in constant values of (BMI) between these two indexes there is an inverse mathematical relation. Therefore, the advantage of combined usage of these indexes could indicate whether the deficit or excess in body mass has occurred due to changes in (FFM), (FM) or both categories combined.

For example (Schutz, Kyle & Pichard, 2002), a person 1.85m tall and lifting 100 kg has (BMI) 29.2 kg/m^2, which places him/her into the category of pre-obese, on the borderline of becoming obese. This would be true is (FMI) is higher than referential values and vice versa if (FFMI) of that person is not simultaneously increased. Therefore, (FMI) can identify persons with "normal" values of (BMI) who are prone to potential risk due to the (FM) increase. Person, who falls into the "normal" category according to their (BMI), can have increased values of (FMI) which then indicates that they need to normalize their body fat regardless of (BMI) values (Schutz, Kyle & Pichard, 2002).

For example, during aging and menopause, changes in (FFM) and (FM) are not adequately followed by changes in (BMI) since, as described in the previous text; two components of (BMI), (FFMI and FMI) can vary in various directions. Decrease of height with aging is an additional factor for calculating (BMI), (FMI) and (FFMI), (Schutz, Kyle & Pichard, 2002). Since height naturally decreases with age, values of (BMI), (FFMI) and (FMI) should increase with aging. This is why the application of this two component structural concept of (BMI) enables anticipation of four typical situations (Schutz, Kyle & Pichard, 2002):

- low (FFMI) and high (FMI) - sarcopenic obesity;
- low (FFMI) and low (FMI) - chronic deficit in energy;
- high (FFMI) and low (FMI) - proof of muscle hypertrophy;
- high (FFMI) and high (FMI) - indicates combined excess of (FFM) and (FM) (sumo somatotype).

In short, (FMI) and (FFMI) can be used as indicative values for evaluating the status of nourishment (over nourishment and undernourishment) in healthy people and can provide additional information in comparison with the classic presentation of referential values of body composition (Schutz, Kyle & Pichard, 2002).

If precise evaluation of variables of percentage of fat tissue and percentage of muscle tissue is possible (measuring skin folds, bioelectrical impedance or NIR method), it can be assumed that the application of (MFR) (muscle to fat ratio) model would provide a better insight into the relations of body constitution and motor performance than (BMI).

Generally speaking, it can be supposed that it is necessary to gain insight into relations between (BMI) and (MFR), when (BMI) is used as substitution measurement in evaluation of the influence of body constitution on the efficiency of motor performances (Anđelković, Baralić, Đorđević et al., 2015; Djordjevic, Baralic, Kotur-Stevuljevic et al., 2012). It is usual to claim that it is better to have a lower (BMI), since this implies that a balanced body mass is in the structure of an athlete's body. However, there are no guarantees for such a claim, considering the fact that in this relatively lower body mass which was the cause of lower (BMI), there is also less muscle mass when compared to fat mass, which is unfavorable from the aspect of influence of body constitution on motor performances. Also, an athlete with higher or increased values of (BMI) can be motoric more efficient, under the condition that he/she has a harmonious muscle-fat ratio (MFR), i.e. that the percentage of body muscle is increased in relation to body fat in the structure of body mass.

Therefore, the very change in the value of (BMI), i.e. its increase, is not a signal that there is something wrong in body composition which could result in inefficiency of motor performance, since it is possible that an increase of body mass has occurred for the same body height, but in such a way that, under the influence of training, muscle mass has increased and with it, the muscle-fat ratio (MFR). The positive influence of increased muscle mass has already been explained, and with it, the influence of (MFR) on the efficiency of motor performance in most motor performances.

Therefore, with such analyses it should be pointed out that body mass index (BMI) has limited usage, and that additional measuring is necessary. Therefore, certain limitations in applying (BMI) have to be taken into consideration while using it, such as body fat, especially in persons with increased body mass, since (BMI) is above all a measurement of excessive body mass, not excessive body fat. Also, stated facts indicate that persons who fall into the "normal category according to (BMI) can have increased values of fat (FM) which indicates the need for these persons to normalize their body fat regardless of the values of (BMI). Discrepancy of all previous statements indicates that new concepts and models in explaining the influence of body composition on the efficiency of motor performance are necessary. Apart from the necessary evaluation of variables of fat tissue percentage and percentage of muscle tissue, it can be assumed that the application of two component (BMI) and/or (MFR) model would provide a better insight into these relations. The discrepancy of all previous statements indicates that new concepts and models are needed in the explication of the influence of body composition on the efficiency of motor expression.

REFERENCES

1. Anđelković M, Baralić I, Đorđević B, Stevuljević JK, Radivojević N, Dikić N, Škodrić SR, Stojković M. (2015). Hematological and biochemical parameters in elite soccer players during a competitive half season. *J Med Biochem*, 34(4): 460─466
2. Arabaci, R., Gorguu, R., & Catikkas, F. (2010). Relationship Between Agility and Speed, Reaction Time and Body Mass Index in Taekwondo Athletes. *Sport Sciences*, *5*(2), pp.71-77.
3. Baine, B., Gorman, D., Kern, C. J., Hunt, B. S., Denny, S. G., & Farris, W. J. (2009, April). Relationship between Body Mass Index and motor skills of children. In Exhibit Hall RC Poster Sessions (Tampa Convention Center).
4. Barth, N., Ziegler, A., Himmelmann, G.W., Coners, H., Wabitsch, M., Hennighausen, K., Mayer, H., Remschmidt, H., Schäfer, H. & Hebebrand, J. (1997). Significant weight gains in a clinical sample of obese children and adolescents between 1985 and 1995. *International journal of obesity*, *21*(2), pp.122-126.
5. Berrigan, F., Simoneau, M., Tremblay, A., Hue, O., & Teasdale, N. (2006). Influence of obesity on accurate and rapid arm movement performed from a standing posture. *International Journal of Obesity*, 30(12), 1750-1757.
6. Biewener, A. A. (1989). Scaling body support in mammals: limb posture and muscle mechanics. *Science*, 245(4913), 45-48.
7. Bundred, P., Kitchiner, D., & Buchan, I. (2001). Prevalence of overweight and obese children between 1989 and 1998: population based series of cross sectional studies. *Brisish Medical Journal*, 322(7282), 326.
8. Carter, J. L. (1970). The somatotypes of athletes—a review. *Human biology*, 535-569.
9. Castetbon, K., & Andreyeva, T. (2012). Obesity and motor skills among 4 to 6-year-old children in the United States: Nationally-representative surveys. *BMC pediatrics*, 12(1), 1-9.
10. Chaouachi, A., Brughelli, M., Levin, G., Boudhina, N. B. B., Cronin, J., & Chamari, K. (2009). Anthropometric, physiological and performance characteristics of elite team-handball players. *Journal of sports sciences*, 27(2), 151-157.
11. Chatrath, R., Shenoy, R., Serratto, M., & Thoele, D. G. (2002). Physical fitness of urban American children. *Pediatric cardiology*, 23(6), 608-612.
12. Cohn, S. H. (1987). *New concepts of body composition. In vivo body composition studies.* Oxford, Bocardo Press.
13. Cossio-Bolanos, M., Portella, D., Hespanhol, J. E., Fraser, N., & De Arruda, M. (2012). Body size and composition of the elite Peruvian soccer player. *JEPonline*, 15(3), 30-8.
14. Cronin, J., McNair, P. E. T. E. R., & Marshal, R. (2003). Lunge performance and its determinants. *Journal of sports sciences*, 21(1), 49-57.
15. D'Hondt, E., Deforche, B., De Bourdeaudhuij, I., & Lenoir, M. (2008). Childhood obesity affects fine motor skill performance under different postural constraints. *Neuroscience letters*, 440(1), 72-75.
16. D'Hondt, E., Deforche, B., De Bourdeaudhuij, I., & Lenoir, M. (2009). Relationship between motor skill and body mass index in 5-to 10-year-old children. *Adapted Physical Activity Quarterly*, 26(1), 21-37.
17. Dawkins R. (1990). *The Selfish Gene.* 2nd ed. Oxford University Press.
18. Deurenberg, P., Weststrate, J. A., & Seidell, J. C. (1991). Body mass index as a measure of body fatness: age-and sex-specific prediction formulas. *British journal of nutrition*, 65(2), 105-114.
19. Dikic N, Andjelkovic M. (2013). *Metabolic fitness. 1st ed.* Belgrade, Sport Medicine Association of Serbia.
20. Djordjevic, B., Baralic, I., Kotur-Stevuljevic, J., Stefanovic, A., Ivanisevic, J., Radivojevic, N., Andjelkovic, M. and Dikic, N. (2012). Effect of astaxanthin supplementation on muscle damage and oxidative stress markers in elite young soccer players. *J Sports Med Phys Fitness*, *52*(4), pp.382-92.
21. Frankenfield, D. C., Rowe, W. A., Cooney, R. N., Smith, J. S., & Becker, D. (2001). Limits of body mass index to detect obesity and predict body composition. *Nutrition*, 17(1), 26-30.

22. Gardasevic B, Jakovljevic S, Pajic Z, Preljevic A. (2011). Some anthropometric and power characteristics of elite junior handball and basketball players, *APES*, (1)1: 5-9.
23. Garrow, J. S., & Webster, J. (1985). Quetelet's index (W/H2) as a measure of fatness. *International journal of obesity*, 9(2), 147-153.
24. Godek, S. F., Godek, J. J., & Bartolozzi, A. R. (2004). Thermal responses in football and cross-country athletes during their respective practices in a hot environment. *Journal of Athletic Training*, 39(3), 235.
25. Gallo, P.A.O., Daguerre, R., Batista, J. and Liotta, G., (2002). Relationships Between Age, Biological Maturity, Body Composition and Physical Fitness in Youth Argentinean Soccer Players. *Medicine & Science in Sports & Exercise*, 34(5), p.64.
26. Gorostiaga, E. M., Granados, C., Ibanez, J., & Izquierdo, M. (2005). Differences in physical fitness and throwing velocity among elite and amateur male handball players. *International journal of sports medicine*, 26(03), 225-232.
27. Goulding, A., Jones, I. E., Taylor, R. W., Piggot, J. M., & Taylor, D. (2003). Dynamic and static tests of balance and postural sway in boys: effects of previous wrist bone fractures and high adiposity. *Gait & posture*, 17(2), 136-141.
28. Graf, C., Koch, B., Kretschmann-Kandel, E., Falkowski, G., Christ, H., Coburger, S., Lehmacher, W., Bjarnason-Wehrens, B., Platen, P., Tokarski, W. and Predel, H.G., (2004). Correlation between BMI, leisure habits and motor abilities in childhood (CHILT-project). *International journal of obesity*, *28*(1), pp.22-26.
29. Heyward, V. H., & Wagner, D. R. (2004). *Applied body composition assessment (No. Ed. 2)*. Champaign, Il, Human kinetics.
30. Hill, A. V. (1950). The dimensions of animals and their muscular dynamics. *Science Progress* (1933-), 38(150), 209-230.
31. Hills, A. P., & Parker, A. W. (1991). Gait characteristics of obese children. *Archives of physical medicine and rehabilitation*, 72(6), 403-407.
32. Hills, A. P., & Parker, A. W. (1992). Locomotor characteristics of obese children. *Child: care, health and development*, 18(1), 29-34.
33. Jakovljevic S, Pajic Z, Gardasevic B, Visnjic D. (2011a). Some anthropometric and power characteristics of 12 and 13 years old soccer and basketball players, In Proceedings *Anthropological aspects of sports physical education and recreation.* University of Banja Luka. Faculty of Physical Education and Sport, 42-48.
34. Jakovljević, S., Karalejić, M., Pajić, Z., & Mandić, R. (2011). Acceleration and speed of change of direction and the way of movement of quality basketball players. *Fizička kultura*, 65(1), 16-23.
35. Jakovljević, S., Karalejić, M., Pajić, Z., Gardašević, B., & Mandić, R. (2011). The influence of anthropometric characteristics on the agility abilities of 14 year-old elite male basketball players. Facta universitatis-series: *Physical Education and Sport*, 9(2), 141-149.
36. Kapetanakis, S., Papadopoulos, K., Fiska, A., Vasileiadis, D., Papadopoulos, P., Papatheodorou, K., Adamopoulos, P. & Papanas, N. (2010). Body composition and standing long jump in young men athletes aged 6-13 years. *Journal of Medicine and Medical Sciences*, *1*(9), 418-422.
37. Karalejic, M., Jakovljevic, S., & Macura, M. (2011). Anthropometric characteristics and technical skills of 12 and 14 year old basketball players. *The Journal of sports medicine and physical fitness*, 51(1), 103-110.
38. Katch, F. I., & Katch, V. L. (1984). The body composition profile. Techniques of measurement and applications. *Clinics in sports medicine*, 3(1), 31-63.
39. Kinnunen, D. A., Colon, G., Espinoza, D., Overby, L. Y., & Lewis, D. K. (2001). Anthropometric correlates of basketball free-throw shootings by young girls. *Perceptual and motor skills*, 93(1), 105-108.
40. Korsten-Reck, U., Kaspar, T., Korsten, K., Kromeyer-Hauschild, K., Bös, K., Berg, A., & Dickhuth, H. H. (2007). Motor abilities and aerobic fitness of obese children. *International journal of sports medicine*, 28(09), 762-767.
41. Krneta Z, Keric M, & Pelemis M. (2011). Analysis of mobile status of young adolescents of both sexes in relation to the value of the body mass index. *Sport and health VI*; 1: 80-85.
42. Krustrup, P., Mohr, M., Amstrup, T., Rysgaard, T., Johansen, J., Steensberg, A., Pedersen, P.K. and Bangsbo, J., 2003. The yo-yo intermittent recovery test: physiological response, reliability, and validity. *Medicine & Science in Sports & Exercise*, 35(4), pp.697-705.
43. Lee, J. S., Auyeung, T. W., Kwok, T., Lau, E. M., Leung, P. C., & Woo, J. (2007). Associated factors and health impact of sarcopenia in older Chinese men and women: a cross-sectional study. *Gerontology*, 53(6), 404-410.
44. Lopes, V. P., Stodden, D. F., Bianchi, M. M., Maia, J. A., & Rodrigues, L. P. (2012). Correlation between BMI and motor coordination in children. *Journal of Science and Medicine in Sport*, 15(1), 38-43.

45. Malina, R. M. (2007). Body composition in athletes: assessment and estimated fatness. *Clinics in sports medicine*, 26(1), 37-68.
46. Malina, R. M., Bouchard, C., & Bar-Or, O. (2004). *Growth, maturation, and physical activity*. Champaign, Il, Human kinetics.
47. Marc, A., Sedeaud, A., Guillaume, M., Rizk, M., Schipman, J., Antero-Jacquemin, J., Haida, A., Berthelot, G. & Toussaint, J.F. (2014). Marathon progress: demography, morphology and environment. *Journal of sports sciences*, *32*(6), pp.524-532.
48. Marshall, J. D., & Bouffard, M. (1994). Obesity and movement competency in children. *Adapted Physical Activity Quarterly*, 11(3), 297-305.
49. Massuça, L., & Fragoso, I. (2011). Study of portuguese handball players of different playing status. a morphological and biosocial perspective. *Biology of Sport*, *28*(1).
50. McGraw, B., McClenaghan, B. A., Williams, H. G., Dickerson, J., & Ward, D. S. (2000). Gait and postural stability in obese and nonobese prepubertal boys. *Archives of physical medicine and rehabilitation*, 81(4), 484-489.
51. Nelson, F. E., Gabaldón, A. M., & Roberts, T. J. (2004). Force–velocity properties of two avian hindlimb muscles. Comparative Biochemistry and Physiology Part A: *Molecular & Integrative Physiology*, 137(4), 711-721.
52. Newman, A.B., Kupelian, V., Visser, M., Simonsick, E., Goodpaster, B., Nevitt, M., Kritchevsky, S.B., Tylavsky, F.A., Rubin, S.M., Harris, T.B. and Health ABC Study Investigators, (2003). Sarcopenia: alternative definitions and associations with lower extremity function. *Journal of the American Geriatrics Society*, *51*(11), pp.1602-1609.
53. Nummela, A., Keränen, T., & Mikkelsson, L. O. (2007). Factors related to top running speed and economy. *International journal of sports medicine*, 28(08), 655-661.
54. Okely, A. D., Booth, M. L., & Chey, T. (2004). Relationships between body composition and fundamental movement skills among children and adolescents. *Research quarterly for exercise and sport*, 75(3), 238-247.
55. Onetti-Onetti, W., Molina-Sotomayor, E., González-Jurado, J.A. and Castillo-Rodriguez, A., (2020). Comparison between sexes of the relationships between body composition and maximum oxygen volume in elderly people. *Sustainability*, 12(8), p.3156.
56. Ortega, F. B., Ruiz, J. R., & Sjöström, M. (2007). Physical activity, overweight and central adiposity in Swedish children and adolescents: the European Youth Heart Study. *International Journal of Behavioral Nutrition and Physical Activity*, 4(1), 1-10.
57. Pajic Z, Ilic J, Jakovljevic S, Macura M, Preljevic A. (2011). Relations between morphological and characteristics and speed of movement direction changes in professional soccer players. In M. Mikalački, & G. Bala (eds.) 2nd *International Scientific Conference Exercise and quality of life*, Novi Sad: Faculty of Sport and PE, 393-398.
58. Pajić Z. (2006). *Effects of inertial loads on the motor, morphological and biomechanical performance of movement at maximum speed.* Doctoral thesis. Belgrade. Faculty of Sport and Physical Education.
59. Pavlou, K. N., Steffee, W. P., Lerman, R. H., & Burrows, B. A. (1985). Effects of dieting and exercise on lean body mass, oxygen uptake, and strength. *Medicine and Science in Sports and Exercise*, 17(4), 466-471.
60. Payette, H., Hanusaik, N., Boutier, V., Morais, J. A., & Gray-Donald, K. (1998). Muscle strength and functional mobility in relation to lean body mass in free-living frail elderly women. *European journal of clinical nutrition*, 52(1), 45-53.
61. Pedersen, A. N., Ovesen, L., Schroll, M., Avlund, K., & Era, P. (2002). Body composition of 80-years old men and women and its relation to muscle strength, physical activity and functional ability. *The Journal of nutrition, health & aging*, 6(6), 413-420.
62. Pissanos, B. W., Moore, J. B., & Reeve, T. G. (1983). Age, sex, and body composition as predictors of children's performance on basic motor abilities and health-related fitness items. *Perceptual and motor skills*, 56(1), 71-77.
63. Plank, L. D., Connolly, A. B., & Hill, G. L. (1998). Sequential changes in the metabolic response in severely septic patients during the first 23 days after the onset of peritonitis. *Annals of surgery*, 228(2), 146.
64. Prentice, A. M., & Jebb, S. A. (2001). Beyond body mass index. *Obesity reviews*, 2(3), 141-147.
65. Ramadan J, Byrd R. (1987). Physical characteristics of elite soccer players. *J Sports Med Phys*; 27: 424-428.
66. Reid, K. F., Naumova, E. N., Carabello, R. J., Phillips, E. M., & Fielding, R. A. (2008). Lower extremity muscle mass predicts functional performance in mobility-limited elders. *The journal of nutrition health and aging*, 12(7), 493-498.

67. Rico-Sanz, J. (1998). Body composition and nutritional assessments in soccer. International *Journal of Sport Nutrition and Exercise Metabolism*, 8(2), 113-123.
68. Riddiford-Harland, D. L., Steele, J. R., & Storlien, L. H. (2000). Does obesity influence foot structure in prepubescent children?. *International journal of obesity*, 24(5), 541-544.
69. Rolland, Y., Lauwers- Cances, V., Cournot, M., Nourhashémi, F., Reynish, W., Rivière, D., Vellas, B. & Grandjean, H. (2003). Sarcopenia, calf circumference, and physical function of elderly women: a cross- sectional study. *Journal of the American Geriatrics Society*, *51*(8), pp.1120-1124.
70. Rolland, Y., Lauwers-Cances, V., Pahor, M., Fillaux, J., Grandjean, H., & Vellas, B. (2004). Muscle strength in obese elderly women: effect of recreational physical activity in a cross-sectional study. *The American journal of clinical nutrition*, 79(4), 552-557.
71. Roubenoff, R., & Hughes, V. A. (2000). Sarcopenia: current concepts. The Journals of Gerontology Series A: *Biological Sciences and Medical Sciences*, 55(12), M716-M724.
72. Ryan, A. S., & Nicklas, B. J. (1999). Age-related changes in fat deposition in mid-thigh muscle in women: relationships with metabolic cardiovascular disease risk factors. *International journal of obesity*, 23(2), 126-132.
73. Savelsbergh, G. J., Bennett, S. J., Angelakopoulos, G. T., & Davids, K. (2005). Perceptual-motor organization of children's catching behaviour under different postural constraints. *Neuroscience letters*, 373(2), 153-158.
74. Schutz, Y., Kyle, U. U. G., & Pichard, C. (2002). Fat-free mass index and fat mass index percentiles in Caucasians aged 18–98 y. *International journal of obesity*, 26(7), 953-960.
75. Sharma, R., & Nigam, A. K. (2011). A study of body mass index in relation to motor fitness components of school going children involved in physical activities. *Journal of exercise science and physiotherapy*, 7(1), 29-33.
76. Sheppard JM, & Young WB. (2006). Agility literature review: Classification, training and testing. *J Sports Sci*; 24(9): 919-932.
77. Shin, H., Liu, P. Y., Panton, L. B., & Ilich, J. Z. (2014). Physical performance in relation to body composition and bone mineral density in healthy, overweight, and obese postmenopausal women. *Journal of geriatric physical therapy*, 37(1), 7-16.
78. Siervogel, R. M., Maynard, L. M., Wisemandle, W. A., Roche, A. F., Guo, S. S., Chumlea, W. C., & Towne, B. (2000). Annual changes in total body fat and fat- free mass in children from 8 to 18 years in relation to changes in body mass index: the Fels Longitudinal Study. *Annals of the New York Academy of Sciences*, 904(1), 420-423.
79. Silvestre, R., Kraemer, W.J., West, C., Judelson, D.A., Spiering, B.A., Vingren, J.L., Hatfield, D.L., Anderson, J.M. & Maresh, C.M. (2006). Body composition and physical performance during a National Collegiate Athletic Association Division I men's soccer season. *Journal of Strength and Conditioning Research*, 20(4), p.962.
80. Singh, S., Singh, K., & Singh, M. (2010). Anthropometric measurements, body composition and somatotyping of high jumpers. *Brazilian Journal of Biomotricity*, 4(4), 266-271.
81. Sinha, R., Dufour, S., Petersen, K.F., LeBon, V., Enoksson, S., Ma, Y.Z., Savoye, M., Rothman, D.L., Shulman, G.I. and Caprio, S., (2002). Assessment of skeletal muscle triglyceride content by 1H nuclear magnetic resonance spectroscopy in lean and obese adolescents: relationships to insulin sensitivity, total body fat, and central adiposity. *Diabetes*, *51*(4), pp.1022-1027.
82. Southall, J. E., Okely, A. D., & Steele, J. R. (2004). Actual and perceived physical competence in overweight and nonoverweight children. *Pediatric Exercise Science*, 16(1), 15-24.
83. Sporiš, G., Vuleta, D., Vuleta Jr, D., & Milanović, D. (2010). Fitness profiling in handball: physical and physiological characteristics of elite players. *Collegium antropologicum*, 34(3), 1009-1014.
84. Sum, C. F., Wang, K. W., Choo, D. C. A., Tan, C. E., Fok, A. C. K., & Tan, E. H. (1994). The effect of a 5-month supervised program of physical activity on anthropometric indices, fat-free mass, and resting energy expenditure in obese male military recruits. *Metabolism*, 43(9), 1148-1152.
85. Taaffe, D. R., Cauley, J. A., Danielson, M., Nevitt, M. C., Lang, T. F., Bauer, D. C., & Harris, T. B. (2001). Race and sex effects on the association between muscle strength, soft tissue, and bone mineral density in healthy elders: the Health, Aging, and Body Composition Study. *Journal of bone and mineral research*, 16(7), 1343-1352.
86. Temfemo, A., Hugues, J., Chardon, K., Mandengue, S. H., & Ahmaidi, S. (2009). Relationship between vertical jumping performance and anthropometric characteristics during growth in boys and girls. *European journal of pediatrics*, 168(4), 457-464.

87. Tokmakidis, S. P., Kasambalis, A., & Christodoulos, A. D. (2006). Fitness levels of Greek primary schoolchildren in relationship to overweight and obesity. *European journal of pediatrics*, 165(12), 867-874.
88. Toriola, A. L., & Igbokwe, N. U. (1986). Age and sex differences in motor performance of pre- school Nigerian children. *Journal of Sports Sciences*, 4(3), 219-227.
89. Visser, M., Deeg, D.J., Lips, P., Harris, T.B. & Bouter, L.M. (2000). Skeletal muscle mass and muscle strength in relation to lower- extremity performance in older men and women. *Journal of the American Geriatrics Society*, *48*(4), 381-386.
90. Visser, M., Goodpaster, B.H., Kritchevsky, S.B., Newman, A.B., Nevitt, M., Rubin, S.M., Simonsick, E.M. & Harris, T.B., (2005). Muscle mass, muscle strength, and muscle fat infiltration as predictors of incident mobility limitations in well-functioning older persons. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *60*(3), pp.324-333.
91. Visser, M., Harris, T.B., Langlois, J., Hannan, M.T., Roubenoff, R., Felson, D.T., Wilson, P.W.F. & Kiel, D.P., (1998). Body fat and skeletal muscle mass in relation to physical disability in very old men and women of the Framingham Heart Study. *The Journals of Gerontology Series A: Biological Sciences and Medical Sciences*, *53*(3), pp.M214-M221.
92. Vukašinović-Vesić, M., Anđelković, M., Stojmenović, T., Dikić, N., Kostić, M., & Ćurčić, Đ. (2015). Sweat rate and fluid intake in young elite basketball players on the FIBA Europe U20 Championship. *Vojnosanitetski pregled*, 72(12), 1063-1068.
93. Weyand, P. G., Sternlight, D. B., Bellizzi, M. J., & Wright, S. (2000). Faster top running speeds are achieved with greater ground forces not more rapid leg movements. *Journal of applied physiology*, 89(5), 1991-1999.
94. Whatley, J. E., Gillespie, W. J., Honig, J., Walsh, M. J., Blackburn, A. L., & Blackburn, G. L. (1994). Does the amount of endurance exercise in combination with weight training and a very-low-energy diet affect resting metabolic rate and body composition?. *The American journal of clinical nutrition*, 59(5), 1088-1092.
95. Wilmore JH. (1982). Body composition and athletic performance. *J Appl Physiol; 82*(5): 1508-1516.
96. Wolinsky, I., & Driskell, J. A. (2008). *Sports Nutrition; Energy Metabolism and Exercise*, New York. In Library of Congress Cataloging (Vol. 420).
97. Wong, A. K. Y., & Cheung, S. Y. (2006). Gross Motor Skills Performance of Hong Kong Chinese Children: *Asian Journal of Physical Education & Recreation*, 12(2), 23-29.
98. Wright, S. E. T. H., & Weyand, P. G. (2001). The application of ground force explains the energetic cost of running backward and forward. *Journal of Experimental Biology*, 204(10), 1805-1815.