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# **Kinanthropometry and Sport Practice**

Settori Scientifico-Disciplinari: BIO/08

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COORDINATOR Prof. *Silvano Capitani*

# Kinanthropometry and Sport Practice

Scientific-Disciplinary sectors: BIO/08

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# 1. Introduction

As all sport practitioners have realized with their personal experience, consistent training and prolonged or intense efforts bring many different consequences on their physical appearance and general condition, which can be described as forms of *adaptation*. This is an on-going process, consisting in the physical, physiological and behavioral modifications which are needed to cope with the environment, its changes and the resulting stress it imposes on the body. This process never stops during our entire life time and – taken to its extreme consequences - failing to adapt means failing to survive. Adaptation implies elasticity and resilience, and gives the individuals the possibility to prolong their lives. The rigidity of a corpse is the best example of lack of adaptation and it is contrasted by the strength and flexibility of young athletes. Of course, adaptation is never perfect - and this is one of the possible causes of death - but it is definitely a necessity.

## 1.1 The benefits of physical activity

Physical activity consists in the voluntary activation of the muscles: from standing to walking, and from jogging to sprinting (or cycling, climbing the stairs etc.), we always have to contract our muscles in order to move. Also an isometric contraction, which does not produce an observable movement, implies the activation of some muscles in order to resist an external force or absorb some shock (falling, in a car accident etc.) and therefore the consumption of energy.

This is true even if we are pushing against a wall. The fact that no displacement occurs implies that no mechanical work is produced, since it is defined as the scalar product of force times displacement:

$$W = \vec{F} \cdot \vec{d}$$

Still, it does not mean that there is no energy expenditure. In fact, also isometric contractions produce work, of electric nature, which requires some calories to be burnt. Once we have accepted the inevitability of physical activity, we can move on to assess its value.

Let alone the times in which hunting, running and fighting were the most popular forms of physical activity - on which individuals had to rely in order to survive - even sitting still on a couch implies a considerable load on the muscle-skeletal system. In fact, a seated subject is continuously adapting to the mechanical stresses imposed on his or her body by gravity and the peculiar posture. This stress is not necessarily mild (Pope et al. 2002), especially if extended, and the negative sides of sedentary behaviors like obesity (an excess of body fat) have been widely assessed (Aranceta Bartrina 2013, González-Gross

and Meléndez 2013, León-Muñoz et al. 2013, Santaliestra-Pasías et al. 2013, Zamora-Navarro and Pérez-Llamas 2013).

Quoting Sir Sherrington<sup>1</sup>, we can say that if we want to either move a mountain or bat an eyelash, in both cases we have to contract some muscles. Therefore, physical activity cannot be avoided and even if we decide to stop breathing, our heart will keep on beating. At least for some time.

On the other side, it is advisable that we do perform some kind of moderate-to-vigorous physical activity because of the evident benefits of it (Lee and Ory 2013), especially in addressing diabetes (Alibasic et al. 2013, Cox et al. 2013, Devries et al. 2013, Jalilian et al. 2013, Venkatasamy et al. 2013) and preventing cardiovascular diseases (Conti and Macchi 2013, Figueiredo et al. 2013, Figueroa et al. 2011, Kawasaki et al. 2011, Tanaka 2009, Williams and Stewart 2009), in particular in older adults. Still, intense physical activity should be promoted among young people, in order to prevent arterial stiffness and related cardiovascular problems which may occur later in life (Van de Laar et al. 2010).

We can try to make a distinction between a generic physical activity and sport. The hiatus is not necessarily so neat, unless we consider only sport performance, at professional/agonistic level, as in competition. This is definitely something more specific than physical activity - even if it certainly is a kind of – because it involves the strive for maximum efficiency and output, and lastly excellence and victory within a codified set of rules. Still, a golf tournament may be less demanding than recreational climbing or wrestling, from a muscular, cardiovascular and energetic point of view.

In the following chapters we shall take into consideration some kinds of physical exercise which are usually considered sports - like mountaineering and weightlifting - since they can involve competition, even if not necessarily. We shall therefore refer to them as sport practice.

## 1.2 Kinanthropometry and physical adaptation

Regardless of the kind of sport or generic physical activity practiced by a subject, it is necessary to assess the relevant adaptations occurring as a consequence of exercising, in order to evaluate the benefits, especially for general health. Different means can be used by the researchers. This dissertation mostly rely on *kinanthropometry*, the study of the human body in terms of size, proportion, composition (in terms of fat and fat free mass) and function, in order to understand growth, performance and nutritional status, especially in relation to sport practice.

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<sup>1</sup> Nobel prize winner in 1932 and discoverer of the law of reciprocal inhibition, see Tyler and Hutton 1986.

In addition, some measures of strength have been taken into consideration in order to evaluate performance - in terms of biomechanical force production - and health. In particular, hand grip strength has been chosen because of the ease with which it can be measured by means of a dynamometer, and because of its relationship with overall strength and health, at least in adults and older people (Rantanen et al. 1992, 1999, Bohannon 2008, Sasaki et al. 2007). This is consistent with the observation that, in everyday life, whenever we want to lift a weight, we have to use the hands. The same happens in functional training, where no fitness machines are used but barbells, dumbbells, kettlebells and similar implements (Barbieri 2013a) which must be lifted by means of the hands.

### 1.2.1 Body mass and weight

Body mass and weight are not necessarily related to health, as fat and fat free mass are. In fact, an athlete - a shot putter or a football lineman - may have a very large body mass, like that of an obese subject with the same height, but his or her overall body mass has a much larger amount of lean muscles and dense bones. Still, body mass is actually needed to estimate body density and therefore body composition.

Body mass (BM) is easily assessed in kilograms by means of a scale (necessarily, a professional one). Such piece of equipment actually measures body weight (BW), the physical force with which the Earth and the body mass attract each other. According to the law of Newton, force is defined as the product of mass times acceleration:

$$\overrightarrow{BW} = BM \vec{g}$$

where  $g$  is gravitational acceleration, corresponding to  $9.81 \text{ m/s}^2$  approximately and on average. Its value depends on the distance from the center of gravity of the Earth and therefore varies slightly according to the place where the body weight is being measured (Mt. Everest, the Death Valley etc.).

The standard unit of measure of force is the Newton [N], 1 N corresponding to 1 kg of mass being accelerated at  $1 \text{ m/s}^2$ . One kg has therefore a weight of 9,81 N on average within the Earth gravitational field. Scales usually adopt the more common kilogram-force (kgf) as a unit of measure for body weight, and not the standard Newton. One kgf represents the force exerted by 1 kg of mass inside the Earth gravitational field. Therefore  $1 \text{ kgf} \cong 9.81 \text{ N}$ , which means that the value read on the scale can be used for both body weight (a force) and body mass as well. The dimensional relationship between force (kgf or N) and mass (kg) is the following:

$$[\text{kgf}] = [\text{N}] = [\text{kg}] \frac{[\text{m}]}{[\text{s}^2]}$$

### 1.2.2 Body density

Overall average body density (BD) is defined as

$$BD = BM/BV$$

where BV is total body volume. It is an important anthropometric parameter, which can be measured in order to assess body composition, that is the percentage of body fatness (%F) on total body mass and therefore the relative amount of fat mass (FM) and fat free mass (FFM).

In a simplified, two-component model of the body (Figure 1), total body mass is made up of fat mass and fat free mass:

$$BM = FM + FFM$$

which implies that:

$$BD = D_F * \%F + D_{FFM} * (1 - \%F) \rightarrow \%F = (BD - D_{FFM}) / (D_F - D_{FFM})$$

where  $D_F$  is the density of fat mass and  $D_{FFM}$  is the density of fat free mass, which are given.

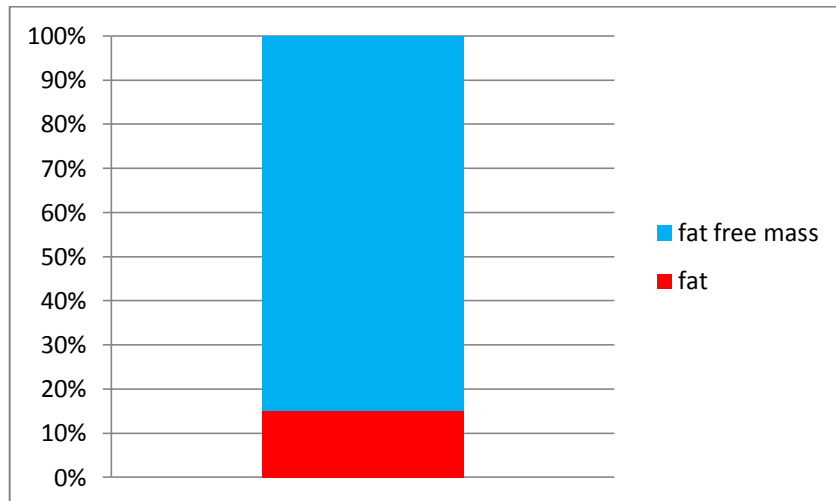


Fig. 1. Model of the body with 2 components.

A more detailed description of the composition of human body would acknowledge 4 components (Figure 2). In fact, fat free mass is made of proteins, minerals – i.e. muscles and bones, roughly speaking - and water, all of which have a higher density than fat:  $D_{FFM} > D_F$  (Table 1). Therefore, from a physical point of view, a high body density implies a low percentage of fat (accordingly, the numerator of the fat equation above  $BD - D_{FFM}$  diminishes its module as  $BD$  increases).



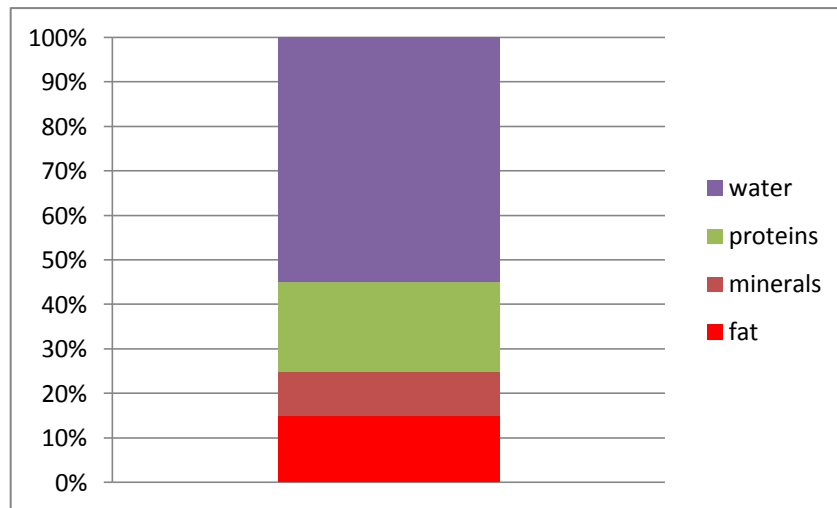


Fig. 2. Model of the body with 4 components.

TABLE 1. DENSITY OF COMPONENTS OF FAT FREE MASS AND FAT.

Component	Density (g/ml)
Water	0.9937
Protein	1.34
Mineral	3.038
Fat free mass (estimated average)	1.100
Fat	0.9007

Density at 36°C. Adapted from Brožek et al. 1963.

Unfortunately, the accuracy of the estimate is negatively affected by the fact that the different components of fat free mass do not have the same density and are not present with the same percentages in different individuals and populations. Therefore, fat free mass may have different average density than in Table 1. Athletes, who usually have a higher-than-average bone mass and density (Nichols et al. 2007, Nindl et al. 1998, Tsai et al. 1996), will have a higher fat free mass average density than assumed, and therefore the fat mass estimate may be lower than it actually is.

Different means can be employed in order to measure average body density. One of the most accurate (in “gold standard” terms) is the Bod Pod (Figure 3), or *Air Displacement Plethysmograph* (ADP), which uses whole-body densitometry to determine body composition. A plethysmograph is a piece of equipment which measures changes in body volume.



Fig.3. Bod Pod.

Body mass must be measured by means of an accurate scale. Then the Bod Pod measures body volume using two separate chambers. The test or measurement chamber has a pre-established capacity  $V_1$  (the empty space filled by air). The law of Boyle,  $pV=k$ , defining the relationship between volume and pressure at constant temperature, is used to measure the volume  $V_2$  of the chamber with the subject sitting inside it (Figure 4). The reference chamber has the instrumentation which is used to measure the difference in pressure. Body volume is calculated as  $BV=V_1-V_2$ . Body density is then calculated by the Bod Pod computer using the equation for body density:  $BD = BM/BV$ .

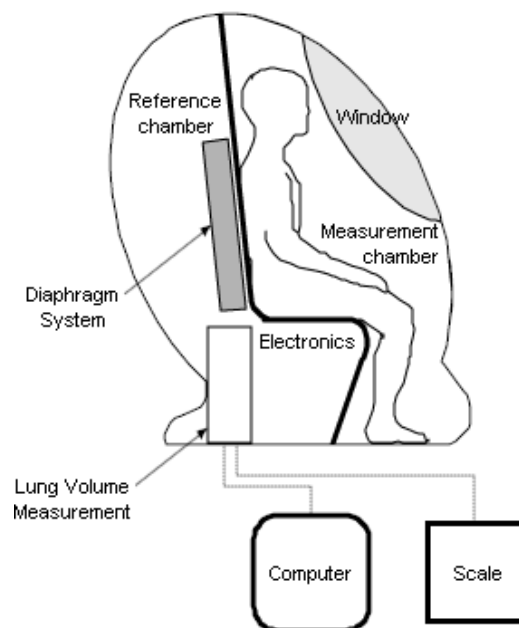


Fig. 4. Body volume measurement by means of the Bod pod.

Another way of assessing body density is standard surface anthropometry, by means of the skinfold method. A plicometer is used to measure skinfolds (Figure 5) at different body sites (e.g. triceps, biceps etc.) and then several equations are available to calculate overall body density from skinfolds' thickness. Those elaborated by Jackson and Pollock (1985) are among the most commonly used equations for the general population and for both sexes:

$$BD(\text{men}) = 1.112505 - 0.0013125 \cdot X_3 + 0.0000055 \cdot (X_3)^2 - 0.000244 \cdot \text{age}$$

where  $X_3$  is the sum of the following skinfolds: triceps, chest and sub-scapular;

$$BD(\text{women}) = 1.089733 - 0.0009245 \cdot X_3 + 0.0000025 \cdot (X_3)^2 - 0.0000979 \cdot \text{age}$$

where  $X_3$  is the sum of the following skinfolds: triceps, supra-iliac and abdominal. Age is always in years.

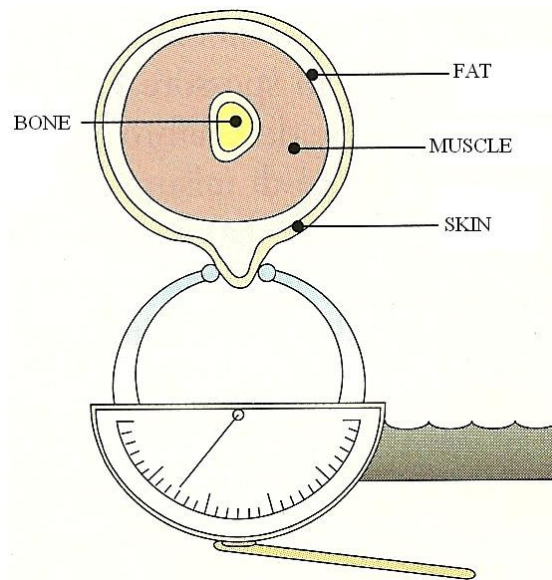


Fig. 5. Skinfold thickness measurement (adapted from McArdle et al. 1998).

Other generalized equations can be found in the specific literature, e.g. the equations of Durnin and Womersley (1974):

$$BD = c - m \log_{10} \sum_i skf_i$$

where  $\sum skf_i$  is the sum of the skinfolds. Coefficients  $c$  and  $m$  vary according to sex, age and skinfolds (from 1 to 4 among the following: biceps, triceps, sub-scapular and supra-iliac). Some parametric values for the two coefficients, in case of 2 or 3 skinfolds, can be found in Table 2.

TABLE 2. REGRESSION EQUATIONS' COEFFICIENTS.

Sex	Skinfolds	Coeff.	Age				
			17-19	20-29	30-39	40-49	≥50
M	Biceps + triceps	c	1.1423	1.1307	1.0995	1.1174	1.1185
		m	0.0687	0.0603	0.0431	0.0614	0.0683
	Biceps + triceps + subscapular	c	1.1643	1.1593	1.1213	1.1530	1.1569
		m	0.0727	0.0694	0.0487	0.0730	0.0780
F	Biceps + triceps	c	1.1290	1.1398	1.1243	1.1230	1.1226
		m	0.0657	0.0738	0.0646	0.0672	0.0710
	Biceps + triceps + subscapular	c	1.1509	1.1605	1.1385	1.1303	1.1372
		m	0.0715	0.0777	0.0654	0.0635	0.0710

Adapted from Durnin and Womersley 1974.

The equations above have been found by means of a statistical procedure. A gold standard method was used to assess the accurate values of body density in a large sample of individuals. Then, skinfolds at different sites were measured for each subject, according to standardized surface anthropometric procedures (Lohman et al. 1988). By means of regression (Figures 6a and 6b), it was possible to find the mathematical relationship between the sum of skinfolds and body density.

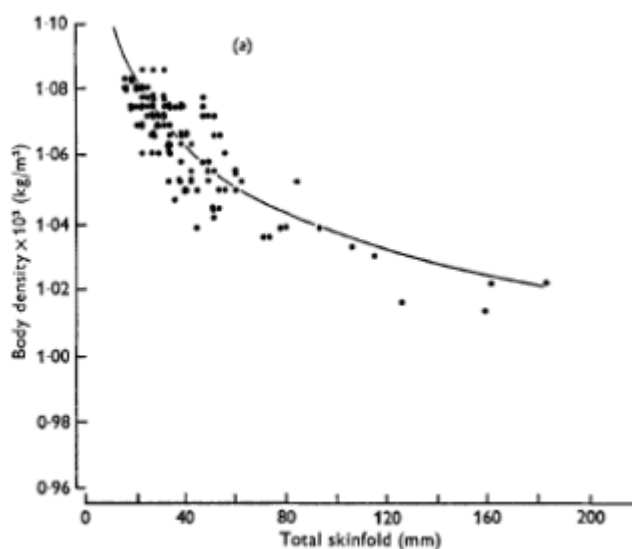


Fig. 6a. Individual values for body density and sum of four skinfolds with best-fit regression line derived from *log* values of skinfolds, for (a) men (adapted from Durnin and Womersley 1974).

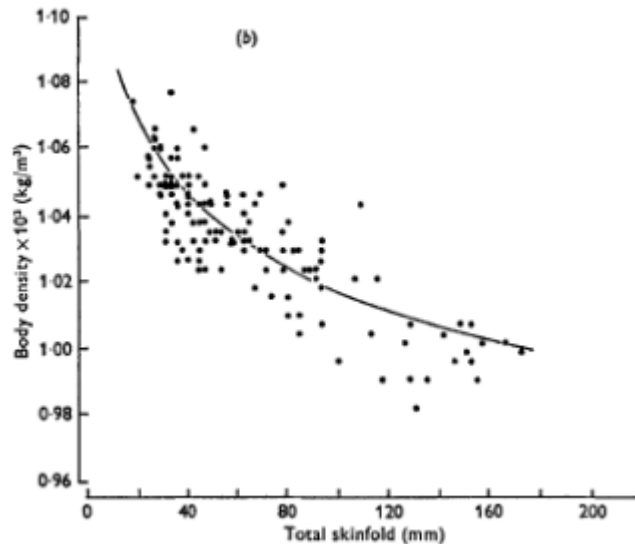


Fig. 6b. Individual values for body density and sum of four skinfolds with best-fit regression line derived from *log* values of skinfolds, for (b) women (adapted from Durnin and Womersley 1974).

Usually, the gold standard method adopted was *hydro-densitometry*, which relies on the principle of Archimede. Even if accurate, this method is highly unpractical, and this is the reason why sport and exercise professionals prefer to adopt other methods, like surface anthropometry. In hydro-densitometry the subject is weighted outside and inside water. Then body density BD is calculated using the following equation:

$$BD = \frac{BW}{\frac{(BW - IBW)}{WD} - (RV + GI)}$$

where:

- BW is the weight of the subject in the air.
- WD is the density of water at immersion temperature (which can be found in a specific table and it is about 1 g/ml at 4°C).
- IBW (immersed body weight) is the weight of the subject while completely immersed in water.
- GI is the gastro-intestinal gas and it is estimated at 100 ml approximately (Buskirk 1961).
- RV (residual volume) is the volume of air in the lungs after complete exhalation. The expiratory reserve volume (ERV), that is the air we can exhale with a maximal exhalation, can be easily measured by means of a spirometer, which records the volume of the air exhaled through a pipe. Unfortunately though, we cannot measure in this way the remaining air inside the lungs, RV. We first need to measure the functional residual capacity (FRC), that is the volume of the air in the lungs after a normal exhalation, which can be done by means of the helium dilution technique. Then we can calculate RV as  $FRC - ERV$ .

- $BW-IBW$  is the weight of the displaced water, therefore  $[(BW-IBW)/WD]-(RV+GI)$  is the volume of the body.

The corrections are needed in order for the equation to take into account air in the lungs and in the abdomen during measurement, although the weighted person is told to exhale maximally. Since the density of water is known and the two weights are measured, then the equation can be easily solved for body density.

### 1.2.3 Body fat percentage

Once body density has been determined, the percentage of fat mass %F is calculated applying the equation of Siri (1956, 1961):

$$\%F = \left( \frac{4.95}{BD} - 4.5 \right) \times 100$$

where the two constants' estimates are based on the density of FM and FFM at 37°C. Another equation which is commonly adopted in the scientific literature on the topic is the formula of Brožek et al. (1963), where the two constants' estimates are based on the density of FM and FFM at 36°C:

$$\%F = \left( \frac{4.57}{BD} - 4.142 \right) \times 100$$

Cut-points associated to different body fat percentages may vary according to the source. Table 3 lists the ones suggested by COSMED, producer of the Bod Pod, for male and female adults, including suggestions on how to cope with corresponding ratings of body fatness.

TABLE 3. BODY FAT PERCENTAGE RATINGS.

Rating	Male %F	Females %F	Explanation
Risky (too high)	>30%	>40%	Ask your health care professional how to safely modify your body composition.
Excessive	20-30%	30-40%	Indicates an excessive accumulation of fat.
Moderately lean	12-20%	22-30%	Fat level is acceptable for good health.
Lean	8-12%	18-22%	Lower body fat level than many people. This range is generally excellent for health and longevity.
Ultra lean	5-8%	15-18%	Fat levels often found in elite athletes.
Risky (too low)	<5%	<15%	Ask your health care professional about how to safely modify your body composition.

Adapted from McArdle et al. (1998).

### 1.2.4 Fat mass and fat free mass

Once fat mass percentage has been estimated, the following equations can be used to calculate fat mass (FM) and fat free mass (FFM) from body mass (BM):

$$FM = BM \times \%F$$

$$FFM = BM - FM$$

Body fat percentage must be expressed in decimals (e.g. 12% → 0.12) in the first equation above to immediately calculate fat mass. The whole process of assessing body composition is described in Figure 7.

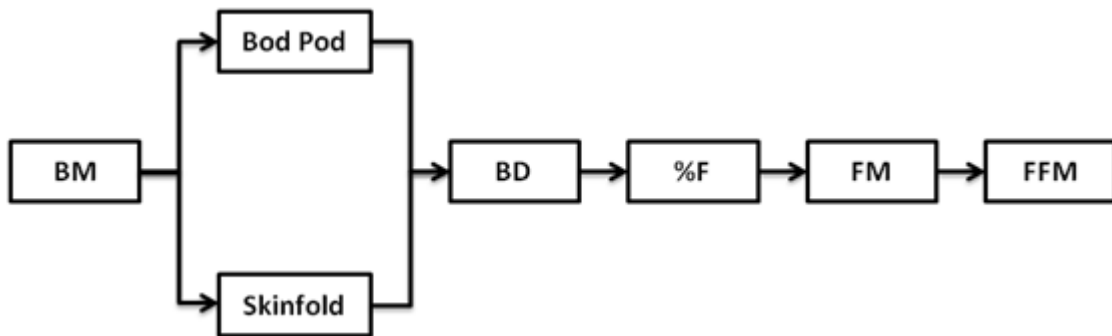


Fig.7. Body composition evaluation process.

The evaluation of the composition of human body in terms of fat mass and fat free mass is one of the most important anthropometric tasks, because of the relationship between body composition and both sport performance and human health.

In fact, in most cases, a low body fat/fat free mass ratio improves physical performances, while the opposite ratio diminishes them (Claessens et al. 1994, Crawford et al. 2011, Haakonssen et al. 2013, Manchado et al. 2013, Nikolaidis 2013). In particular, excessive adiposity is negatively correlated to performance in sports which require to run or jump, which are instead improved by increased muscle mass (Sporis et al. 2011, Takai et al. 2013). Body fat has a negative correlation to performance also in sports where weight classes exist (Slater et al. 2005, Franchini et al. 2011, García-Pallarés et al. 2011, Ye et al. 2013) like wrestling, martial arts, weightlifting etc. In these disciplines, strength-to-body weight ratio (i.e. relative strength:  $F_r = F/BW$ ) plays a major role, while added body fatness may compel the athlete to move to a higher weight category, where stronger opponents compete, without any benefit. In fact, only lean muscle mass may provide increased strength and performance.

Excessive body fatness also negatively affects general health, especially in terms of increased cardiovascular risks (Ford and Caspersen 2012, Van de Laar et al. 2013, Chomistek et al. 2013) and metabolic risks (Matthews et al. 2012), including diabetes (Bastard et al. 2006, Antuna-Puente et al. 2008, Lee et al. 2013).

It must be highlighted that a reduction in body fatness can only be related to a negative balance between energy intake and energy expenditure:  $energy\ intake < energy$

*expenditure* (McArdle et al. 1998, pp. 618-619, Figure 8), since physiology must respect the law of physics. For the same reason, an increase in body fatness must necessarily come as a consequence of a positive energetic balance:  $energy\ intake > energy\ expenditure$ . This is true also in order to increase lean muscle mass, which necessarily require a positive energetic balance (*a nihilo nihil*).

Body weight instead can vary even in case of energetic balance, since water has a mass but brings no calories. A significant variation in the level of hydration of the body implies a variation in body weight. This may happen, for example, after a sauna, where no significant reduction in body fatness is experienced but fluid is lost because of intense sweating. Similarly, a measurable body weight reduction can be experienced after abundant urination.

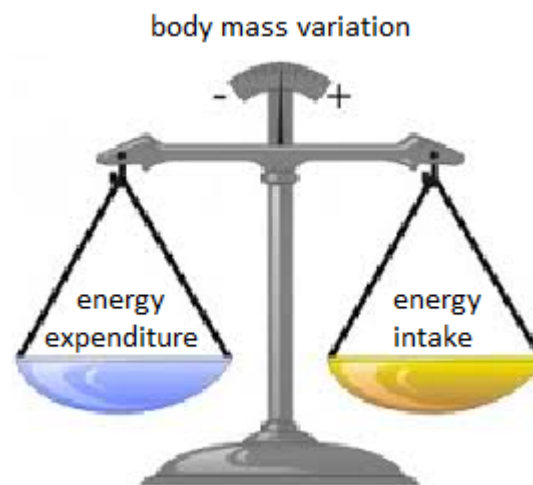


Fig. 8. Body mass variation (at a constant hydration level).

A complete body composition report can be seen in Figure 9. The assessment was performed in May 2013 at the Faculty of Kinesiology of the University of Zagreb by means of the Bod Pod system.



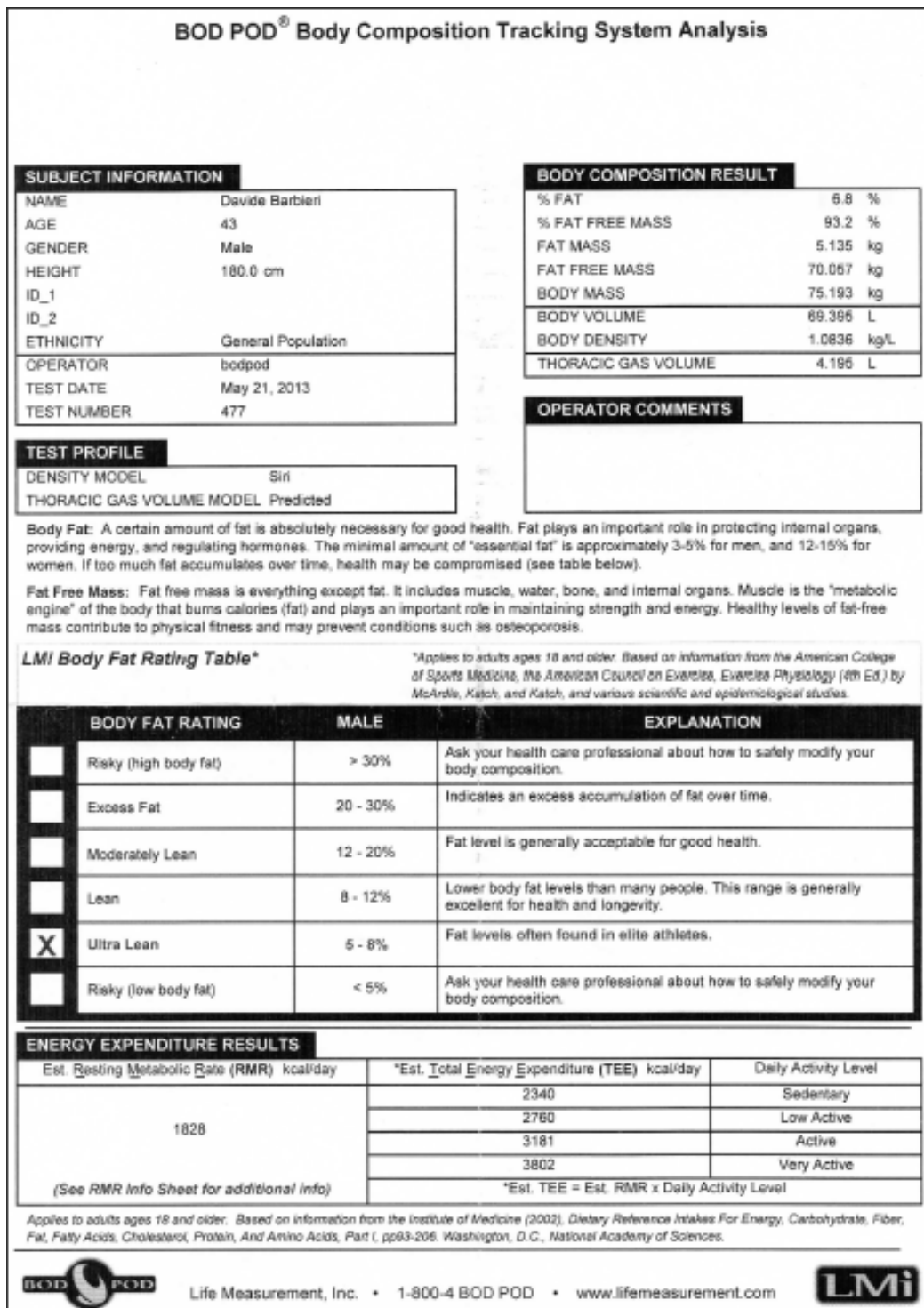


Fig. 9. Body composition report.

### 1.2.5 The body mass index

As it can be inferred from the explanations above, to correctly measure the fat mass of an individual is quite cumbersome: it either requires expensive equipment, like the Bod Pod, or it is not easy to do it accurately (for example by means of hydro-densitometry). Even the less accurate skinfold method requires some equipment (a caliper) and skill.

For these reasons and for a wider adoption at population level, other indirect measures of body fatness have been proposed. The most popular is probably the body mass index (BMI):

$$BMI = BW/H^2$$

where H is the height in *m* of the subject being measured. This a very easy index to acquire, even by family practitioners or physical education instructors at school, since all they need are a scale to measure body mass and a stadiometer to measure height.

Unfortunately though, since the definition of BMI does not take into account the varying proportions of fat and fat free mass, it cannot be considered an accurate estimate of adiposity. Even if specificity (i.e. the percentage of overweight people who are actually overfat) is usually good, BMI has low sensitivity<sup>2</sup> (i.e. a high percentage of misses, overfat people who do not fall into the overweight category, Table 4) missing more than a half of the individuals with excessive fat in the general population (Romero-Corral et al. 2008, Oliveros et al. 2014) so that we can actually speak of normal weight obesity (De Lorenzo et al. 2006). These findings have been confirmed by a recent research on Italian university students: sensitivity was poor in both sexes, but particularly in females (Zaccagni et al. under review).

TABLE 4. CORRECT CLASSIFICATIONS AND ERRORS.

	High %F	Normal or low %F
High BMI	Overweight and overfat (true positives)	Overweight but not overfat (false alarms, type I errors)
Normal or low BMI	Normal weight but overfat (misses, type II errors)	Not overweight and not overfat (true negatives)

A similar situation could be found among adolescent females. Even if specificity is good, sensitivity is very low, thus missing to correctly classify as overweight (according to the World Health Organization, WHO) many individuals who were actually overfat (Neovius et al. 2004). This is consistent with the observation that in the general population (i.e. non athletes) people who are overweight are usually not very muscular, and therefore their body mass has a relatively high percentage of fat. WHO cut points are listed in Table 5 and displayed in Figure 9.

TABLE 5. BMI CATEGORIES<sup>3</sup>.

Cut point	Nutritional status
BMI $\geq$ 30	Obese
25 $\leq$ BMI<30	Overweight
18.5 $\leq$ BMI<25	Normal
BMI<18.5	Underweight

<sup>2</sup> For an exhaustive explanation of sensitivity and specificity, see Barbieri (2013b).

<sup>3</sup> Taken from [http://apps.who.int/bmi/index.jsp?introPage=intro\\_3.html](http://apps.who.int/bmi/index.jsp?introPage=intro_3.html), accessed 28<sup>th</sup> October 2013.

Conversely, in physically active individuals, like young athletes, because of their dense muscle tissue, BMI can have a high sensitivity but a low specificity (Ode et al. 2007), meaning that many individuals who were classified as overweight were not fat (false alarms). A bodybuilder or a weightlifter with a large body mass may easily fall into the overweight category, even if his or her body fatness is very low. Therefore, in the domain of sport, the BMI has limited applicability. Nonetheless, it is still commonly used as an index of the nutritional status in the general population.

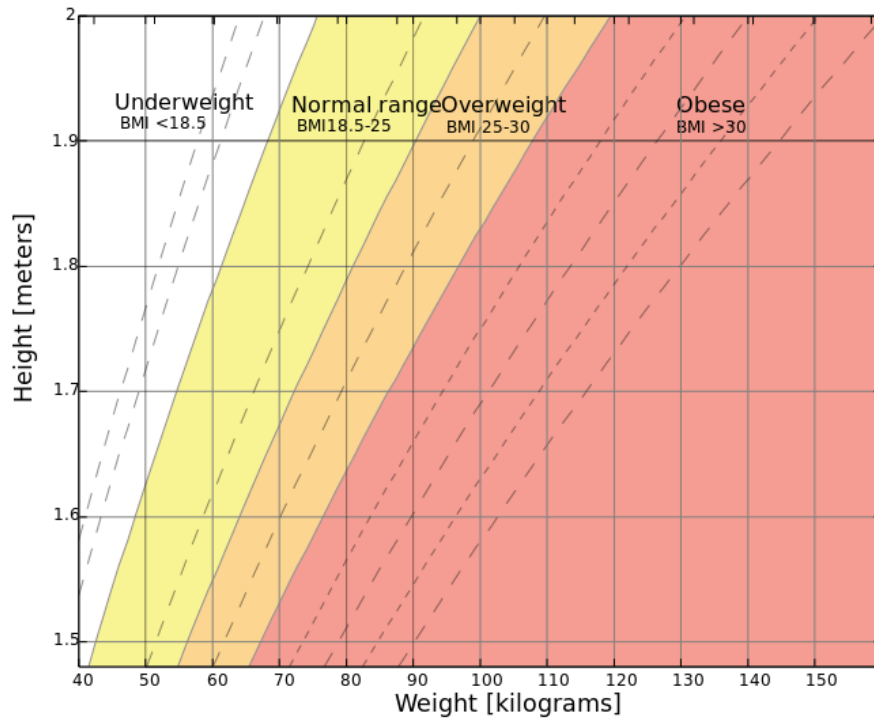


Fig. 10. Body Mass Index chart.

Other indices have been proposed to easily assess the level of fatness of individuals and the related health risks (Martin et al. 2013), like the waist circumference WC (Mihalache et al. 2012), the body adiposity index (BAI), the waist-to-hip ratio (WHR) or the waist-to-stature ratio (WSR, or waist-to-height ratio WHtR, Ashwell and Hsieh 2005). BAI can be calculated as follows (Bergman et al. 2011):

$$BAI = \frac{HC}{H^{1.5}} - 18 = \frac{HC}{H\sqrt{H}} - 18$$

where HC is hip circumference in [cm] and H is height in [m]. Most of them have shown their limitations (Bennasar-Veny et al. 2013, Zaccagni et al. under review) mainly because they do not take into consideration fat and fat free mass. Therefore, they can be considered measures of body proportions rather than adiposity. There is a need for further research in order to find an indirect measure of body fatness which is at the same time accurate and easy and cheap to acquire.

## 1.3 The somatotype

According to the Heath-Carter manual<sup>4</sup> (Carter 2002), the somatotype is a quantification of the human body shape and composition. By definition, it is expressed in terms of three components:

1. Endomorphy, the relative fatness of the subject.
2. Mesomorphy, the relative musculoskeletal robustness.
3. Ectomorphy, the relative slenderness of the body.

Each of the components above is assigned, after proper measurements, a numeric value, indicating its magnitude. In order to do so, the anthropometric method is employed, by means of some standard equipment.

### 1.3.1 Anthropometric measures

The following anthropometric measures, usually taken on the left side<sup>5</sup>, are needed in order to quantify the somatotype of a subject:

- Stature (vertex-planta), which can be taken by means of a stadiometer with the head aligned according to the Frankfurt plane (accuracy 0.1 cm).
- Body mass (or weight), measured by means of a scale to the nearest tenth of a kilogram.
- Skinfolds (by means of a standard plicometer) at the following body sites:
  - Triceps: on the back of the upper arm, half way between the acromion (on the shoulder) and the olecranon (on the elbow).
  - Sub-scapula: on an oblique (45°) line from the inferior angle of the scapula.
  - Supra-spina: 5-7 cm above the anterior iliac spine.
  - Medial calf: at sura (corresponding to the maximum girth).
- Bone breadths (by means of an anthropometric sliding caliper):
  - Biepicondylar breadth of the humerus: width between medial and lateral epicondyles of the humerus, with elbow flexed.
  - Biepicondylar breadth of the femur: width between the medial and lateral epicondyles of the bent knee while the subject is sitting.
- Limb girths (by means of a non-stretchable tape):
  - Upper arm, elbow flexed and tensed muscle, greatest girth.
  - Calf: at sura.

Now that the measures have been taken, the somatotype components can be calculated.

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<sup>4</sup> Downloadable from <http://www.somatotype.org/Heath-CarterManual.pdf>, accessed November 6th 2013.

<sup>5</sup> According to the 1912 Geneva International Anthropometry Standardization Agreement.

### 1.3.2 Somatotype components

To calculate the three somatotype components the following equations are used:

$$\text{Endomorphy} = -0.7182 + 0.1451 * X - 0.00068 * X^2 + 0.0000014 * X^3$$

where  $X = (\text{triceps skinfold} + \text{sub-scapular skinfold} + \text{supra-spinal skinfold}) * (170.18/H)$ , and H is the height of the subject in cm.

$$\text{Mesomorphy} = 0.858 * HB + 0.601 * FB + 0.188 * CAG + 0.161 * CCG - H * 0.131 + 4.5$$

where HB = humerus breadth, FB = femur breadth, CAG (corrected arm girth) = flexed arm girth - triceps skinfold/10, CCG (corrected calf girth) = calf girth - calf skinfold/10. For ectomorphy three different equations are used, according to the height-weight ratio ( $HWR = H/BW^{1/3}$ , where BW is body weight):

- If  $HWR \geq 40.75$  then  $\text{ectomorphy} = 0.732 * HWR - 28.58$
- If HWR is less than 40.75 but greater than 38.25 then  $\text{ectomorphy} = 0.463 * HWR - 17.63$
- If HWR is equal to or less than 38.25 then  $\text{ectomorphy} = 0.1$

Now that the three somatotype components have been calculated, they can be plotted in a 2-D somatocharts, determining the coordinates (x, y) as follows:

- $x = \text{ectomorphy} - \text{endomorphy}$
- $y = 2 * \text{mesomorphy} - (\text{endomorphy} + \text{ectomorphy})$

For example, if the subject's somatotype components are 414, where the first 4 represents endomorphy, 1 represents mesomorphy and the last 4 represents ectomorphy, then his or her somatotype coordinates are (0, -6). In fact,  $x = \text{ectomorphy} - \text{endomorphy} = 4 - 4 = 0$ , and  $y = 2 * \text{mesomorphy} - (\text{endomorphy} + \text{ectomorphy}) = 2 * 1 - (4 + 4) = -6$ . The three values had been previously calculated with the given equations.

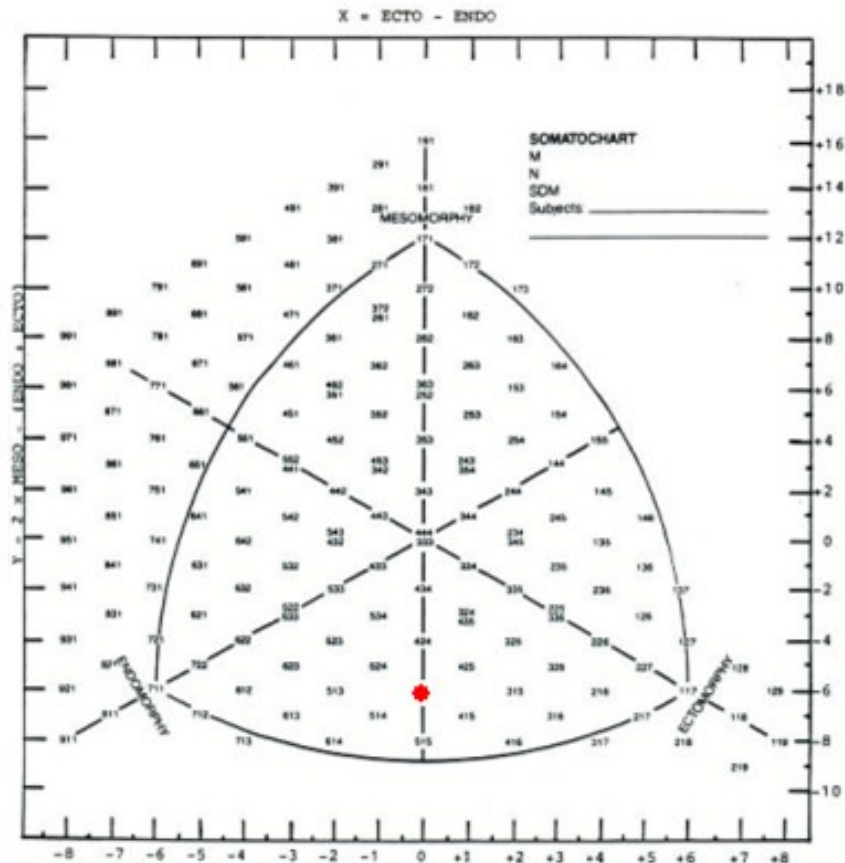


Figure 11. The somatochart.

The three-digit numbers which can be seen on the chart in Figure 11 correspond to the values of the three somatotype components. The closest number to the (x, y) point associated to the individual being assessed approximates his or her components' values. Following the example above, point (0, -6) in red identifies 4-1-4 on the chart.

### 1.3.3 Somatotype categories

The following seven main categories can be used to classify individuals according to their somatotype:

- Central: no component differs by more than 1 from the other two.
- Endomorph: endomorphy is dominant, mesomorphy and ectomorphy are more than 0.5 lower.
- Endomorph-mesomorph: endomorphy and mesomorphy do not differ by more than 0.5, and ectomorphy is smaller.
- Mesomorph: mesomorphy is dominant, endomorphy and ectomorphy are more than 0.5 lower.
- Mesomorph-ectomorph: mesomorphy and ectomorphy do not differ by more than 0.5, and endomorphy is smaller.
- Ectomorph: ectomorphy is dominant, endomorphy and mesomorphy are more than 0.5 lower.

- Ectomorph-endomorph: endomorphy and ectomorphy do not differ by more than 0.5, and mesomorphy is lower.

Six more intermediate categories can be added to the main seven above. They can be graphically identified in the somatochart in Figure 12.

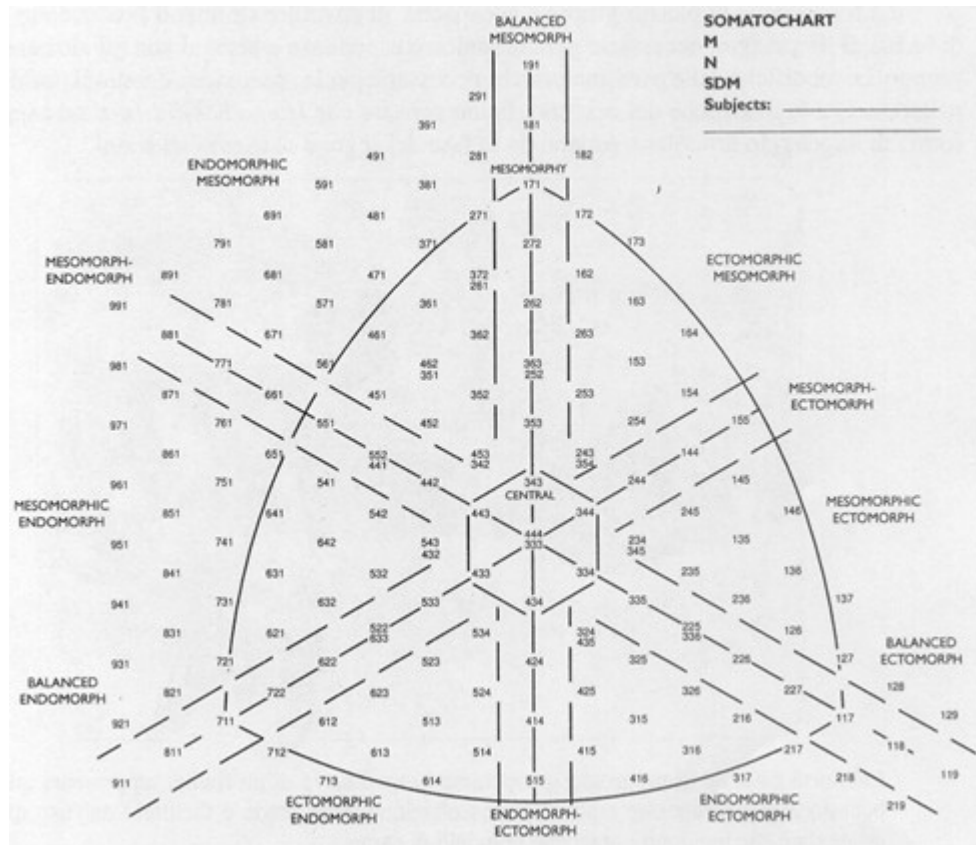


Fig. 12. Somatotype categories (adapted from Carter 2002).

At the end of this process, the individual somatotype is thus determined. The subject in the previous example would be in the endomorph – ectomorph category. This assessment may determine an individual predisposition to different sports. In fact, in order to excel in a discipline, different body proportions may be needed (Marta et al. 2013). For example, in volleyball, mesomorphism prevails (Carvajal et al. 2012), but significant differences in the somatotype were observed at different levels of performance, with top players having a higher ectomorphic component compared to less qualified athletes. Moreover, in relation to roles, the mesomorphic component is maximal in setters, while the ectomorphic one is maximal in centers (Gualdi-Russo and Zaccagni 2001). A previous study showed the predominance of the mesomorphic somatotype in most sports - especially in male rowers and gymnast, and in female martial artists - and at increasing levels of performance (Gualdi-Russo and Graziani 1993).

### 1.3.4 Differences between somatotypes

To evaluate the difference between two somatotypes A and B, which can be the somatotypes of two individuals, an individual and a group or two groups, we can calculate the somatotype attitudinal distance (SAD):

$$SAD_{A,B} = \sqrt{(Endo A - Endo B)^2 + (Meso A - Meso B)^2 + (Ecto A - Ecto B)^2}$$

In case A and/or B is a group, then the group somatotype is the mean of the components:

$$Endo = \frac{1}{n} \sum_i Endo_i; Meso = \frac{1}{n} \sum_i Meso_i; Ecto = \frac{1}{n} \sum_i Ecto_i$$

where  $endo_i$ ,  $meso_i$  and  $ecto_i$  are the somatotype components of individual  $i$ .

The somatotype attitudinal mean (SAM) instead is the mean of a group of somatotypes:

$$SAM = \frac{1}{n} \sum_{i=1}^n SAD_i$$

where  $SAD_i$  is the difference between the somatotype of individual  $i$  and the group mean, and  $n$  is the number of subjects in the group.

## 1.4 Kinanthropometry and sport performance

Different anthropometric characteristics can be associated to success in several sport disciplines. Unfortunately though, it is obvious by definition that the traits which describe top athletes can only be found in a small sample of individuals. Therefore, to speak of what it takes to make a champion, the mean value of the selected anthropometric traits must be far from the mean of the general population, and/or the standard deviation (SD) relatively small. But this is not necessarily the case, at least not always. In fact, in many sport disciplines, the acquired fitness and biomechanical skills can still make the difference, eventually compensating a body shape which is apparently far from optimal.

Nonetheless, looking at the appearance of top athletes in sports like basketball, throws, high jump and many others, we can spot some characteristics, at least at national or world-class level, which push us to admit they have something in common. Basketball players and high jumpers are usually very tall, and throwers have a large body mass. This problem has much in common with that of “universals” in epistemology: What top athletes have in common? What is athleticism? Does a set of general traits determine a top athlete? Is it possible to generalize or not? The answer to these questions will be, of course, statistical, in probabilistic terms, and therefore it will allow for exceptions (outliers) and values far from the mean.



If we compare the distribution (supposed to be normal) of the height of the general male Australian population ( $178.6 \pm 7.1$  cm, mean $\pm$ SD) with that of a sample of top level male high jumpers ( $194.7 \pm 2.6$  cm), we can see that overlapping is minimal. In fact, high jumpers are much taller, on average, and their height is distributed very close to the mean, having a lower standard deviation than the same anthropometric trait in the general population. It is therefore rather unlikely to find a top high jumper with a height close to that of the average Australian male.

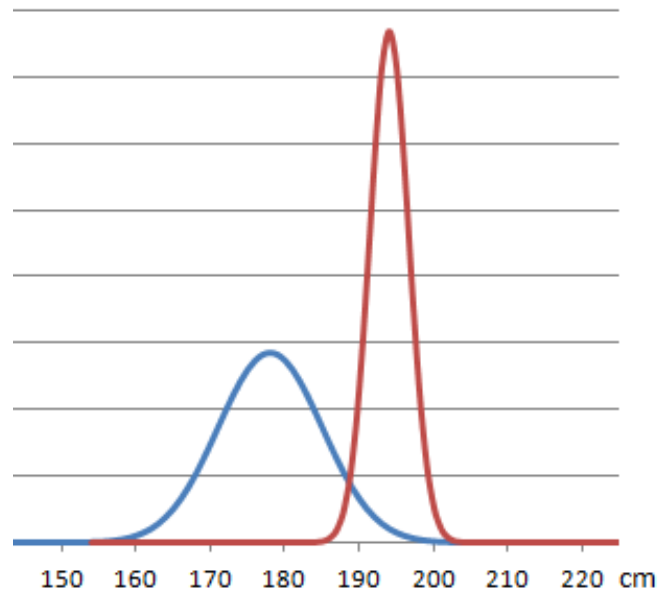


Fig. 13. Height distribution in the general male Australian population (blue) and in a sample of elite high jumpers (red). Data are taken from Norton et al. (2004).

Shorter heights than the general population can instead be found in sports like gymnastics, figure skating and diving. Short limbs reduce moments of inertia, thus facilitating the athletes to move at high angular velocities. Shorter skaters and gymnasts can therefore complete more turns. Also, in gymnastics, shorter upper limbs allow to reduce moment arms in suspended positions (e.g. the iron cross on the rings), diminishing the muscular strength required to successfully complete an exercise.

Shorter limbs and more favorable moment arms may help sprinters to accelerate more quickly, also thanks to high strength-to-body weight ratios, as it can be inferred by relatively high BMI and low fat percentage. On the contrary, marathon runners have a low body mass, because muscle mass do not add any competitive advantage, while requiring a lot of energy to carry it for the whole distance to be covered. Both sprinters and long distance runners show very low levels of body fat, which is detrimental to performance in many sports. This is particularly true in those disciplines, like running or jumping, where relative strength is critical for improvement.

Similarly, sports with weight classes, like wrestling, boxing and weight lifting, compel athletes to minimize their body fat in order to reach their optimal weight and

remain inside their class. In higher classes in fact, added body fat would not result in improved performances and larger, more powerful athletes would be at an advantage.

The human phenotype - shape or morphology - is the result of the interaction between the genotype (the genes of a subject) and environment, the surrounding conditions to which an individual is subjected, including sport training, nutrition, climate, lifestyle, habits etc. Bouchard and Lortie (1984) exemplified this interaction between genetics and non-genetic factors in endurance athletes by means of the following equation:

$$V_P = V_G + V_E + V_{G \times E} + e$$

where  $V_P$  is the total variation observed in the phenotype,  $V_G$  the genetic component,  $V_E$  the non-genetic component (the environment),  $V_{G \times E}$  the interaction effect between the two, and  $e$  is the random error.

## 1.5 Chapters summary

In this dissertation we are going to consider different kinds of physical activity, mainly strenuous and sport-related (like strength training, mountaineering and sprinting), and describe their effects on body composition and other anthropometric traits, in order to improve our understanding of how the body adapts and the relationship between body composition, somatotype and performance.

In the second chapter, we shall examine a review of the studies on strength training before and during adolescence, in order to evaluate its benefits and risks, especially for what concern growth and bones (mass and density). Also, the prolonged benefits for health after adolescence into adulthood will be evaluated - especially in women - in terms of osteoporosis prevention.

In the third chapter - the first original research - physical activity among young adults and its benefits for body composition will be described, assessing in particular the relationship between training volume and anthropometric traits. The sample is represented by a large group of Italian university students of the School of Sport Science of the University of Ferrara.

After children, adolescents and youngsters, adults will be taken into consideration in the second and third original researches. In the fourth chapter, a selected sample of elite mountain climbers will be assessed from an anthropometric point of view, in order to describe their specific characteristics. In the fifth chapter, a study will examine the effects of exposure to high altitude and trekking in a sample of recreational mountaineers by means of repeated measurements before, during and after an expedition on the Himalaya.

In the sixth chapter, an original study on sprinters' anthropometry and muscular strength will be presented. In particular, the relationship between these characteristics and

performance will be discussed, including implications for general health and body mass (fat and fat free) management.

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## **2. Strength training and physical adaptation during growth**

In the following research, the most evident body adaptations during growth and their persistence in adulthood as a consequence of strength training - like weight lifting and plyometrics - have been reviewed (Barbieri and Zaccagni 2013). In particular, the effects on the skeleton (bone mass, density etc.) of adolescent boys and girls, and the eventual benefits for health, specifically for the prevention of osteoporosis in adult women, have been evaluated.

Physical activity has proved to be an effective means of preventing several diseases and improving general health. In most cases, though, light to moderate efforts are suggested, for both youngsters and adults. Common sense advices call for late inception of intense, strength-related activities, like weight lifting and plyometrics, which are usually postponed at the end of the growth age, even among sport practitioners. However, such advices seem to have a mainly anecdotal nature. The purpose of this review is to evaluate risks and benefits of early inception of strength training, at adolescence or even earlier, and to verify whether concerns can be grounded scientifically.

Current literature does not seem to have any particular aversion against the practice of strength training by children and adolescents, provided that some safety rules are followed, like medical clearance, proper instruction from a qualified professional and progressive overload. At the same time, several studies provide consistent findings supporting the benefits of repeated and intense physical efforts in young subjects. Improved motor skills and body composition, in terms of increased fat free mass, reduced fat mass and enhanced bone health, have been extensively documented, especially if sport practice began early, when the subjects were pubescent. It can be therefore concluded that strength training is a relatively safe and healthy practice for children and adolescents.

### **2.1 Introduction**

Modern Western societies imply increasingly sedentary life styles and reduced physical exercise. Technological progress, limited outdoor activities and economic improvement have modified dietary habits and reduced the amount of exercise performed by children and adolescents (Morano and Colella 2009). It is well known that regular moderate intensity physical activity – such as walking or cycling – has significant benefits for health. According to the 2008 guidelines of the European Commission, school-aged youth should participate in moderate to vigorous daily physical activity for 60 minutes or more.

Obesity, sedentary lifestyle and poor cardio-respiratory fitness in childhood and adolescence may increase the risk of health problems later in life. The teenage years bring

many physical, social and psychological changes for the individual. From infancy to adulthood, growth, maturation and development occur simultaneously and interact: growth consists in the increase of the size of the body as a whole and of its parts, maturation refers to progress towards the biologically mature state and development refers to the acquisition of behavioral competence (Malina 2006a).

Changes in body dimensions and composition during growth and maturation are factors affecting strength and motor performance (Malina et al. 2004). Some changes in anthropometric traits and strength in a sample of Italian adolescents studied by Gualdi-Russo and Toselli (1997) are reported in Figures 1-4.

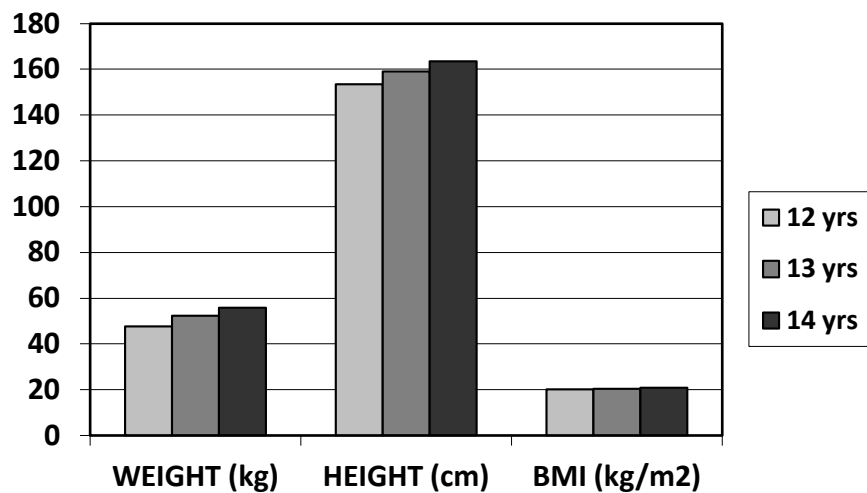


Fig. 1. Anthropometric traits in a sample of Italian adolescent males (adapted from Gualdi-Russo and Toselli 1997) by age.

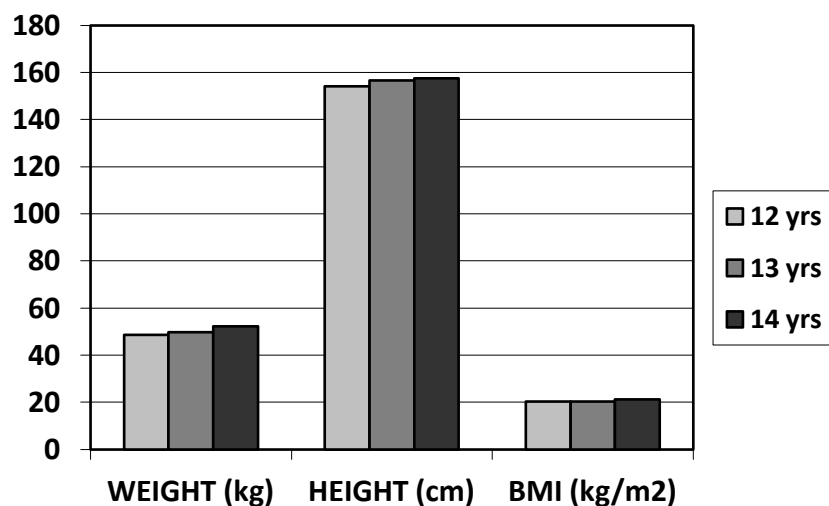


Fig. 2. Anthropometric traits in a sample of Italian adolescent females (adapted from Gualdi-Russo and Toselli 1997) by age.

Strength and motor performance vary during childhood and adolescence in relation to biological and environmental factors. Among biological factors the specific contribution

of maturity status is apparent: the strength advantage of early-maturing subjects is related to their larger body size in comparison to late-maturing ones. These differences are more marked in boys than in girls. Regular physical activity is an important factor during growth and maturation, regulating body weight and, particularly, fatness.

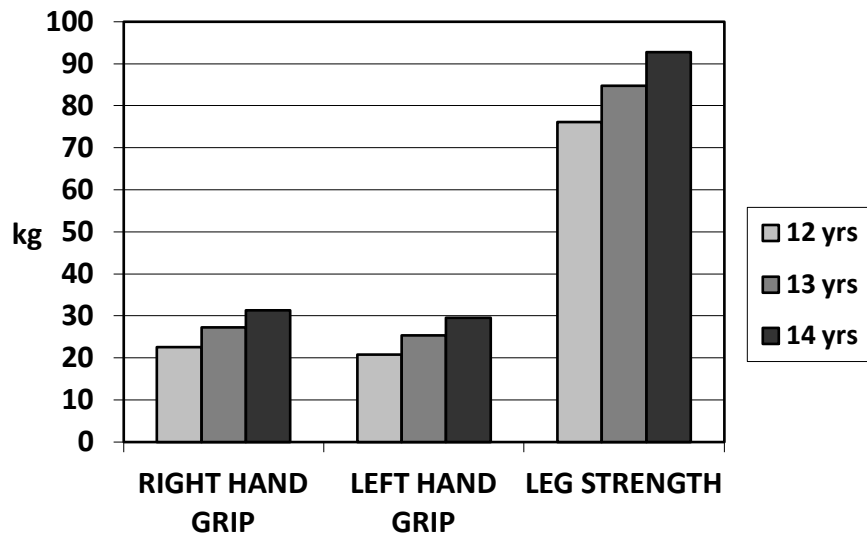


Fig. 3. Strength values in a sample of Italian adolescent males (adapted from Gualdi-Russo and Toselli 1997) by age.

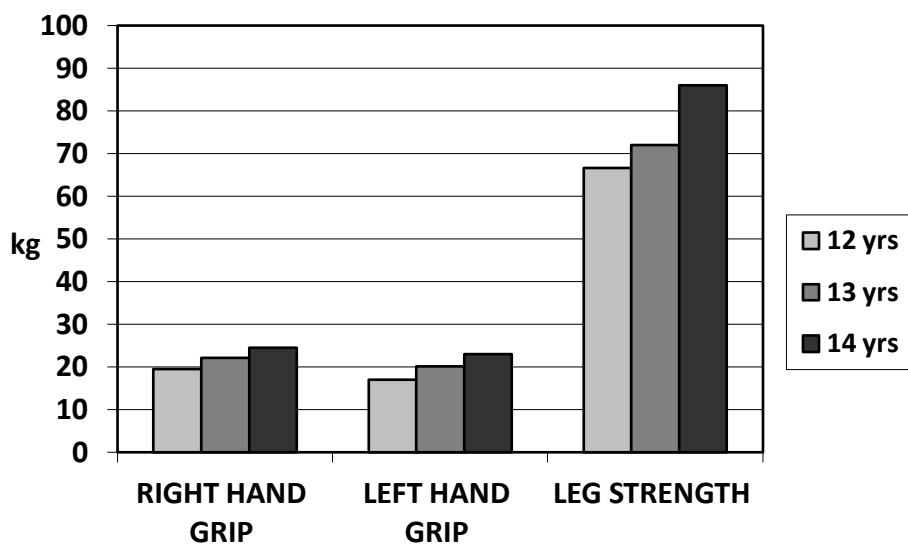


Fig. 4. Strength values in a sample of Italian adolescent females (adapted from Gualdi-Russo and Toselli 1997) by age.

Information on the characteristics of elite young athletes in a variety of sports is rather limited. The evaluation of the maturity status is essential when working with young athletes because individual differences in the timing and tempo of biological maturation, particularly during adolescence, influence body size and composition, muscular strength

and behavior. Inter-individual variability has important implications for performance, age-group competitions and talent identification, selection and development.

Albeit BMI is widely used in surveys of health and nutritional status, its interpretation in young adults, especially athletes, as an indicator of fatness should be taken with caution. Therefore, in kinanthropometry, in order to evaluate the positive effects of physical activity on body composition, the athlete's body fat percentage, fat mass and fat free mass are assessed. Changes in body composition from early to late adolescence can be summarized as follows: males gain almost twice as much fat free mass as females, and females gain about twice as much fat mass as males.

Large fat free mass is important in performances that require force to be exerted against an object, as in shot put or weight lifting, but can be a limiting factor in tasks in which the body must be projected as in vertical jump or moved across space, as in running. Fat free mass is significantly related to strength in male adolescents (Malina 2006a).

In sport practice, strength training was usually introduced at the end of the somatic growth, that is when the athlete was 18 years old or so. In particular, to avoid weight lifting before and during adolescence was a common suggestion in many different contexts connected to physical activity, from commercial gyms to physical education courses. This conservative approach has a mainly anecdotal origin, since usually no scientific evidence is given in order to support it.

Most of the concerns are related to the possibility of injuries or diminished growth potential. Still, many of the young athletes who regularly compete in various sport disciplines begin their training very early, when they are pubescent or even pre-pubescent. Beside the fact that students begin physical education at primary school in many countries, early inception of sport practice is often suggested in order to take advantage of the ease and quickness with which children and adolescents improve their motor control and acquire new sport skills.

Furthermore, adolescents can be observed while lifting weights during their usual daily activities, outside a sport or training facility: carrying a schoolbag, a suitcase, a shopping bag or other items, lifting them from the floor. Without proper training, they may do it rounding their back or using any other improper technique, while the correct one could be learnt under supervision from a weight lifting instructor, inside a gym.

It is therefore necessary to evaluate whether the advice to postpone strength training in general and weight lifting in particular at the end of adolescence is sound and can be substantiated scientifically. The main purposes of the present review are the following: to find any evidence in current literature of benefits or dangers for the health of the adolescents related to early inception of strength training, and to compare the relative stress of this kind of physical activity to other common sport practices.

## 2.2 Strength training: concepts and objectives

Strength training is a form of physical activity, usually structured and planned, involving intense efforts against a resistance. Its main aim is to increase muscular strength, in order to improve performance, at least in case a sport is practiced. It is extensively adopted in power-oriented sports, like sprinting (Delecluse 1997) and soccer (Wisløff 2004), even if its benefits are recognized also in endurance sports, like long distance running (Yamamoto et al. 2008, Paavolainen et al. 1999) and cross-country skiing (Hoff et al. 2002, Østerås et al. 2002).

In a non-competitive environment instead, strength training is adopted for many different purposes. For example, strength training may be used to improve overall fitness, increasing muscle hypertrophy and reducing body fatness at the same time. In fact, strength training can be an effective means to improve body composition (Paoli et al. 2010). In other cases, some individuals may adopt it in order to accomplish some professional goal, like achieving the degree of physical fitness which is required in the military or to join the fire brigade.

To train strength, muscular force is applied against some kind of resistance. In most cases, especially when the individual is healthy, resistance is provided by free weights, like barbells, dumbbells or the athlete's own body weight, or by weight machines, like the leg press, the lat machine etc. This kind of training is usually adopted in sport conditioning, because the load can be increased progressively according to the athlete's strength, which can be considerable.

Athletes employ gravity also in other ways in order to improve their performances, like in plyometrics or high-impact training, where body mass is accelerated dropping from a pre-determined height, according to the athlete's ability and conditioning level. This kind of strength training is usually considered the most dangerous, because the real impact forces applied to the athlete's body (bones, muscles, tendons, ligaments etc.) are not easily measured, as in weight lifting.

Physical force, a vectorial quantity, is defined as follows:

$$\vec{F} = m\vec{a}$$

that is mass times acceleration. Weight lifting mainly focuses on the first factor, adding mass to the barbell to be lifted (if the load is lifted at constant speed, as it usually happens in body building), while plyometrics relies on the second, that is gravitational acceleration, in order to produce force. Nonetheless, also weights can be accelerated, as in Olympic weightlifting, in order to increase force production without adding kilograms, and advanced plyometrics may imply added weight by means of weighted belts or vests.

It must be considered, though, that similar strength training effects can be found in sport practices other than weight lifting or plyometrics, like sprinting, gymnastics and other

kinds of power-oriented sports, or team sports involving leaping and bouncing, like volleyball and basketball. These types of physical efforts produce great acceleration, which, applied to the athlete's body mass, produce great force. Nonetheless, these intense efforts are usually practiced by children, even outside a sport environment, simply while playing with their peers.

Strength training has an important role in rehabilitation after injuries, especially those which involve surgery and/or a long period of immobilization, in order to re-gain the physiological muscle hypertrophy and joint range of motion (Ageberg et al. 2008, Fithian et al. 2010, Lorenz and Reiman 2011, Markatos et al. 2012, Augustsson 2012, Waters 2012). In case of injuries to lower limbs, when the patient is still lying in bed, body weight can be excessive and not suitable for post-surgery rehabilitation. Therefore, non-bodyweight bearing exercises can be used, by means of cables and/or small weights, attached to the ankles of the patient, like in leg raises and knee extensions.

Body weight can be excessive also for healthy individuals who have a low relative strength, that is a low strength-to-body weight ratio. A push up, a pull up (Figure 5) or even a body weight squat can be a demanding task for people who are too young, elderly, overweight or out of shape.

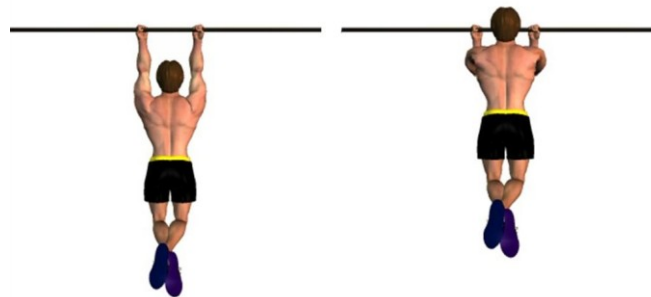


Fig. 5. Pull-up.

Free weights or machines can provide a controlled and adjustable source of resistance. For example, a push up can be effectively substituted by a bench press, a pull up by a lat pull down using a lat machine, a body weight squat by a leg press, involving more or less the same muscle groups. Weights can be adapted to the individuals' actual strength, which may be relatively low compared to their own body weight.



Fig. 6. Bench press.

Other kinds of resistance than weights may be applied in order to increase muscular strength, like elastic bands, or friction, as in water or on a steady bike. In fact, gravity is not necessarily present or not fully applicable. For these reasons, astronauts during space missions are at risk of losing considerable amounts of muscle mass (Stein and Gaprindashvili 1994, Stein 1999). Orthopedics patients may have access to a swimming pool, where the weight-bearing effort of an injured knee, ankle or hip can be reduced. At the same time, also competitive swimmers may use swim paddles to increase the resistance provided by water.

Exercises are usually performed in sets of several repetitions (i.e. consecutive lifts). If heavy loads are employed, providing stimulus for maximal strength, then repetitions are necessarily low in numbers. When the load is moderate, in order to improve body composition and cardiovascular fitness, then the overall number of repetitions can be considerably high.

The main training parameters are intensity and volume. Intensity is given as percentage of the maximal load which can be lifted for the prescribed number of repetitions: 1 repetition-maximum (RM) is the load which can be lifted just once, 10 RM is the load which can be lifted 10 times within one set. Strength training implies relatively heavy loads, between 60% and 100% of 1 RM, the so-called “strength training zone” (Siff and Verkoshansky 1998). For example, the 90% of 1 RM is a quasi-maximal load, allowing for small volume (i.e. low repetitions). Volume is the total number of repetitions per exercise. For example, performing 3 sets of 10 repetitions in one given exercise determines a volume of 30 repetitions.

The most common strength training exercises are listed in Table 1, with the discipline in which they are usually practiced, even if in most cases athletes involved in different sports may use a blend of them. This is especially true in body building, where the overall balanced development of muscle mass is of great importance.

TABLE 1. COMMON STRENGTH TRAINING EXERCISES.

Olympic weightlifting	Powerlifting	Body Building	Body weight training
Snatch	Squat	Overhead presses	Push ups
Clean & jerk	Bench press	Biceps curls	Pull ups
Front squat	Deadlift	Leg extensions	Parallel dips
Overhead squat		Leg curls	One-leg squats
Push press		Rowers	Sit ups

Therefore, bodybuilders use most of the listed exercises (and even more than those), while strength training for athletes usually comprises a small set of exercises, like the clean (Figure 7), the squat (Figure 8) and the bench press, involving most skeletal muscles in a coordinated fashion.



Fig. 7. Clean.

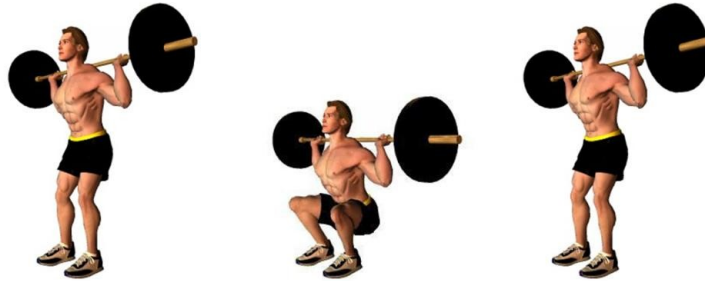


Fig. 8. Squat.

## 2.3 Benefits and risks of strength training

For reasons which have been mainly reported anecdotally, strength training, especially if involving weight lifting, has been considered dangerous for children and adolescents, and at risk of limiting their growth. However, the American College of Sports Medicine highlights that there is no current scientific evidence of the fact that strength training and weight lifting are inherently dangerous or can restrain the growth of children and adolescents. Like any other kind of sport practice, there are some risks which can be considerably diminished following a small set of suggestions: proper supervision from an expert adult, warm up and stretching before lifting, focus on proper form rather than load, gradual resistance increases as technique, strength and control improve (Lavallee 2002).

The American Academy of Pediatrics (1990, 2001, 2008) gives comparable guidelines, implying that strength training can be safe and effective for children and adolescents, provided that medical clearance is granted. At the same time, it discourages them from practicing sports, like Olympic weightlifting (Figure 9) and powerlifting, which involve maximal lifts. A similar position has been taken by the National Strength and Conditioning Association, which is in favor of supervised and appropriately prescribed strength training for both pre-adolescents and adolescents (Faigenbaum et al. 2009).





Fig. 9. Olympic weightlifting: the snatch.

In strength training, the gains in muscular strength are often associated with improvements in body composition. In a study by Faigenbaum et al. (1993), a group of boys and girls aged between 8 and 12 followed a twice-a-week resistance training program for 8 weeks. After warm up and stretching, the training group performed the following 5 exercises: leg extension, leg curl, bench press, overhead press and biceps curl. Both training and control groups continued physical education at school.

As expected, strength gains in the training group were significant compared to both pre-training and control. Also improvements in body composition were significant: skinfold thickness decreased of 2.3% on average, compared to an increase of 1.7% in control group. It is interesting to note that upper arm, chest and hip girths did not change significantly. The only exception was the thigh girth, which anyway increased relatively less than control (+2.4% vs +3.9%).

The volume-intensity schema adopted was the popular Delorme method: 3 sets of 10 repetitions each, the first one with 50% of 10 RM, the second one with 75% of 10 RM and the third one with 100% of 10 RM. Delorme (1945) was among the first physicians who realized the importance of strength training – and weight lifting in particular – in rehabilitation after injuries.

A similar pyramiding method was adopted in a study by Schwingshandl et al. (1999). Obese children and adolescents were prescribed a diet with caloric restriction. Unfortunately, diet alone may reduce both fat and fat free mass. Subjects were therefore divided into 2 groups: training and control. After some light aerobics and stretching as a warm up, the training group performed 3 to 4 sets, 10 repetitions each, of the prescribed exercises, which were chosen to involve all major muscle groups. The first set was performed using the 50% of 10 RM. Load was increased progressively in each set, until

muscle failure because of fatigue. When the child was able to complete more than the prescribed 10 repetitions in the last set, the load was increased in the following training session. After 12 weeks, weight change was not significant in both groups, while the increase in fat free mass was significantly higher in the training group than in control, implying that resistance training may have a positive effect on body composition in fat reduction programs for obese children and adolescents.

Supervised strength training, involving weight lifting (bench press, leg extension, lat pull down etc.) and stretching, after an adequate warm up, has proved to be effective in a group of children, males and females, increasing strength, reducing skinfold thickness, improving body composition, motor skills and flexibility (Lillegard et al. 1997).

In a study by Watts et al. (2004) obese adolescents were involved for 8 weeks in a strength training program consisting in 1 hour of circuit training, 3 times per week, including both cycle ergometer and resistance training. Since the program was primarily designed to treat obesity rather than improving strength, exercise intensity was kept between 55%-70% of pre-training 1 RM. Training reduced abdominal and trunk fat, thus diminishing cardiovascular and metabolic risks, and increased strength, body composition and overall fitness at the same time.

Even if the main purpose of strength training is to increase muscle strength, it seems to have a positive carryover also in bone density and therefore it qualifies as an interesting means for preventing and reducing osteoporosis. This is particularly true for children: if strength training is adopted early, bone mass gains last longer. Skeletal exposure to mechanical loading during growth seems to be an effective strategy to increase bone mass and density, according to Khan et al. (2000).

In a study by Fuchs et al. (2001), high impact training is used to verify its efficacy in improving skeletal mass in a group of elementary school children. Bone mineral content, bone area and bone mineral density were adopted as indices of bone health. The training protocol consisted in 100 drop jumps (Figure 10) from a 61 cm box, 3 times per week for 7 months, implying ground reaction forces up to 8 times body weight. However, the adopted method proved to be safe and effective in improving the above mentioned parameters at the femoral neck (Figure 11) and lumbar spine. Actually, in a popular sport like gymnastics, impact forces in drop landings range from 8.2 to 11.6 times body weight, according to a study by Ozguven and Berme (1988).



Fig. 10. Drop jumps (adapted from Fuchs et al. 2001).

The authors convey the idea that the program could be introduced in physical education classes. Its main limitation may be in the fact that high-impact training may result in an excessive effort for overweight children. Still, in the training group no injuries occurred during the whole duration of the study. Actually, selected children had to be within the 20% of the recommended weight for height and age. The benefits at the femoral neck persisted even after several months of detraining, when the same bone health parameters were re-assessed in both exercise and control group (Fuchs and Snow 2002).

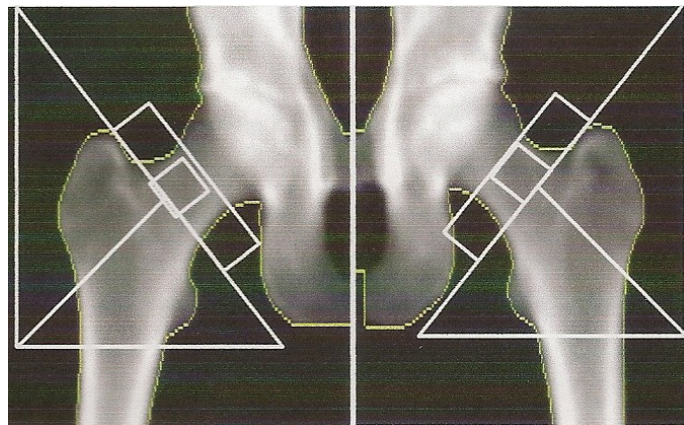


Fig. 11. Femoral neck.

Significant positive effects of impact training on bone mineral content at the hip was also found by Gunter et al. (2008) in a longitudinal study. The benefits of 7 months of impact training on a group of school children were partially maintained up to 8 years later.

Osteoporosis is a major problem especially for adult women. Even if considerable improvements in terms of bone health can be assessed in adults engaging in some form of strength training, the benefits do not seem to persist as long as in children or adolescents, suggesting that early inception of intense physical exercise may be prescribed for long-lasting improvements. A study by Winters and Snow (2000) assessed bone mineral density

in a group of females aged 30-45, before and after a 12 month training period. The training program included both high impact and resistance training (squats, lunges and calf raises).

Drop jumps off a box generated ground reaction forces of 4 to 5 times body weight. Intensity was gradually increased using weighted vests. After the training period, exercisers improved their bone mineral density and strength significantly, with respect to both baseline (pre-training) and control values. Unfortunately though, after 6 months of detraining, values decreased significantly towards baseline values.

A study by Kannus et al. (1995) evaluated the effects of playing starting age on bone mineral content of the dominant arm in a group of female tennis players. Athletes had a significantly higher difference in bone mineral content between dominant and non-dominant arm compared to control. The difference was 2 to 4 times greater in individuals who had started playing tennis before or at menarche, compared to those who had started 15 years after menarche. Tennis resembles strength training and may carry over similar effects on the bones since it consists of ballistic and explosive movements, handling a light implement. Even if the involved masses are small (ball and racquet), the acceleration produced during the impact may be very large, producing great force against the dominant arm.

Similar positive effects on bone mineral density of female gymnasts were found by Proctor et al. (2022) in the whole body and in particular in the upper limbs, without any significant bilateral differences, which is a major advantage compared to tennis. Gymnastics exercises, like pull ups and ring or parallel dips, are often employed in body weight strength training, for their carry over to upper body muscle strength.

Swimming and cycling are among the most popular sports and bring several health benefits. However, bones seem to be less directly addressed by these activities, because of their non-weight-bearing nature, which limits the loading on the skeleton. A group of well trained adolescent females, including track and field athletes, gymnasts and water polo players were assessed by Greene et al. (2012). Although all the selected sports require intense physical work, gymnastics involves weight-bearing in both the upper and lower body, track-and-field (sprints and jumps) only in the lower body, and water polo has no weight-bearing component.

Water polo players did not show greater bone strength or muscle size in the lower leg compared to controls. On the contrary, gymnasts showed significantly greater bone strength than non active females. Also track-and-field athletes displayed greater bone strength in the lower leg, compared to controls. The gymnasts showed the greatest musculoskeletal benefits in the upper body. Despite intense training, water polo players showed no significant benefits in musculoskeletal health in the lower body and only limited benefits in the upper body when compared with non active girls.

Ferry et al. (2011) investigated bone mineral density in female adolescent soccer players, swimmers and control group. Bone mineral density was significantly higher in

soccer players compared with swimmers. In contrast, swimmers had weaker bones than controls, despite the fact that female swimmers cannot be considered sedentary subjects.

Effects of strength training on connective tissues (ligaments and tendons in particular) have not been as widely assessed as those on bones. However, a recent study has found a positive correlation between resistance training (in particular Olympic weightlifting) and cruciate ligaments' cross sectional areas (Grzelak et al. 2012). The authors conclusions are that the benefits were induced by early inception of heavy training at the age of puberty.

## **2.4 Discussion and conclusions**

An meaningful distinction should be made between weight lifting for strength training and Olympic weightlifting. The latter implies competitions in which maximal or even supra-maximal (when the lift fails) loads are employed, as in powerlifting. In strength training instead, sub-maximal weights, which can be lifted more than once, are used. This distinction may account for a different risk factor between the aforementioned disciplines. In general, whenever a maximal effort is required, as in competitive sport, it is believed that risks tend to be present in a higher percentage than in recreational activities. More specifically, even if strength training may be strenuous and intense, if no maximal loads are employed, than it can be considered a safe and effective form of physical activity for most individuals, including children and adolescents, provided that proper instruction and supervision are given.

However, a study by Hamill (1994) questions the common belief that resistance training is safer than Olympic weightlifting, since both appear to be relatively safe according to his findings, especially if compared to other sports. The surveyed subjects were UK students, aged 13 to 16. Practicing both Olympic weightlifting and weight training had an injury rate of only 0.0012 per 100 participation hours. Individually, both disciplines scored well below other popular British sports, like soccer, rugby or even athletics.

In a study by Risser et al. (1990) muscle strain, a non-disabling injury, was reported to be the most common accident among high school American football players practicing weight lifting as a form of strength training. The cumulative percentage of injuries among all athletes was a reasonable 7.6%, corresponding to 0.082 injuries per person/year. Much higher rates can be found in adolescent (Schneider et al. 2013) or amateur (Sousa et al. 2012) soccer players. However, the study did not specify whether injuries were caused by maximal lifts (i.e. excessive load) or poor form, as it may happen in a competitive environment, where fatigue and strive for performance may lead to an excessive demand on the athlete's physical capabilities.

The topic of growth and strength training could be further assessed from an endocrine point of view, considering the relationship between exercise and hormonal responses. A review by Kraemer and Ratamess (2005) highlights the well established finding that resistance training and growth hormone are positively correlated, but further research is needed in order to verify whether strength training could induce positive endocrine responses in adolescents.

When lifting heavy loads, athletes naturally hold their breath for a few seconds, to increase intra-abdominal pressure and trunk stability (Lamberg and Hagins 2010). This behavior has been consistently questioned. Still, holding breath does not seem to be dangerous, since heart rate and blood pressure are not significantly elevated (Lapley and Hatzel 2010). At the same time, the practice of strength training may reduce the arterial and esophageal pressure responses in young adults (Sale et al. 1994). It can be adopted as a safe method of cardiac rehabilitation in older subjects with heart disease (McCartney 1998), as it has proved to reduce heart rate and arterial pressure during exercise as a consequence of weight lifting (McCartney et al. 1993). To counter muscle hypotrophy (a hallmark of chronic heart failure) and improve quality of life, the recommendations are for moderate intensity (50-60% of 1 RM) and the adoption of dynamic resistance training, in a circuit/interval training fashion (Volaklis and Tokmakidis 2005).

In conclusion, early inception of strength training, at adolescence or even earlier, does not seem to imply higher risks than other popular sport disciplines, provided that the young athletes follow the aforementioned guidelines. In particular, the most common advices which must be adhered to are:

- Supervision by an expert instructor.
- Focus on proper technique.
- Cautious progression in increasing loads.
- Training sessions should be preceded by a proper dynamic warm up.

All these points are consistently reviewed and addressed in studies by Faigenbaum and Myer (2010) and Malina (2006b), who stresses the importance of a low participants-to-instructor ratio. The same author adds that the frequency of injuries is relatively low and that weight training does not negatively affect neither maturation nor growth of pre- and early-pubertal youth.



Fig. 12. Proper squatting technique.

Athletes often lift weights on the shoulders, as in squatting, or from the ground, as in Olympic weightlifting or in powerlifting when practicing the deadlift. These are common situations which can be easily reproduced in everyday life, in contrast to what happens with machine training, which in most cases compel to perform non-functional movements (Barbieri 2013). Still, herniated disks do not seem to be associated with weight lifting, which may on the contrary be protective of the spine (Mundt et al. 1993). In order to protect the spine when practicing these lifts, athletes should adopt a shoulder-width - or slightly larger - stance, and an arched back (the so-called *power position*, Figure 12, Barbieri 2008), in order to maintain a neutral, physiological lumbar curve.

On the positive side, resistance training has proved to increase basic motor skills, like muscle strength, coordination and flexibility, but also body composition, in terms of improved fat free-to-fat mass ratio and increased bone health.

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## **3. First study: Physical activity and body composition in young adults**

One of the main purposes of anthropometry is to find easily measurable somatometric characteristics that are related to indices of health status (e.g. adiposity). In fact, the direct and accurate measure of body fatness is not always feasible, easy or cheap. In the following study, a sample of 734 students, both sexes, from the University of Ferrara were assessed from an anthropometric point of view, in order to assess the main health-related anthropometric characteristics in relation to sex, amount of physical activity and sport discipline, and to investigate the accuracy of the Body Mass Index (BMI) and Waist-to-Stature Ratio (WSR) as indicators of body fat percentage (%F) in young adults.

A self-administered questionnaire acquired socio-demographic information (sex, age) and sport participation (hours/week, sport discipline). Anthropometric measurements and grip strength values were acquired according to standardized procedures. Body composition was assessed by means of the skinfold method. Most subjects had normal BMI, WSR and %F. In addition to significant statistical differences between sexes, one-way ANOVAs within sexes showed statistically significant differences among different levels of physical activity and among different sport disciplines. In conclusion, the amount of physical activity had a positive impact on body composition parameters. In particular, in the study sample, the most active males had the least amount of %F and the most active females had the greatest amount of FFM, across groups of increasing weekly physical activity. BMI and WSR are not accurate indices of adiposity in young adults.

### **3.1 Introduction**

Body composition assessment is used to monitor performance and training in the athletic community, and to verify the health status of the population in general. The Body Mass Index (BMI, Figure 1) is often used to evaluate the weight status, even if it does not discriminate between different components of the overall body mass by definition ( $BMI = \text{weight}/\text{height}^2$ ). Therefore, the adoption of BMI as a predictor of adiposity and therefore of health risk should be used with caution (De Lorenzo et al., 2011), especially with physically active individuals, who usually have a higher body density (BD) and fat free mass (FFM) than the general population (Barbieri et al., 2012; Kugland Torstveit and Sundgot-Borgen, 2012; Zaccagni et al., 2009). Body fat percentage (%F) instead is correlated with increased health risk, especially for metabolic and cardiovascular diseases (Cho et al., 2009; Chuang et al., 2012; Gokulakrishnan et al., 2011; Onisto et al., 2009; Tanaka et al., 2002).

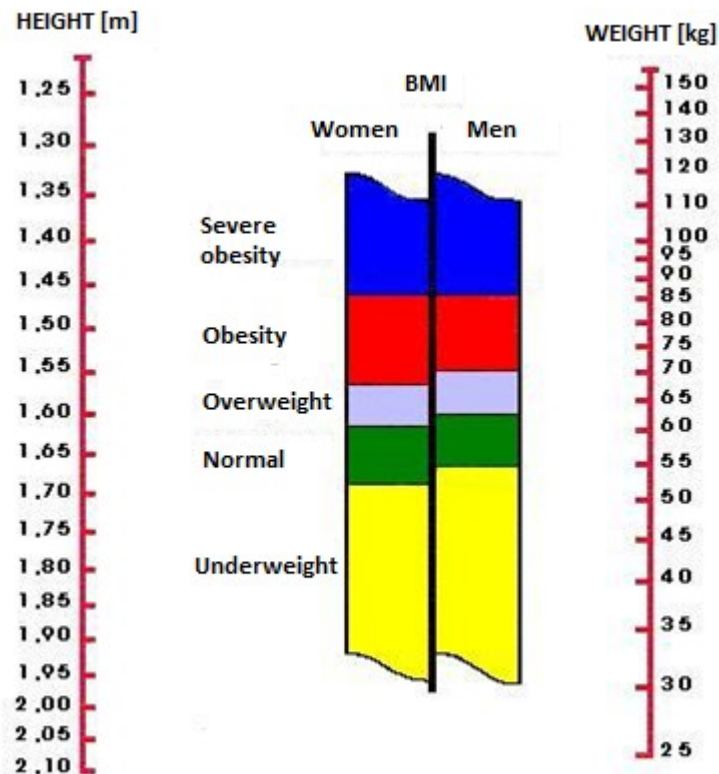


Fig. 1. Body Mass Index chart.

Waist-to-Stature Ratio (WSR) and Waist Circumference (WC) are supposed to have greater discriminatory power compared to BMI (Ashwell et al., 2012; Gualdi-Russo et al., 2009) and to be more sensitive than BMI as an early predictor of health-related risks (Ashwell and Hsieh, 2005). In particular, WSR is probably the most sensitive anthropometric index for the screening of the metabolic syndrome in Mediterranean populations, compared to both BMI and WC (Mombelli et al., 2009).

Low levels of physical activity may place individuals at increased risk of obesity and cardiovascular diseases (Romaguera et al., 2011; Sacheck et al., 2010). On the other side, physical activity has been suggested as a means to reduce and control body fatness. More in general, regular physical activity has proved to effectively diminish diverse health risk factors, especially those related to cardiovascular diseases and metabolic syndrome (Reimers et al., 2012; Wagner et al., 2012). In particular, the American College of Sports Medicine recommends that adults engage in at least 150 min/wk of moderate intensity cardiovascular exercise and at least 75 min/wk of vigorous intensity training, in order to maintain a sufficient level of cardio-respiratory fitness. Resistance training is also suggested 2-3 d/wk (Garber et al., 2011). We can therefore assume that these recommendations amount for a total of more than 4 h/wk of moderate-to-intense physical activity.

The purpose of this research was to assess the main health-related anthropometric characteristics of a group of university students, in order to evaluate their relationship with

quantity and type of physical activity according to sex. In particular, FFM, %F, WC, WSR, BMI and grip strength were taken into consideration. Grip Strength was chosen as a biomechanical index of strength for the following reasons:

- It can be easily measured by means of a relatively cheap instrument like a dynamometer.
- It can be considered an index of general strength (Fry et al., 2006), especially in the upper body (Bohannon, 2009).
- It can be used as an index of the health status, especially for what concern bone mineral density (Bijlsma et al., 2013), and nutritional status (Matos et al., 2007).

Furthermore, the accuracy of BMI and of WSR as predictors of %F was evaluated.

## **3.2 Sample and methods**

This was a cross-sectional study carried out on a total of 734 university students, 354 females aged  $21.47 \pm 2.88$  yrs (mean  $\pm$  SD) and 380 males aged  $22.06 \pm 3.61$  yrs, of the School of Sport Science (Faculty of Medicine, University of Ferrara, Italy) who volunteered for the study. The sample was composed of North Italian students (mainly coming from the regions of Emilia Romagna and Veneto). The research protocol was approved by the Ethic Committee for Biomedical Research of the University of Ferrara, and all subjects provided written informed consent.

A questionnaire on training and physical activity patterns was administered to participants. The mean weekly amount of physical activity was  $6.68 \pm 4.20$  hrs for males and  $4.23 \pm 3.81$  hrs for females; 28 males (7.4% of the total male sub-sample) and 83 females (23.4% of the total female sub-sample) did not practice any sport activity. All measures were taken in the Anthropometry Laboratory at the University of Ferrara, during the tutorials for the students of the course of Anthropometry and Ergonomics in the second year of the School of Sport Science.

Height (H, cm) and sitting height (SH, cm) were measured to the nearest 0.1 cm using a wall-mounted stadiometer (Magnimeter, Raven Equipment Limited, UK). Weight (W, kg) was measured to the nearest 0.1 kg using a calibrated electronic scale. BMI was calculated as  $W/H^2$  ( $\text{kg}/\text{m}^2$ ). Skinfold thicknesses at biceps (Figure 2) and triceps (Figure 3) were measured to the nearest 0.1 cm using a Lange caliper (Figure 4, Beta Technology Inc.).



Fig. 2. Biceps skinfold.



Fig. 3. Triceps skinfold.



Fig. 4. Lange caliper.

All girths (Waist Circumference WC, Contracted Arm Girth CAG, Relaxed Arm Girth RAG) were measured to the nearest 0.1 cm (as in Figure 5) using a non-metallic and

non-stretchable tape (Figure 6). WSR was calculated as  $WC/H$ . According to the National Institute for Health and Clinical Excellence guidelines,  $WC \geq 102$  cm for men and  $\geq 88$  cm for women are prerequisite risk factors for the diagnosis of the metabolic syndrome, as  $WSR \geq 0.5$  for both males and females (Ashwell and Hsieh, 2005).



Fig. 5. Relaxed arm girth.



Fig. 6. Non-stretchable tape.

All measurements were taken on the left side of the body, according to standardized procedures (Lohman et al., 1988). During the anthropometric measurements, all participants were barefoot and clothed appropriately. Left and right hand grip strength was measured to the nearest 0.5 kg by means of a Takei dynamometer (T.K.K. 5001 Grip-A Takei scientific instruments Co., LTD, Japan, Figure 7). The highest value of two trials was recorded, after an adequate period of rest between sets, for each hand.



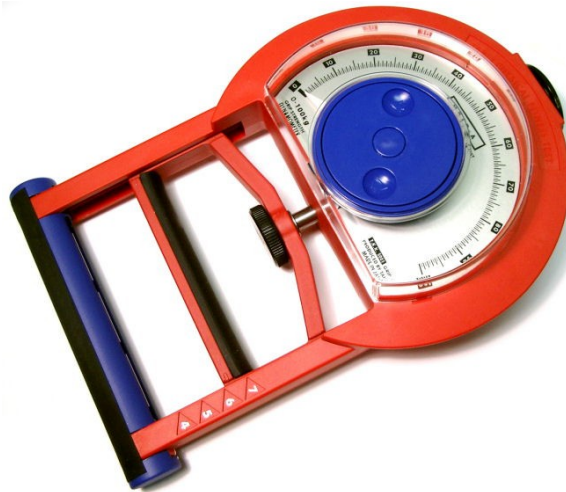


Fig. 7. Takei dynamometer TKK 5001 Grip-A.

Body density (BD) was calculated using Durnin and Womersley (1974) equations with two skinfolds (biceps and triceps), according to sex and age of the subject. %F was calculated from BD using Siri equation (1956). Fat Mass (FM, kg) was calculated as  $(\%F \cdot W)/100$  and FFM (kg) as  $W - FM$ .

According to the World Health Organization (James et al., 2001), underweight was defined as  $BMI < 18.5 \text{ kg/m}^2$ , normal weight as  $18.5 \text{ kg/m}^2 \leq BMI < 25 \text{ kg/m}^2$ , overweight as  $25 \text{ kg/m}^2 \leq BMI < 30 \text{ kg/m}^2$ , and obesity as a  $BMI \geq 30 \text{ kg/m}^2$ . Because of the small number of subjects with a  $BMI \geq 30 \text{ kg/m}^2$  (only one female and 15 males), they were included in the overweight group for further elaboration.

Even if there is widespread consensus on cut-points for the weight status, this is not the case for what concern fatness. According to Gallagher et al. (2000),  $\%F \geq 20\%$  in males and  $\%F \geq 33\%$  in females are the cut-points adopted to define overfatness, corresponding to overweight classification using BMI in a population of young adults.

To determine the accuracy of BMI as a measure of overfatness - and therefore of poor health status - participants were classified into one of four categories: 1) overweight and overfat (True Positive, TP), 2) overweight and normal fat (False Positive, FP), 3) normal weight and overfat (False Negative, FN), and 4) normal weight and normal fat (True Negative, TN).

Sensitivity, specificity and predictive values of BMI were calculated for each group. Sensitivity was calculated as the proportion of overfat individuals who were correctly identified as overweight by BMI (i.e.  $TP/(TP+FN)$ ). Specificity was calculated as the proportion of normal fat individuals who were correctly identified as normal weight by BMI (i.e.  $TN/(TN+FP)$ ). Positive predictive value (PPV) was calculated as the probability that a subject identified as overweight by BMI was truly overfat:  $PPV = TP/(TP+FP)$ . Negative predictive value (NPV) was calculated as the probability that a subject who was identified as normal weight by BMI was normal fat:  $NPV = TN/(TN + FN)$  (McNeil et al., 1975; Barbieri, 2013). Test accuracy increases as the total number of FP and FN decreases.

To verify the accuracy of WSR as a measure of overfatness, the same procedure was adopted, substituting the overweight category with excessive WSR.

All variables were checked for normality and logarithmically (10-based) transformed where necessary (skinfold at biceps and triceps). Results were expressed as mean  $\pm$  standard deviation (SD). Comparisons between sexes were carried out using a two-sample Student's t-test for continuous data and a chi-square ( $\chi^2$ ) test for categorical data for BMI categories. Correlation analysis between total weekly hours of physical activity and anthropometric variables was carried out.

Subsequently, both females and males were divided into 3 tertiles, according to their level of weekly physical activity: low ( $\leq 3$  h/wk for females,  $\leq 5$  h/wk for males), medium ( $3 < \text{h/wk} < 6$  for females,  $5 < \text{h/wk} < 8$  for males) and high ( $\geq 6$  h/wk for females,  $\geq 8$  h/wk for males). One-way ANOVAs were used to assess the differences in anthropometric variables and grip strength among the 3 groups and post hoc comparisons were performed using Tukey test.

In order to assess the anthropometric differences among subjects practicing different activities, one-way ANOVA was performed on sports with at least 10 participants: soccer, body building, basketball, swimming and volleyball in males; gymnastics, other gym activities, ballet, volleyball, swimming and jogging in females. When a significant F value was obtained, post-hoc comparisons were performed by means of Tukey test. The statistical significance was set at  $p < 0.05$ . All analyses were performed using "Statistica" for Windows, Version 11.0 (StatSoft Italia srl, Padua, Italy).

### 3.3 Results

There were significant differences among all anthropometric traits between sexes (Table 1). Males were on average heavier, taller, leaner and stronger than females and had wider girths. Females had thicker skinfolds than males, as expected (Durnin and Womersley, 1974; Gualdi-Russo et al., 1992), therefore they had lower BD and higher %F; 72% of males and 89% of females were normal fat, while 27.3% of males and 10% of females were overfat. Only 4 females (1.2% of the sub-sample) had  $WC \geq 88$  cm and 7 males (2.0% of the sub-sample) had  $WC \geq 102$  cm; 5% of females and 13% of males had  $WSR \geq 0.5$ .

TABLE 1. ANTHROPOMETRIC TRAITS IN SAMPLE BY SEX.

Trait	Males	Females
	mean± SD	mean± SD
H (cm)	177.6±6.3	163.9±6.0
W (kg)	75.6±10.2	58.7±8.2
BMI (kg/m <sup>2</sup> )	24.0±2.8	21.8±2.6
SH (cm)	92.9±3.5	87.0±3.6
T Sk (mm)	10.8±5.0	16.1±5.5
B Sk (mm)	5.5±3.2	8.7±4.5
WC (cm)	81.7±7.3	70.3±6.5
WSR	0.46±0.04	0.43±0.04
CAG (cm)	32.5±3.1	27.4±2.7
RAG (cm)	29.5±3.0	25.7±2.6
RHG (kg)	50.2±8.0	30.8±5.1
LHG (kg)	48.3±8.1	29.2±5.0
BD (g/cm <sup>3</sup> )	1.059±0.011	1.039±0.011
%F	17.3±4.9	26.6±5.2
FM (kg)	13.3±5.1	16.0±4.9
FFM (kg)	62.4±7.4	42.9±4.9

BMI mean values were in the normal range according to WHO weight status categories (James et al., 2001).  $\chi^2$  test proved there was a significant difference ( $p<0.001$ ) between sexes in weight status distribution. No male student was underweight, compared to 5.6% of females who fell into this category. Most males (71.7%) and females (80.9%) were normal weight. Males were more overweight (24.2%) and obese (4.2%), than females (13.2% overweight and only 0.3% obese).

ANOVAs within male sub-sample with different levels of physical activity (Table 2) show significant statistical differences in biceps skinfold, WC, WSR, BD, %F and FM, supporting the positive effects of physical activity on health-related anthropometric traits. Tukey post-hoc test shows significant differences only between the low and high level groups. Statistical correlations in males between hours of physical activity and BMI, triceps and biceps skinfolds, WC, WSR, BD, %F and FM were significant ( $p<0.05$ ).

TABLE 2. ANTHROPOMETRIC TRAITS IN MALES BY LEVEL OF PHYSICAL ACTIVITY.

MALES	Low	Medium	High	
Trait	(1st tertile)	(2nd tertile)	(3rd tertile)	<i>p</i>
	mean±SD	mean±SD	mean±SD	
H (cm)	177.2±6.2	177.6±6.4	178.1±6.3	0.557
W (kg)	76.4±11.3	75.7±10.5	74.9±8.8	0.507
BMI (kg/m <sup>2</sup> )	24.3±3.3	24.0±3.0	23.6±2.2	0.151
SH (cm)	92.9±3.4	92.8±3.6	93.0±3.6	0.872
T Sk (mm)	11.6±5.7	10.9±4.2	10.0±4.7	0.054
B Sk (mm)	6.0±3.1 <sup>a</sup>	5.5±3.3	5.2±3.2	0.043
WC (cm)	83.1±7.9 <sup>a</sup>	81.8±8.2	80.3±5.5	0.009
WSR	0.47±0.05 <sup>a</sup>	0.46±0.05	0.45±0.03	0.002
CAG (cm)	32.8±3.1	32.3±3.1	32.4±3.2	0.483
RAG (cm)	29.7±2.9	29.4±3.0	29.3±3.0	0.515
RHG (kg)	49.9±7.6	49.9±7.8	50.6±8.5	0.691
LHG (kg)	48.7±7.8	48.1±7.9	48.1±8.6	0.805
BD (g/cm <sup>3</sup> )	1.057±0.012 <sup>a</sup>	1.059±0.010	1.061±0.011	0.009
%F	18.2±5.4 <sup>a</sup>	17.5±4.3	16.3±4.8	0.009
FM (kg)	14.2±5.9 <sup>a</sup>	13.4±4.7	12.4±4.5	0.022
FFM (kg)	62.5±8.0	62.0±7.5	62.6±6.8	0.835

Note: Tukey post-hoc test: <sup>a</sup> p<0.05 compared with high.

ANOVAs within female sub-sample with different levels of physical activity (Table 3) show significant statistical differences in weight, BMI, contracted and relaxed arm girths and FFM, supporting the positive effects of physical activity, particularly on FFM. Tukey post-hoc test shows significant differences between the high level group and the other two. Statistical correlations in females between hours of physical activity and biceps skinfold, left and right hand grip strength, BD, %F, and FFM were significant (p<0.05).

TABLE 3. ANTHROPOMETRIC TRAITS IN FEMALES BY LEVEL OF PHYSICAL ACTIVITY.

FEMALES	Low (1st tertile)	Medium (2nd tertile)	High (3rd tertile)	
Trait	mean±SD	mean±SD	mean±SD	<i>p</i>
H (cm)	163.5±5.9	163.8±5.6	164.4±6.6	0.521
W (kg)	57.9±8.8	57.6±7.5 <sup>b</sup>	60.3±8.0	0.019
BMI (kg/m <sup>2</sup> )	21.6±2.9	21.5±2.4 <sup>b</sup>	22.3±2.4	0.035
SH (cm)	86.6±3.5	87.0±3.2	87.4±3.9	0.224
T Sk (mm)	16.5±5.4	15.8±6.1	16.1±5.1	0.497
B Sk (mm)	9.2±4.5	8.4±5.1	8.4±3.8	0.253
WC (cm)	70.3±7.9	69.5±6.1	70.7±5.4	0.403
WSR	0.43±0.05	0.43±0.04	0.43±0.03	0.488
CAG (cm)	26.9±2.7 <sup>a</sup>	27.1±2.5 <sup>b</sup>	28.0±2.7	0.004
RAG (cm)	25.4±2.6 <sup>a</sup>	25.5±2.4	26.1±2.6	0.045
RHG (kg)	30.0±5.2	31.0±4.6	31.5±5.3	0.076
LHG (kg)	28.4±5.0	29.4±4.8	29.8±5.1	0.068
BD (g/cm <sup>3</sup> )	1.038±0.011	1.040±0.012	1.039±0.010	0.337
%F	27.2±5.4	26.1±5.6	26.5±4.8	0.337
FM (kg)	16.1±5.2	15.3±4.9	16.3±4.5	0.315
FFM (kg)	41.9±5.0 <sup>a</sup>	42.4±4.6 <sup>b</sup>	44.1±4.8	0.001

Note: Tukey post-hoc test: <sup>a</sup>  $p < 0.05$  compared with high; <sup>b</sup>  $p < 0.05$  compared with high.

ANOVAs between sport discipline with more than 10 participants in males (Table 4) show significant statistical differences in relaxed and contracted arm girths, left and right hand grip strength and FFM. Tukey post-hoc test shows significant differences between body building and other sports for all the traits above, especially soccer.

Body builders had the highest BMI – similar to that of volleyball players-, arm girths, right and left hand grip strength, BD and FFM, and the lowest H, skinfold thicknesses, %F and FM. Volleyball players had the highest W, WC and FM, and the lowest SH. Basketball players had the highest H and SH, and the lowest BMI. Swimmers had the thickest skinfolds and the highest %F. Correlation analysis between BMI and %F per sport discipline showed no significance in basketball players ( $p=0.300$ ) and body builders ( $p=0.906$ ) in males. In fact, one third of the subjects who were classified as overweight according to BMI, but who were actually normal fat, practiced body building.

TABLE 4. ANTHROPOMETRIC TRAITS BY SPORT IN MALES.

MALES	Soccer N=132	Swimming N=25	Basketball N=26	Bodybuilding N=41	Volleyball N=13	
Traits	mean±SD	mean±SD	mean±SD	mean±SD	mean±SD	<i>p</i>
H (cm)	177.0±6.1	177.8±6.0	180.0±6.9	176.9±6.9	178.2±6.3	0.298
W (kg)	74.5±9.3	74.5±9.0	75.7±9.9	77.7±9.3	78.4±13.5	0.295
BMI (kg/m <sup>2</sup> )	23.8±2.4	23.6±2.6	23.5±3.2	24.8±2.4	24.8±4.7	0.141
SH (cm)	92.8±3.6	93.4±3.0	94.0±3.6	92.5±3.7	92.0±3.3	0.391
T Sk (mm)	10.8±5.1	11.3±5.5	10.9±3.9	9.5±4.2	11.0±4.0	0.452
B Sk (mm)	5.9±3.8	6.0±3.3	4.9±2.1	4.6±2.0	4.9±1.9	0.145
WC (cm)	81.3±6.3	81.0±5.8	82.9±6.6	81.9±6.8	83.3±14.0	0.184
WSR	0.46±0.04	0.46±0.03	0.46±0.04	0.46±0.04	0.47±0.09	0.763
CAG (cm)	31.5±2.7	33.0±2.5	31.9±2.5	36.0±3.2 <sup>a</sup>	32.1±2.8	0.000
RAG (cm)	28.5±2.6	29.7±2.4	28.8±2.5	32.4±3.1 <sup>a</sup>	29.4±2.4	0.000
RHG (kg)	47.9±7.7	50.2±5.6	50.2±6.8	55.0±8.5 <sup>b</sup>	48.9±7.1	0.000
LHG (kg)	45.6±7.4	48.4±4.1	49.9±6.6	52.5±9.5	49.5±8.4	0.000
BD (g/cm <sup>3</sup> )	1.059±0.011	1.058±0.011	1.060±0.008	1.062±0.011	1.059±0.011	0.618
%F	17.4±4.9	18.0±4.8	17.1±3.7	16.2±4.8	17.6±4.8	0.620
FM (kg)	13.1±5.0	13.7±4.9	13.0±3.6	12.7±4.4	14.2±5.6	0.837
FFM (kg)	61.2±6.6	60.9±6.1	62.4±8.4	65.2±8.2 <sup>b</sup>	64.2±10.2	0.035

Note: Tukey post-hoc test: <sup>a</sup> Bodybuilding vs all other sports  $p < 0.001$  <sup>b</sup> Bodybuilding vs soccer  $p < 0.05$

ANOVAs between sport disciplines with more than 10 participants in females (Table 5) show significant statistical differences in H, W, BMI, WC, RAG, left and right hand grip strength, FM and FFM. Tukey post-hoc test shows significant differences between volleyball players, gymnasts and dancers for the traits above. Volleyball players had the highest H, SH, W, BMI, triceps skinfold, girths, hand grip strength, %F and FFM. Gymnasts were the shortest and lightest and had the greatest BD, the lowest SH, skinfold thickness, WC, %F, FM and FFM. Dancers had the smallest arm girths (RAG values being similar to those of gymnasts) and grip strength. Correlation analysis between BMI and %F per sport discipline showed no significance in gymnasts ( $p=0.752$ ) in the female sex.

TABLE 5. ANTHROPOMETRIC TRAITS BY SPORT IN FEMALES.

FEMALES	Gymnastics N=19	O.G.A. N=50	Swimming N=39	Jogging N=16	Ballet N=47	Volleyball N=47	p
Traits	mean±SD	mean±SD	mean±SD	mean±SD	mean±SD	mean±SD	
H (cm)	161.2±6.0	163.0±5.8	164.7±6.6	163.7±4.7	163.4±4.5	166.2±7.0 <sup>a</sup>	0.033
W (kg)	54.9±5.9	58.3±8.7	58.0±8.1	58.3±9.4	57.1±6.1	62.8±7.9 <sup>a,b</sup>	0.002
BMI (kg/m <sup>2</sup> )	21.0±2.0	21.9±2.9	21.3±2.3	21.7±2.7	21.4±1.9	22.7±2.3	0.049
SH (cm)	86.3±3.0	86.4±3.7	87.1±4.0	87.3±3.1	87.1±3.3	88.4±4.0	1.635
T Sk (mm)	14.3±4.1	14.9±5.8	16.0±6.5	15.2±4.1	15.8±4.7	17.5±5.0	0.177
B Sk (mm)	6.6±2.4	8.9±4.6	9.7±5.0	9.6±3.6	7.6±3.5	8.7±3.5	0.083
WC (cm)	67.1±4.8	69.4±6.1	70.6±7.6	70.6±7.1	68.3±4.1	71.9±5.0 <sup>a</sup>	0.023
WSR	0.42±0.03	0.43±0.04	0.43±0.05	0.43±0.04	0.42±0.02	0.43±0.03	0.359
CAG (cm)	26.9±1.2	27.4±2.7	27.2±2.6	27.1±2.5	26.6±2.4	28.3±2.3	0.063
RAG (cm)	24.9±1.5	25.5±2.6	25.7±2.7	25.5±2.8	24.9±2.2	26.6±2.3 <sup>b</sup>	0.033
RHG (kg)	30.1±4.6	31.8±5.4	30.7±4.8	31.3±4.3	28.3±3.6 <sup>c</sup>	31.8±5.3 <sup>b</sup>	0.008
LHG (kg)	29.3±4.8	29.8±5.5	28.7±4.6	29.9±5.1	26.7±3.9 <sup>c</sup>	30.1±4.8 <sup>b</sup>	0.018
BD (g/cm <sup>3</sup> )	1.043±0.01	1.040±0.01	1.038±0.014	1.038±0.01	1.040±0.01	1.037±0.01	0.333
%F	24.4±4.0	26.1±5.4	26.8±6.3	26.9±4.2	26.0±4.5	27.6±4.5	0.329
FM (kg)	13.2±2.1	15.6±5.1	15.8±5.3	16.0±4.4	14.9±3.9	17.8±4.4 <sup>a</sup>	0.009
FFM (kg)	40.9±4.6	43.1±5.2	42.5±5.2	42.2±5.9	41.6±3.1	45.4±4.4 <sup>a,b</sup>	0.003

Note: Tukey post-hoc test: <sup>a</sup> volleyball versus gymnastics  $p<0.05$ , <sup>b</sup> volleyball vs ballet  $p<0.01$ , <sup>c</sup> ballet vs other gym activities  $p<0.05$ , O.G.A. = other gym activities.

Figures 8 and 9 are scatterplots of %F versus BMI in the male and female samples, respectively. There was a significant positive correlation between BMI and %F in males ( $r=0.476$ ,  $p<0.001$ ) and in females ( $r=0.622$ ,  $p<0.001$ ). In males, 12% of total participants fell within the FP quadrant and 10% in the FN one. Sensitivity was 0.62 and specificity was 0.83, while PPV was 0.58 and NPV was 0.85. In females, 7% of total participants were classified as FP and 4% as FN. Sensitivity was 0.59 and specificity was 0.92, while PPV was 0.45 and NPV was 0.95. Therefore, sensitivity was poor for both sexes, reflecting the fact that the individuals who were at the same time classified as overfat (according to their %F) and overweight (according to their BMI) were only a small proportion of those who were actually overfat. Also PPV of BMI was poor, because really fat individuals were about a half of those who were classified as overweight.

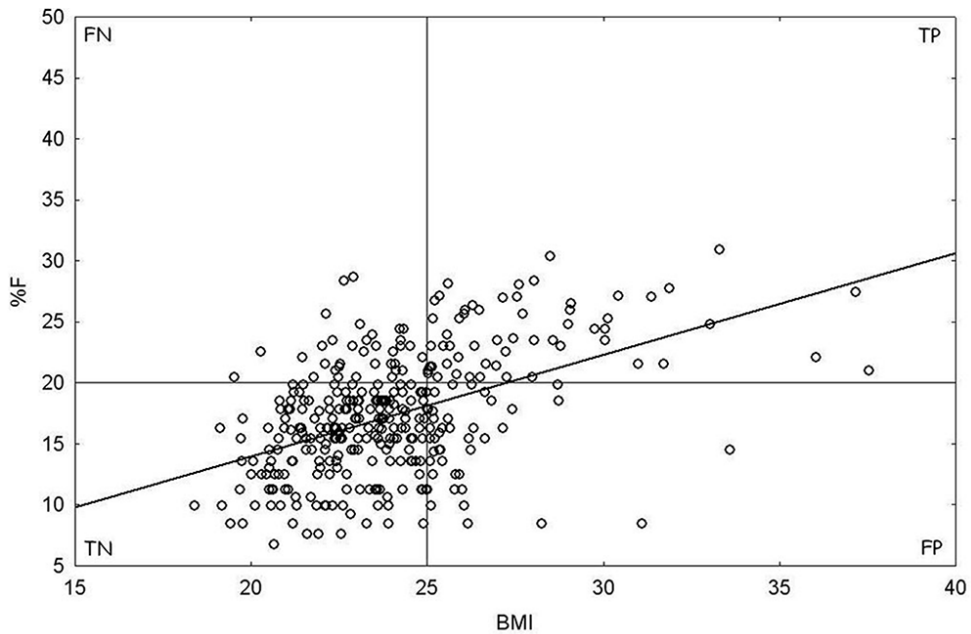


Fig. 8. Scatterplot of BMI and %F for each male study participant. The four quadrants are labelled FN (false negative), TP (true positive), TN (true negative), and FP (false positive) to illustrate the correct classifications and misclassifications.

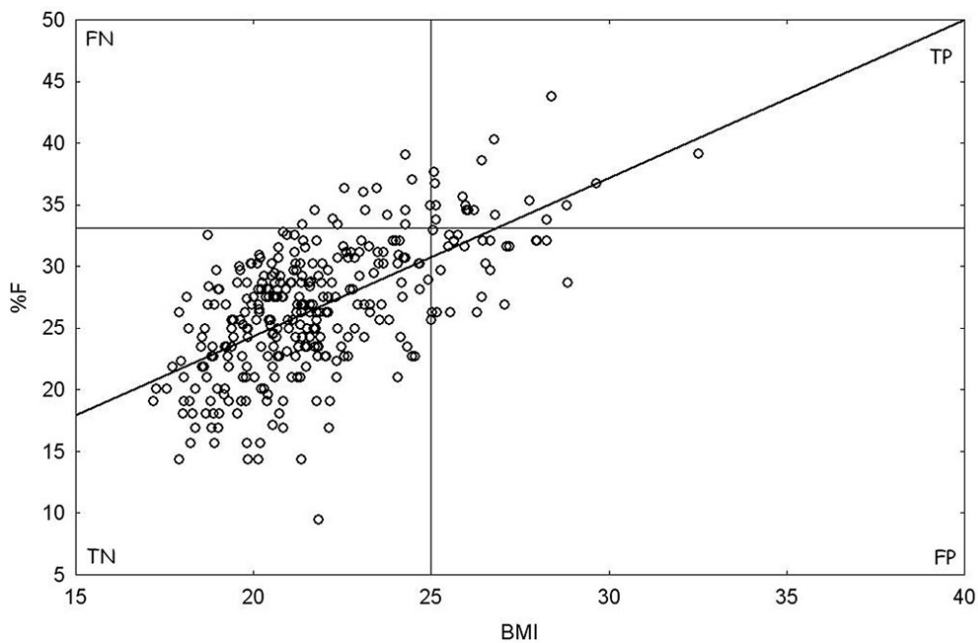


Fig. 9. Scatterplot of BMI and %F for each female study participant. The four quadrants are labelled FN (false negative), TP (true positive), TN (true negative), and FP (false positive) to illustrate the correct classifications and misclassifications.

Figures 10 and 11 are scatterplots of %F versus WSR in the male and female samples, respectively. There was a significant positive correlation between WSR and %F in males ( $r=0.439$ ,  $p<0.001$ ) and in females ( $r=0.527$ ,  $p<0.001$ ). In males, 4% of total participants fell in the FP quadrant and 17% in the FN one. Sensitivity was 0.36 and specificity was 0.95, while PPV was 0.73 and NPV was 0.80. In females, 3% of total



participants fell within the FP quadrant and 8% in FN one. Sensitivity was 0.24 and specificity was 0.97, while PPV was 0.47 and NPV was 0.92. Therefore, sensitivity was poor for both sexes, and PPV was poor especially in females.

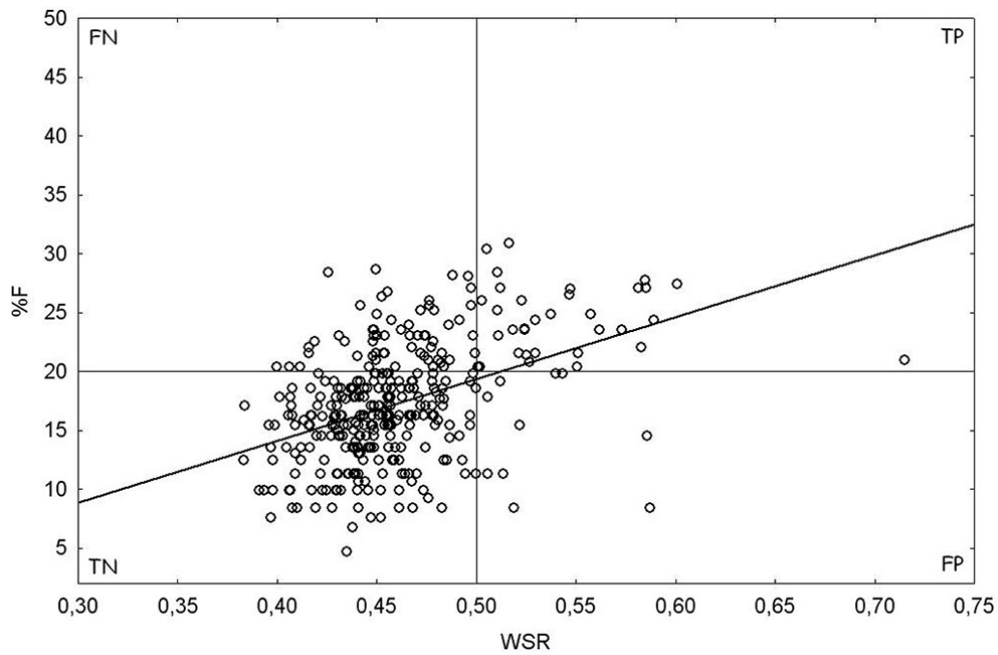


Figure 10. Scatterplot of WSR and %F for each male study participant. The four quadrants are labelled FN (false negative), TP (true positive), TN (true negative), and FP (false positive) to illustrate the correct classifications and misclassifications.

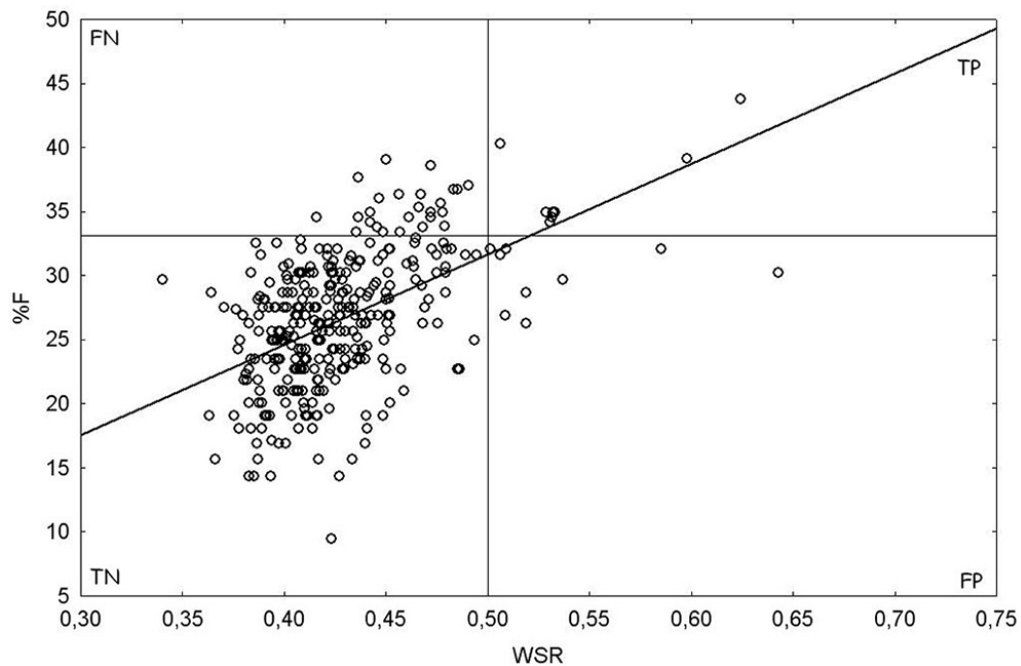


Figure 11. Scatterplot of WSR and %F for each female study participant. The four quadrants are labelled FN (false negative), TP (true positive), TN (true negative), and FP (false positive) to illustrate the correct classifications and misclassifications.

### 3.4 Discussion

A significant sexual dimorphism was found in weight status distribution according to the classification proposed by WHO: 5.6% of females presented a weight lower than recommended (there were no males in this group), whereas 28.3% of males and 13.5% of females were in the overweight or obese range.

For what concern body composition parameters, we found a different trend in the two sexes in relation to training volume: female students performing more hours of weekly physical activity had a significantly higher amount of FFM compared to the less active individuals, while male students showed a lower %F and FM. These different behaviors may be consistent with both sex-related differences and sport preferences. The examined females are more often than males engaged in individual sports (gym activities, gymnastics). Males are more often than females engaged in team sports (soccer, basketball, volleyball) or in strength-related activities, like body building, both involving intense repeated efforts, which have been positively correlated to fat loss (Sijie, Hainai, Fengying, and Jianxiong, 2012; Tremblay, Simoneau, and Bouchard, 1994). So the different adaptation could be sport-related.

Body building determines an evident increase in muscle hypertrophy, which is significant in comparison to soccer. This fact may contribute to the limited accuracy of BMI as an index of body fatness and general health status, since body builders have a high BMI, close to overweight, even if they have the lowest %F in our sample. Also, females are less physically active, on average, therefore it can be hypothesized that physical adaptation in response to moderate physical activity can be correlated to increased muscle mass, and, vice-versa, that physical adaptation in response to high volume of weekly physical activity can be correlated to reduced %F.

The variance in weekly hours of physical activity within the sample determined significant differences in body composition, and showed the limits of BMI and WSR as indices of adiposity. Intersecting BMI values with %F, we have obtained important indications on its limited applicability in a sample of young adults with different levels of weekly training hours.

The analysis of specificity and sensitivity showed that neither BMI nor WSR can be considered accurate indices of the health status of the population of young adults because they are not consistent measures of body fatness. In fact, both BMI and WSR had good specificity versus %F, but low sensitivity, suggesting that a significant percentage of overfat individuals were classified as normal according to BMI or WSR.

A possible limiting factor of the present study is that physical activity assessment (weekly training hours and type of sport) was based only on a self-reported questionnaire. Also, the training volume does not account for training intensity and quality (mainly aerobic, anaerobic etc.). A lower volume of weekly training hours involving a strenuous

practice may have more significant outcomes than a higher volume with a less intense effort, in particular for what concern body composition.

### 3.5 Conclusion

This study examined a large sample of Italian university students from the same geographical area by means of rigorous anthropometric procedures. In conclusion, results of the current study on multiple anthropometric traits indicate that the most physically active individuals show lower signs of metabolic and cardiovascular risks. In particular, the most active males have lower %F than less active individuals. In females instead, the most active individuals have more FFM than the less active.

BMI and WSR have been suggested as indirect measures of %F, because of the ease with which they can be collected. Unfortunately, the present study confirms their low accuracy. In fact, in females, misclassification (FP+FN) is 11% for both BMI and WSR. In males, misclassification is 22% for BMI and 21% for WSR. Therefore, regardless of the fact that WSR has been proposed as a better index of physical health than BMI, both indices show similar low accuracy and they cannot be considered reliable predictors of body fatness, especially in young males. Greater accuracy can be found in females, possibly because of lower overall FFM compared to males. In fact, high FFM contributes to increased BMI, without any real detrimental effect (e.g. in body builders).

Some of the practical implications of the present study can be listed as follows:

- Different physical activity patterns/habits between sexes
- Subsequent sexual dimorphism in body composition parameters with amount of PA
- WSR is a poor indicator of fatness as BMI.

Our findings confirm that an active life style, including regular weekly physical activity, improves body composition and therefore reduces metabolic and cardiovascular risks.

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## **4. Second study: Anthropometry of elite mountain climbers**

In order to investigate the peculiar traits of their body composition and somatotype, 10 Italian experienced mountain climbers were assessed from an anthropometric point of view, before a high altitude ascent (Barbieri et al. 2012). Body mass, height, girths, skinfolds and bone breadths were gathered and used to calculate body composition and somatotype of each subject.

Means and standard deviations of the subjects' anthropometric characteristics were calculated. Mesomorphism ( $5.28 \pm 1.10$ ) was the dominant somatotype component in all but one the participants, endomorphism ( $1.55 \pm 0.49$ ) is low and body fat percentage ( $11.76\% \pm 2.93$ ) is low. Comparisons with athletes involved in other climbing sub-disciplines highlight the specificity of elite mountain climbers anthropometry.

The elite mountain climbers in our sample were predominantly mesomorphic with somatotype attitudinal mean values lower than reported for male athletes participating in free-climbing, volleyball, gymnastics and soccer. Anthropometric characteristics may therefore play a role in mountain climbing, even though the trainable components may be more relevant than the non-trainable ones.

### **4.1 Introduction**

The study of the human form in sports may be a useful tool to monitor and evaluate the effectiveness of a training protocol, or for early talent discovery. In fact, type, intensity and volume of physical activity affect some anthropometric characteristics, like body weight, muscle mass and body fatness. At the same time, some anatomic traits are genetically determined (e. g. height and bones' breadth) and may be more or less favourable to sport excellence. Thus, anthropometry accounts for both trainable and non-trainable performance factors.

Several studies have been dedicated to determine the athletes' body composition and the dominant somatotype in different sports (Carrasco et al., 2010; Claessens et al., 1999; Cortell-Tormo et al., 2010; Gualdi-Russo and Zaccagni, 2001; Rienzi et al., 2000; Sterkowicz-Przybycien, 2009). Mountain climbing is becoming a popular sport, requiring intense physical activity, especially walking across long distances, at high altitude, low temperature, in hypobaric and hypoxic conditions, often carrying heavy rucksacks.

Although there are many studies on free climbers (Cheung et al., 2011; Draper et al., 2008; España-Romero et al., 2009; Grant et al., 1996; Mermier et al., 2000; Morrison and Schöffl, 2007; Sheel, 2004; Watts et al., 2003), there is a dearth of research on

somatotype and body composition of mountain climbers (Bales et al., 1993; Egocheaga et al., 1998; Zamboni et al., 1996). Therefore, the relationship between this sport, body composition and somatotype is worth to be investigated further.

In this study, we take into consideration the anthropometric characteristics - in particular body composition and somatotype – of a sample of Italian experienced mountain climbers and we compare them with athletes involved in other climbing activities, using data taken from the literature on the subject.

## 4.2 Materials and methods

The study was carried out on 10 male Italian climbers, aged  $41.4 \pm 5.5$  (mean  $\pm$  SD), training experience  $21.0 \pm 4.8$  years, weekly training hours  $24.1 \pm 11.7$ . The climbers were assessed a month before the beginning of the “K2 2004 - 50 years later” expedition to the north face of Mt. Everest (Figure 1 and 2) and they all had previous experience of climbing in the Himalayas. Subjects gave their informed consent to the study, which was approved by the scientific board of the *Istituto Nazionale della Montagna* (Italian Mountain Institute, Rome, Italy). The same sample was also studied from the perspective of ventilation by Bernardi et al. (2005) and from the perspective of metabolic and endocrine responses by Benso et al. (2007).



Fig. 1. Mt Everest.

The subjects, in underwear and barefoot, were evaluated by means of standardized anthropometric procedures (Lohman et al., 1988). A properly trained technician made all the measurements. In particular, measures included height, weight, eight girths (upper arm flexed and tensed, maximum, minimum and normal thoracic, waist, hip, thigh and calf), humerus and femur breadths and six skinfold thicknesses (triceps, sub-scapular, supra-iliac, abdominal, thigh and calf).

Standing height was recorded to the nearest 0.1 cm by an anthropometer. Weight was measured using a calibrated electronic scale. Body Mass Index (BMI) was calculated as  $\text{body mass}/\text{height}^2$ , where mass was expressed in [kg] and height in [m]. Girths were measured by means of a non-stretch spring-loaded tape. In particular, thoracic girths were



taken at the mesosternal level: normal thoracic girth during normal breathing, maximum thoracic girth after maximum inhalation and minimum thoracic girth after a maximal exhalation. Breadths were measured using sliding calipers. Biepicondylar breadth of the humerus was taken between the medial and lateral epicondyles of the humerus, with shoulder and elbow flexed at 90 degrees. Biepicondylar breadth of the femur was taken between the lateral and medial epicondyles of the femur. In both the breadths, the technician applied firm pressure on the crossbars in order to compress the subcutaneous tissue (Carter, 2002).



Fig. 2. Mt Everest on the border between Nepal and Tibet (China).

Skinfold thickness was measured to the nearest 0.5 mm with a calibrated Lange caliper (Beta Technology Inc., Cambridge, MD, USA) on the subjects' left side. Each site was measured twice, within a range of 10%, and the average was recorded. Body density was calculated by means of Durnin and Womersley (1974) equations (as suggested by Espana Romero et al., 2009), using three skinfolds: triceps, sub-scapular and supra-iliac. Body fat percentage was calculated using Siri (1956) equation. Subsequently, fat mass and fat-free mass were calculated from total body mass.

Somatotype components, SAD (Somatotype Attitudinal Distance) and SAM (Somatotype Attitudinal Mean) were calculated by means of Heath and Carter equations (Carter, 2002). SAD represents the distance between an individual somatotype and the mean somatotype for the group or between two somatopoints or two somatotype group means. SAM is the SAD's average and measures the scatter of individual somatotypes about the subjects' mean (Carter, 2002).

Values are expressed as mean  $\pm$  standard deviation. Statistical comparisons between mean values from literature were performed by means of Student t-test; significance level

was set at  $p < 0.05$ . The statistical package Statistica for Windows 7.1 was used for all analyses.

### 4.3 Results and discussion

Descriptive statistics of the subjects' anthropometric characteristics are shown in Table 1. BMI is  $22.73 \pm 1.12 \text{ kg/m}^2$  (Figure 3) and indicates a normal nutritional status. According to WHO cut-off values (James et al., 2001), none had a BMI indicating overweight ( $\text{BMI} \geq 25 \text{ kg/m}^2$ ) or underweight ( $\text{BMI} < 18.5 \text{ kg/m}^2$ ). BMI range was 21.45 to  $24.82 \text{ kg/m}^2$ . Fat mass percentage is  $11.76 \pm 2.93\%$ .

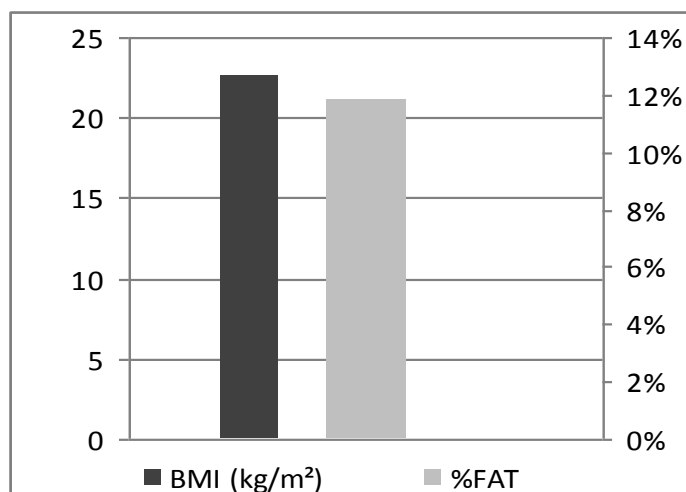


Fig. 3. Mean BMI and fat percentage.

Table 1 also shows the comparison (mean, SD and p-value of t-test) with a group of 53 Italian male adults (Toselli and Gualdi-Russo, 1999). Present study's subjects have significantly more fat free mass, less fat mass, lower fat mass percentage, smaller skinfold thicknesses and lower body mass, even if they were significantly older and their height was not significantly different. Both samples are from Northern Italy. Body composition was assessed with different methods (skinfolds vs bioelectrical impedance). Even if this fact could bias the comparison, to date no other comparable data are available.

TABLE 1. ANTHROPOMETRIC CHARACTERISTICS OF THE STUDY SUBJECTS COMPARED TO A SAMPLE OF MALE ITALIAN ADULTS (TOSELLI AND GUALDI-RUSSO, 1999)

Variable	Present Study Mean $\pm$ SD	Toselli and Gualdi-Russo (1999) Mean $\pm$ SD (N=53)	p
Age, yr	41.40 $\pm$ 5.50	26.9 $\pm$ 5.8	***
Height, cm	176.12 $\pm$ 5.07	177.67 $\pm$ 6.19	
Weight, kg	70.55 $\pm$ 4.97	75.95 $\pm$ 11.04	*
BMI, kg/m <sup>2</sup>	22.73 $\pm$ 1.12		
Humerus breadth (mm)	71.90 $\pm$ 2.69		
Femur breadth (mm)	99.20 $\pm$ 2.44		
Girths (cm):			
Arm	32.00 $\pm$ 2.08		
Maximum thoracic	98.26 $\pm$ 3.76		
Minimum thoracic	92.45 $\pm$ 4.02		
Normal thoracic	94.72 $\pm$ 3.91		
Waist	78.21 $\pm$ 5.04		
Hip	93.38 $\pm$ 3.83		
Thigh	51.43 $\pm$ 2.88		
Calf	36.54 $\pm$ 4.46	37.05 $\pm$ 2.54	
Skinfolds (mm):			
Triceps	5.20 $\pm$ 1.48	9.43 $\pm$ 3.92	***
Subscapular	8.10 $\pm$ 1.37	12.02 $\pm$ 3.25	***
Suprailiac	4.30 $\pm$ 1.77	10.49 $\pm$ 3.73	***
Abdominal	7.60 $\pm$ 4.55		
Thigh	8.70 $\pm$ 3.02		
Calf	5.10 $\pm$ 2.42	9.11 $\pm$ 4.30	***
Density, g/cm <sup>3</sup>	1.072 $\pm$ 0.007		
FM, %	11.76 $\pm$ 2.93	24.92 $\pm$ 6.25	***
FM, kg	8.36 $\pm$ 2.45	19.46 $\pm$ 7.64	***
FFM, kg	62.19 $\pm$ 3.80	56.45 $\pm$ 5.16	**
Endomorphy	1.55 $\pm$ 0.49		
Mesomorphy	5.28 $\pm$ 1.10		
Ectomorphy	2.64 $\pm$ 0.61		
SAM	0.78		

\*p < 0.05; \*\*p < 0.01; \*\*\*p < 0.001. BMI: body mass index; SAM: somatotype attitudinal mean.

The average somatotype is 1.55–5.28–2.64 (Figure 4). Mesomorphy is the dominant somatotype component in all but one the subjects of the sample, as in the Italian males who practice sport on a regular basis (Gualdi-Russo and Graziani, 1993). As expected, endomorphism is low. The somatoplot of the mean somatotype and of each subject is shown in Figure 5: eight subjects out of ten (equal to 80% of the examined

sample) belong to the ectomorphic mesomorph category, one to the endomorphic mesomorph category, and one to the mesomorphic ectomorph category.

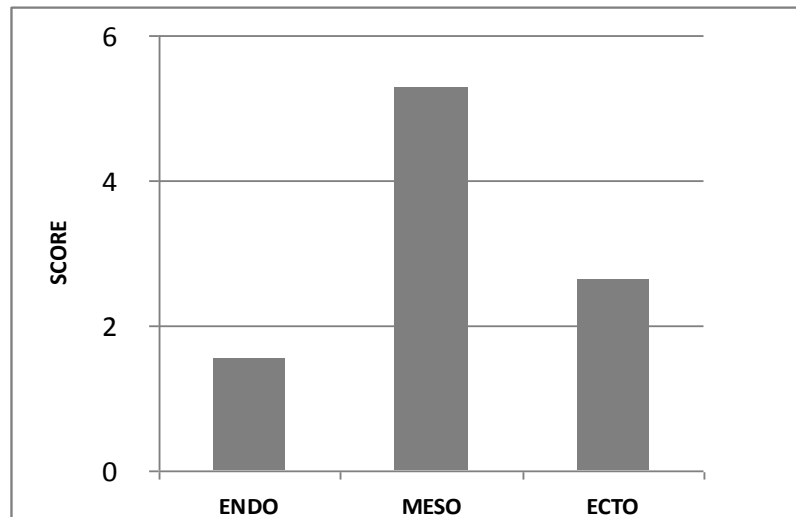


Fig. 4. Mean values of somatotype components.

As shown in Table 2, SAM value is 1.05, which indicates that our sample is the most homogeneous, since the homogeneity of the group increases as SAM value decreases (Carter, 2002).

TABLE 2. SOMATOTYPE ATTITUDINAL MEAN (SAM) OF MOUNTAIN CLIMBERS IN RELATION TO MALE ATHLETES IN OTHER SPORTS.

SAM	Sport	Study
1.05	Mountain climbing	Present study
1.16	Free Climbing	Viviani and Calderan, 1991
1.23	Volleyball	Gualdi-Russo and Zaccagni, 2001
1.44	Gymnastics	Gualdi-Russo and Graziani, 1993
1.55	Soccer	Gualdi-Russo and Graziani, 1993

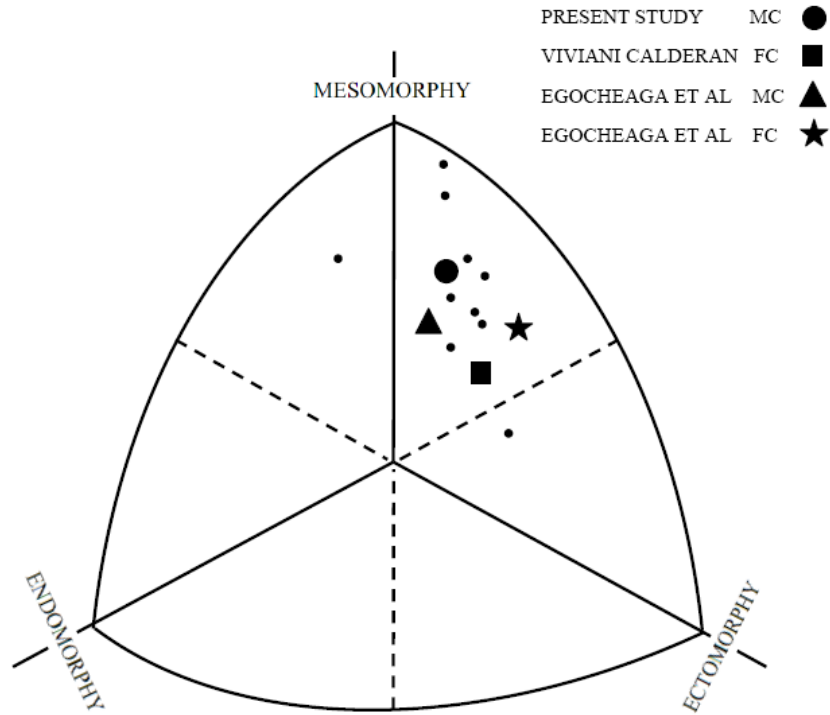


Fig. 5. Distribution of climbers' individual ( • ) and mean ( ● ) somatotypes of our study and comparison with mean somatotypes in other climbing activities. FC, free climbing; MC, mountain climbing.

Comparisons were made with athletes involved in other climbing activities, in order to evaluate sport-specific anthropometric characteristics (Table 3). Present study's subjects are heavier and have a higher fat percentage, on average, even if the height is not significantly different. Exceptions are Egocheaga et al. (1998) mountain climbers, who have a higher body fat percentage, and Mermier et al. (2000) free climbers, who have a higher body weight. Several factors may influence these results: age, ethnicity, sport discipline (e.g. mountain climbing vs free climbing), nutrition, training modalities, etc. Also, it must be taken into consideration the fact that the subjects were evaluated a month before the ascent. Since climbers lose weight at high altitude (Boyer and Blume, 1984; Rose et al., 1988; Reynolds et al., 1999), we can presume that the athletes purposefully tried to gain weight prior to departure. In particular, body fat percentages are significantly higher ( $p < 0.01$ ) than in experienced free-climbers (Watts et al., 1993; Bertuzzi et al., 2001; Egocheaga et al., 1998) and world-class boulderers (Michailov et al., 2009), even if different calipers and %BF equations may have influenced the obtained results.

The athletes' low body fat could be related to performance in sports where strength-to-mass ratio is the key (Watts et al., 1993; Watts et al., 2003; Mermier et al., 2000; Bertuzzi et al., 2005), or endurance is dominant, as suggested in Viviani and Calderan (1991).

TABLE 3. COMPARISON OF BODY FAT PERCENTAGES IN CLIMBING ACTIVITIES.

Study	N	Experience (years)	Age (years)	Height (cm)	Weight (kg)	%F	Skinfold caliper	%F equation
Present study	10	21.0±4.8	41.4±5.5	176.1±5.1	70.55±5.0	11.7±2.9	Lange	Durnin; Siri
Egocheaga et al. 1998	15	NR	35.0±7.2	176.0±5.7	70.3±6.2	12.2±2.9	Holtain	Faulkner
Viviani and Calderan 1991	31	NR	26.1±4.3	175.9±6.2	63.6±4.5	8.3	NR	Durnin and Rahaman; Siri
Watts et al. 1993	7	8.6±3.8	23.9±5.2	179.3±5.2	62.4±4.5	4.8±2.3	Lange	Jackson and Pollock; Brozek
Egocheaga et al. 1998	15	NR	22.0±5.2	171.7±5.2	56.8±5.1	8.2±0.6	Holtain	Faulkner
Michailov et al. 2009	18	13.2±5.6	25.8±5.1	174.6±5.6	67.3±6.0	5.8±1.8	Lange	Jackson and Pollock; NR
Mermier et al. 2000	24	7.2±6.1	30.4±6.0	177.4±8.8	72.8±11.6	9.8 ± 3.5	Lange	Jackson and Pollock; Siri
Bertuzzi et al. 2001	8	6.8±3.1	23.6±5.4	173.3±5.5	62.7±3.4	6.7 ± 3.4	Cescorf	Guedes; Siri

FC = Free Climbing; MC = Mountain Climbing; B= Bouldering; NR= Not Reported

Compared to other forms of mountaineering though, high altitude mountain climbing requires more physical endurance than free-climbing (or sport rock climbing). In fact, the former involves long distances to be covered at high altitude on foot in adverse environmental conditions and carrying heavy rucksacks. The latter instead consists of shorter efforts and is more strength-oriented.

We can suppose that in mountain climbing, the athlete's body weight is lifted differently than in free-climbing. In the former, the athlete uses mainly the lower body strength (especially leg strength) to complete the ascent. In the latter, the upper body strength (especially grip and arm strength) is more involved. Relative strength is more sensitive to body mass variations when the strength of weaker (i.e. upper body) muscles is involved. Therefore, a higher body mass and fat percentage is more detrimental to performance in free-climbing, since the absolute upper body strength is inferior to the lower body one.

Generically, the mesomorphic somatotype is associated to the fittest individuals (Carter and Heath, 1990). At the same time, Mermier et al. (2000) have suggested that most variables predicting performance in mountain climbing are training-related, like strength and endurance, and not anthropometric-related, like height and weight. Still, the present study suggests that mesomorphism could be the dominant somatotype in elite, high altitude mountain climbers. These two findings are not necessarily inconsistent. In fact, some of the anthropometric components that determine the dominant somatotype are conditioned by training, e.g. muscle hypertrophy (therefore girths and body weight) and body fat (therefore skinfolds).

Comparisons of average somatotypes with other studies on climbers are shown in Table 4 and in Figure 1. In particular, present study's subjects are significantly less endomorphic, more mesomorphic and less ectomorphic than Viviani and Calderan's top-level European free climbers. Moreover Viviani and Calderan's free climbers are the furthest (SAD=1.72) while Egocheaga et al.'s mountain climbers are the closest to our sample (SAD=1.14). These values support our thesis, that mountain climbers have specific anthropometric characteristics, different from those of free climbers.

TABLE 4. COMPARISON OF AVERAGE SOMATOTYPES AND SAD VALUES  
IN CLIMBING ACTIVITIES

Study	N	ENDO	MESO	ECTO	SAD	ACTIVITY
Present study	10	1.55 ± 0.49	5.28 ± 1.10	2.64 ± 0.61	-	MC
Egocheaga et al. 1998	15	2.6	5	3	1.14	MC
Egocheaga et al. 1998	15	1.3	5.5	4.1	1.50	FC
Viviani et al. 1991	31	2.0 ± 0.6	4.0 ± 0.8	3.7 ± 0.9	1.72	FC

FC = free climbing; MC = mountain climbing.

Low body fat, low endomorphism and dominant mesomorphism characterize the current sample's subjects. Such anthropometric profile may favor success in mountain climbing. Some limitations to this study should be recognized: the hydration status of the participants was not taken into consideration and the sample size is not large. The availability of a homogeneous sample of elite mountain climbers together with the standardization of anthropometric methodology are notable strengths.

Nonetheless, further research on wider samples is needed in order to confirm these findings. Studies on intermediate or amateur climbers may provide useful information about somatotype and body composition in relation to performance levels.

Since the athlete lifts his/her own body weight against gravity, a low body fat percentage and low endomorphism should be expected when dealing with experienced mountain climbers, as in other sports where strength-to-mass ratio (i.e. relative strength) is positively correlated to performance. It may be relevant to highlight the fact that in other forms of mountaineering, like free climbing, where relative strength is more crucial than in mountain climbing, body fat is lower, even if in the latter endurance is more relevant than in the former.

At the same time, it must be taken into consideration that anthropometric characteristics are conditioned by sport practice (Watts, 1993). Therefore training should be directed towards attaining lower body fat percentages and higher relative strength, which are typical of the mesomorphic-dominant athlete.

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# **5. Third study: Physical adaptation during expeditions at high altitude**

The purpose of this study was to describe the physical adaptations associated to exposure to high altitude in a sample of 18 non-acclimatized Caucasian subjects (10 males and 8 females, 22-59 yrs) who participated to scientific expeditions to Himalaya (Zaccagni et al. 2014). Anthropometric traits (body height and weight, 8 girths and 6 skinfolds) were collected according to standard procedures, before departing at sea level, during ascent (at altitude > 4,000 m above sea level) and after return to low altitude. Body composition was assessed by means of the skinfold method.

Adaptations were associated to weight loss in both fat mass and fat free mass and were faster in males than in females. This is the first research describing physical adaptation in both sexes separately as a consequence to high altitude exposure. In conclusion, the present research has described significant adaptations to high altitude, in terms of body mass reduction, regardless of the amount of performed physical activity.

## **5.1 Introduction**

Many researchers are interested in the adaptive responses of the human body to high altitude (HA) exposure. Extreme climate, hypobaric hypoxia may reduce physical work capacity and increase the necessity of short term adaptations. Changes in anthropometric characteristics caused by exposure to HA have been studied in numerous surveys in search of patho-physiological explanations. Weight loss and body composition modifications are the most common responses in non-acclimatized humans (Tschop and Morrison, 2001). Loss of body weight is frequently observed during exposure to HA, both in experimental studies in hypobaric chambers, and in field studies in expeditionary circumstances.

Weight loss results from a marked difference between energy intake and energy expenditure, assuming that absorption of nutrients is not impaired. It has been suggested that the rate and magnitude of weight loss is related to the achieved altitude (Martin et al. 2010), to the duration of the exposure to HA (Hamad and Travis, 2006; Zamboni et al., 1996; Krzywicki et al., 1969), to the presence or absence of altitude-related illness, to the level of physical activity and food consumption (Fulco, 1992), and possibly to gender (women losing less; Kayser, 1994; Boyer and Blume, 1984).

However, the components of weight loss at HA are not clear. Some investigators have attributed weight loss primarily to fat mass (FM) reduction (Boyer and Blume, 1984; Guillard and Klepping, 1985; Krzywicki et al., 1969; Surks et al., 1966; Armellini et al. 1997; Butterfield et al., 1992; Ermolao et al., 2011), others to loss of body fluid (Consolazio et al., 1968) or more generically to fat free mass (FFM) reduction (Fulco et al.,

1985). Rose et al. (1988) reported that weight loss was from both FM and FFM, in a simulated ascent conducted inside a hypobaric chamber, where temperature was kept constant. Bales et al. (1993) and Westerterp et al. (1992) came to similar conclusions in a real climbing expedition.

The source of weight loss may depend on the extent of physical activity performed by the subjects. Studies reporting a high percentage of muscle mass loss involved subjects who were relatively sedentary during the observation period (Tanner and Stager, 1998 p. 144). In fact, loss of muscle mass has been associated to lack of physical exercise or direct effects of hypoxia on protein synthesis (Kayser, 1994). Further, some anthropometric characteristics are more suitable for sport practice at high altitude, as mountain climbing (Barbieri et al. 2012).

Fulco et al. (1985, p. 224) suggests that the use of skinfolds and/or circumferences to assess body composition alterations at HA should be avoided, because such methods assume euhydration of the subjects, which cannot be given for granted. Still, standard anthropometric procedures are at present the only feasible on the field during HA expeditions and thus they were adopted in this study.

The purposes of the present investigation were: (1) to find out the changes in body composition in sea level-resident individuals, staying for long periods at HA and (2) to test the interaction of exposure to HA with endogenous (sex) and exogenous (practice of trekking) factors.

## **5.2 Materials and methods**

The study was carried out on 20 (12 males and 8 females) healthy volunteers, all Caucasians, aged 22- 59 years. They were sea-level residents and were not acclimatized to higher altitudes at the beginning of the expedition. Ten subjects (6 males and 4 females) participated to the scientific expedition in Nepal, from September 9th 2003 to October 7th 2003 from Kathmandu to the CNR Italian Laboratory (the Pyramid, Figure 1) and back (Figure 2). Other 10 subjects (6 males and 4 females) participated to the scientific expedition in Tibet, from April 23rd 2004 to May 16th 2004, in support of the “K2 2004 - 50 years later” expedition to the north face of Mt. Everest.



Fig. 1. Italian National Research Council laboratory, Mt. Everest.

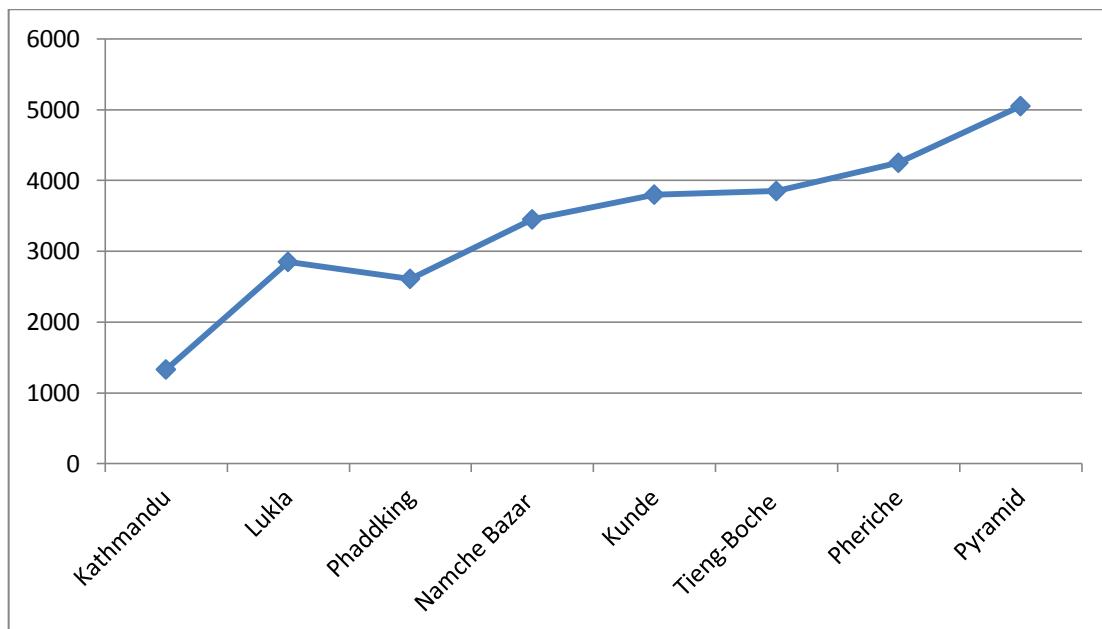


Fig. 2. Ascent profile of the first expedition.

Two male subjects were excluded from the study because they had not completed the 3 measurements. Data for the remaining 18 subjects were used for the analysis. The characteristics of the two expeditions were similar in altitude and duration, and so it was decided to analyze members of both expeditions jointly. Part of the subjects, 10 males and 5 females (trekking group, TG, Figure 3), performed some trekking activity during the expedition, while 2 males and 3 females (non-trekking group, NTG) did not. TG and NTG of both sexes were similar at baseline in terms of FFM, FM and body fat percentage (%F,

comparisons by t-test). The subjects' diet was not regulated during the study, but an adequate amount of palatable food was always available during HA exposure.

Part of the sample (the participants to the expedition in Nepal) was also studied from the perspective of changes in lung volume and flow rates induced by exposure to high altitude (Cogo et al., 2005).



Fig. 3. Trekking group.

The study was conducted during 3 subsequent experimental phases: at sea level (SL, Phase I: pre-altitude), at HA (Phase II: >4000 m above sea level) and post-altitude (PA, Phase III: 1300 m) in Kathmandu. Subjects gave their written informed consent to the study, which was approved by the scientific board of the Italian National Mountain Institute (*Istituto Nazionale della Montagna*, Rome, Italy).

Subjects were evaluated by means of standardized anthropometric procedures (Lohman et al., 1988) prior to, during, and post expedition. All measurements were taken in the morning and the subjects did no trekking the day before. In particular, measures included height (H), body mass (BM), 8 girths (upper arm flexed and tensed, maximum, minimum and normal thoracic, waist, hip, thigh and calf), and 6 skinfold thicknesses (triceps, subscapular, suprailiac, horizontal abdominal, thigh and calf).

Standing H was recorded to the nearest 0.1 cm by means of an anthropometer and weight was measured using a calibrated electronic scale. Body Mass Index (BMI) was calculated as  $BM/H^2$  [ $kg/m^2$ ]. Upper arm girth was taken at mid-point between the acromion and olecranon processes. Thoracic girths were taken at the level of the mesosternale and the maximum, minimum and normal thoracic girths refer to the torso at inhalation, exhalation and mid-inspiration respectively. Waist girth was taken at the level of the narrowest point, between ribs and iliac crest. Hip girth was taken at maximum

posterior extension of buttocks. Girths were measured by means of a non-stretch spring-loaded tape and they were taken in duplicate and the means of the trials were entered into the anthropometric datasheet. Skinfold thicknesses were obtained on the left side of the body by means of a Lange skinfold caliper (Cambridge Scientific Industries; Cambridge, MD) with a pressure of 10 g/mm<sup>2</sup>. Each skinfold thickness assessment was the average of two site-specific values within 10% of each other. All measurements were taken by two trained operators (one for each expedition) and the anthropometrists' TEMs (assessed prior to the project) were < 5% for skinfolds and <1% for other measurements.

The triceps, subscapular and suprailiac skinfolds were used in the equations derived by Durnin and Womersley (1974) according to sex and age, to calculate body density. Body density was then converted to %F by means of the Siri's equation (1956), as its applicability at high altitude was tested by Bharadwaj and co-workers (1977). FM was calculated as (%F\*BM)/100 and FFM as BM – FM.

The values, expressed as mean ± standard deviation, and measured during the different phases of the expeditions, were analyzed by means of the repeated-measures analysis of variance. The Bonferroni post-hoc test was used to determine where the statistical differences occurred among multiple comparisons. Pearson correlation was adopted to assess the significance of body composition changes at the different phases of the expedition. All analyses were performed using Statistica (ver. 11.0; StatSoft Italia srl, Padua, Italy). Statistical significance was set at  $p \leq 0.05$ .

### 5.3 Results

The mean values of the anthropometric characteristics at various stages of the expedition are shown in Table 1 for males and in Table 2 for females. According to BMI, among males, the 75% of the subjects was normal weight and 25% overweight. All females were normal weight but one, who was obese (initial BMI= 33.7 kg/m<sup>2</sup>). Despite the practice of trekking, she reduced her BM minimally and thus maintained her obese status during the entire expedition (final BMI= 31.2 kg/m<sup>2</sup>).

In males, body weight decreased significantly between the first and the second measurement and between the first and the last measurement, but not between the second and the last one. The mean loss was  $3.1 \pm 1.7$  kg over the duration of the expedition. This loss equated to  $4.0 \pm 2.1\%$  of initial body weight. The 3.1 kg weight loss was partitioned in a 1.0 kg decrease in FM (corresponding to a 7.6% decrease of starting FM) and a 2.1 kg decrease in FFM (corresponding to a 3.5% decrease of starting FFM). We can therefore estimate that about 1/3 of the weight loss was from fat stores and 2/3 was from FFM. Percentage reduction was therefore greater in FM than in FFM, actually more than double. All girths, except waist, decreased. Hip, thigh and calf girths decreased significantly. Skinfold measurements at trunk sites decreased, while those at limb sites increased but statistical significance was never reached.

TABLE 1. CHARACTERISTICS OF THE MALE SUBJECTS DURING THE EXPEDITION

Variables	1 <sup>st</sup> SL	2 <sup>nd</sup> HA	3 <sup>rd</sup> PA
Age, yrs	33.3±11.6	-	-
Height, cm	177.4±6.9	-	-
Weight, kg	76.4±7.1* <sup>a,b</sup>	73.5±6.8	73.4±6.5
BMI, kg/m <sup>2</sup>	24.1±2.1* <sup>a,b</sup>	23.2±2.0	23.2±2.2
Girths, cm			
Arm	28.7±2.1	28.3±2.4	28.2±1.9
Maximum thoracic	98.6±5.4	98.6±5.6	98.5±5.2
Minimum thoracic	92.2±4.5	91.0±4.9	91.5±5.3
Normal thoracic	94.3±5.2	93.2±5.2	94.1±5.5
Waist	81.4±8.7	80.0±7.1	82.4±7.1
Hip	97.7±4.6* <sup>a,b</sup>	94.5±3.7	94.5±4.4
Thigh	53.7±3.4	55.5±4.5* <sup>c</sup>	52.7±5.3
Calf	37.1±1.8* <sup>a</sup>	35.9±2.4	36.2±2.4
Skinfolds, mm			
Triceps	9.0±3.3	9.1±2.4	9.3±3.3
Subscapular	11.5±3.2	11.3±2.2	11.2±2.7
Suprailiac	11.1±5.4	9.5±4.6	9.9±3.9
Abdominal	15.5±5.5	14.4±4.7	14.7±5.7
Thigh	14.0±4.7	12.9±3.8	14.1±5.6
Calf	9.1±3.2	9.2±2.7	9.5±3.1
Density, g/cm <sup>3</sup>	1.060±0.014	1.061±0.012	1.061±0.012
%F	17.0±6.2	16.4±5.3	16.4±5.3
FM, kg	13.2±5.6	12.2±4.7	12.2±4.6
FFM, kg	63.3±5.6* <sup>a,b</sup>	61.2±4.8	61.1±4.4

SL: sea level; HA: high altitude; PA: post altitude. Values: mean ± SD; \*level of significance  $p < 0.05$  <sup>a</sup> 1<sup>st</sup> vs 2<sup>nd</sup>; <sup>b</sup> 1<sup>st</sup> vs 3<sup>rd</sup>; <sup>c</sup> 2<sup>nd</sup> vs 3<sup>rd</sup>.

During the expedition, females lost an average of  $2.4 \pm 2.6$  kg, equated to  $4.1 \pm 3.6$  % of the starting BM. Body composition analysis showed that BM reduction was partitioned in 0.7 kg of FM (corresponding to a 5.0% decrease of starting FM) and 1.6 kg of FFM (corresponding to a 3.6% decrease of starting FFM). These data represent the same proportions of BM loss as in males. Percentage reduction was greater in FM than in FFM, but less than in males, since the percentage reduction ratio FM/FFM was 1.4. A significant reduction was observed in maximum thoracic and hip girths.

Significant changes in males are evident between the first and the second measurement, and are confirmed by the third, as showed by post-hoc Bonferroni test. In females instead, changes are significant between the second and third measurement.



TABLE 2. CHARACTERISTICS OF THE FEMALE SUBJECTS DURING THE EXPEDITION

Variables	1 <sup>st</sup> SL	2 <sup>nd</sup> HA	3 <sup>rd</sup> PA
Age, yrs	28.5±3.6		
Height, cm	161.8±7.4	-	-
Weight, kg	58.3±10.8* <sup>a</sup>	56.9±10.7	55.9±9.4
BMI, kg/m <sup>2</sup>	22.3±4.9	21.9±4.9	21.5±4.3
Girths, cm			
Arm	24.9±3.1	24.7±3.1	24.9±3.6
Maximum thoracic	87.8±5.9* <sup>a</sup>	88.8±7.4	86.2±5.7
Minimum thoracic	81.8±6.8	81.7±6.4	80.0±5.9
Normal thoracic	83.7±5.9	84.3±7.5	82.2±5.2
Waist	67.4±8.0	66.9±9.2	67.4±7.7
Hip	95.4±8.2* <sup>a</sup>	91.9±8.9	91.7±8.2
Thigh	52.9±5.1	51.8±5.5	52.1±4.7
Calf	35.4±2.7	34.3±2.9	34.5±2.7
Skinfolds, mm			
Triceps	13.4±5.4	13.3±3.1	13.9±4.9
Subscapular	10.9±5.1	11.6±6.7	11.2±6.7
Suprailiac	11.3±5.7	9.4±5.0	9.9±5.8
Abdominal	12.8±4.7	11.9±6.9	12.4±6.5
Thigh	21.8±6.2	19.3±4.8	19.6±5.4
Calf	14.8±4.2	14.3±6.0	13.7±5.9
Density, g/cm <sup>3</sup>	1.045±0.012	1.046±0.012	1.046±0.014
%F	23.8±5.6	23.4±5.5	23.5±6.2
FM, kg	14.3±6.3	13.8±6.2	13.6±6.1
FFM, kg	44.0±4.9	43.1±4.7	42.4±3.9

SL: sea level; HA: high altitude; PA: post altitude. Values: mean ± SD; \*level of significance  $p < 0.05$  <sup>a</sup> 1<sup>st</sup> vs. 3<sup>rd</sup>.

The influence of initial %F on body composition changes has been explored by correlation. In males, initial %F was positively correlated to FM loss between the first and the second measurement ( $r=0.712$ ,  $p=0.02$ , Figure 4), and negatively to FFM loss between the first and the third measurement ( $r = -0.697$ ,  $p = 0.02$ , Figure 5). Thus, at HA leanest subjects lost more FFM and less FM than the fattest ones. In females, no significant correlation was found.

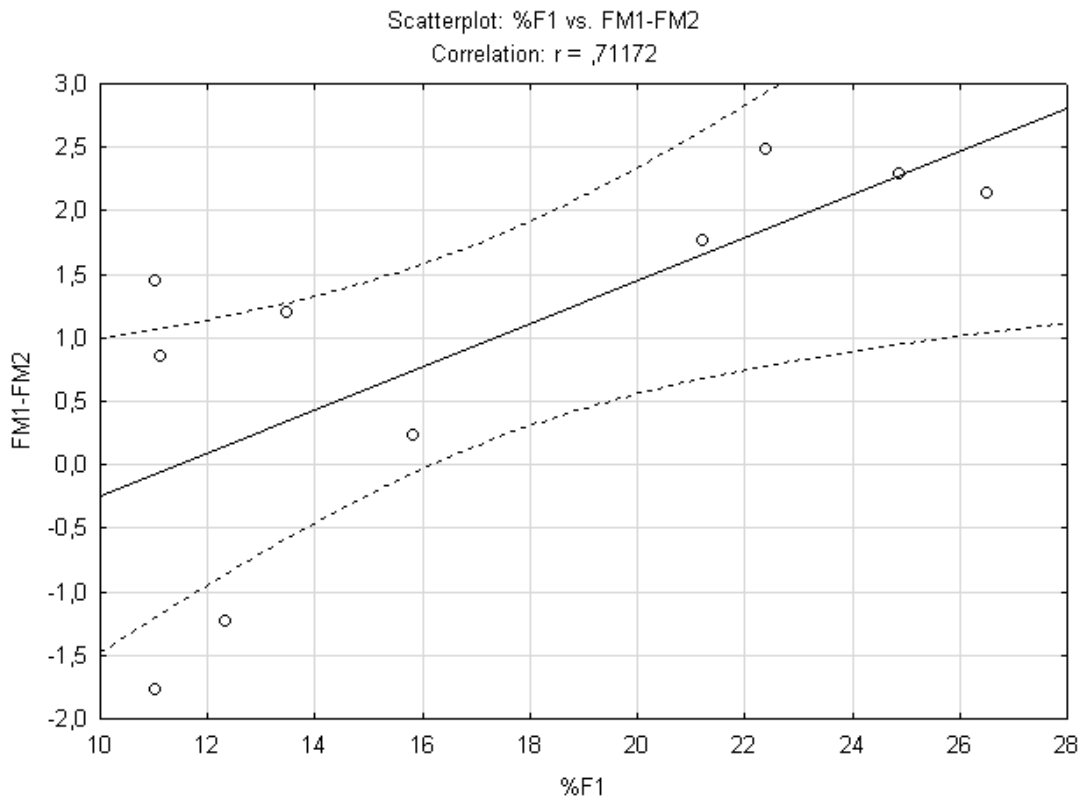


Figure 4. Scatterplot of FM reduction as a function of initial %F in males.

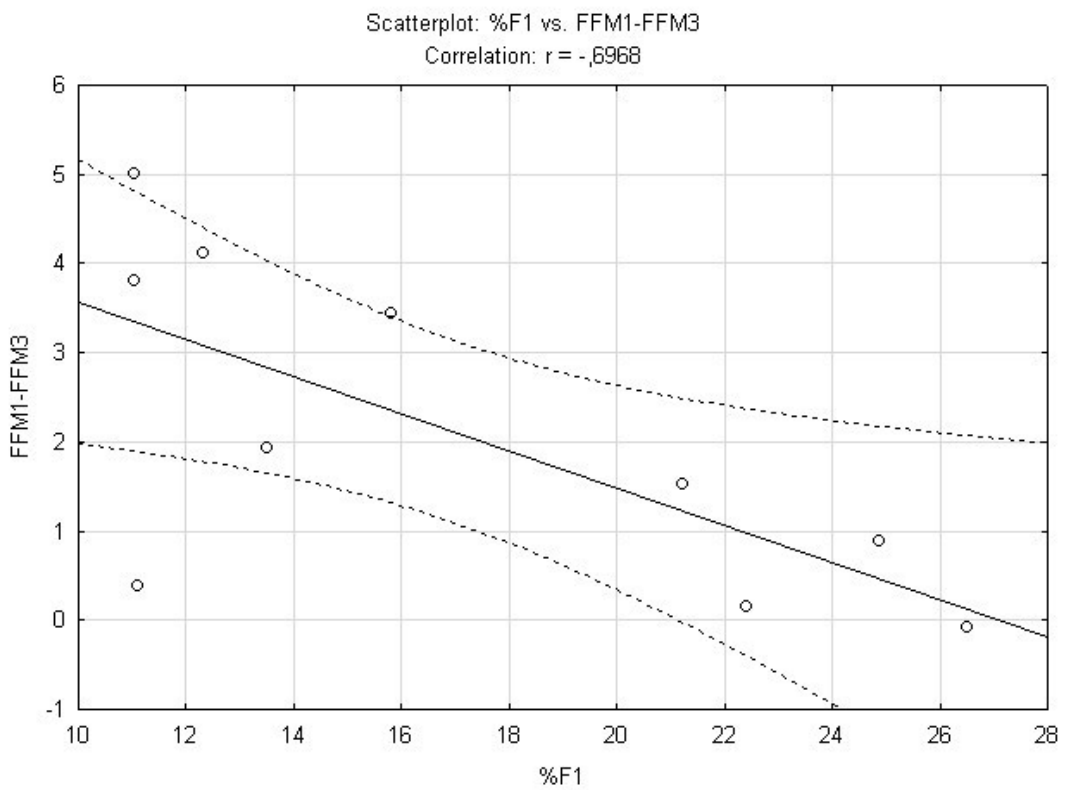


Figure 5. Scatterplot of FFM reduction as a function of initial %F in males.

On average, in males (Table 3) TG and NTG both lost 1 kg of FM, but TG lost 2 kg of FFM, while NTG lost 3 kg of FFM. Therefore, weight loss proportions were 1/3 FM and 2/3 FFM in TG, and 1/4 FM and 3/4 FFM in NTG, suggesting that physical activity helped preserving FFM.

TABLE 3. EFFECTS OF TREKKING ON BODY COMPOSITION IN MALES DURING EXPEDITION

MALES Variables	TG n=10			NTG n=2		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
Height, cm	176.8±7.1	-	-	180.1±6.9	-	-
Weight, kg	76.5±7.8	73.4±7.3	73.7±7.0	76.0±5.7	74.0±8.5	72.0±5.7
BMI, kg/m <sup>2</sup>	24.0±2.4	23.1±2.2	23.5±2.5	23.4±0.1	22.8±0.9	22.2±0.0
Girths, cm						
Arm	28.7±2.2	28.4±2.6	28.1±2.0	29.0±2.0	28.2±1.8	28.7±2.1
Max. thoracic	99.0±5.9	98.7±6.2	98.7±5.8	96.8±0.6	97.9±0.4	97.6±1.6
Min. thoracic	92.1±4.8	90.7±5.2	91.6±6.0	92.5±3.8	92.5±3.5	90.9±1.8
Normal thoracic	94.4±5.6	92.9±5.6	94.2±6.3	93.7±3.5	94.7±2.9	93.8±0.6
Waist	81.0±9.5	80.5±7.7	83.3±7.7	83.4±3.3	77.4±2.5	78.7±0.7
Hip	97.3±4.6	94.7±3.7	94.3±4.7	97.2±6.9	93.3±4.7	95.0±4.2
Thigh	54.2±3.3	55.3±4.8	53.4±5.8	50.1±2.1	53.8±4.0	49.9±1.8
Calf	37.0±1.8	35.9±2.5	36.1±2.5	36.8±1.9	34.8±2.3	36.6±3.0
Skinfolds, mm						
Triceps	9.2±3.4	9.2±2.6	9.9±3.5	6.0±0.0	7.8±0.4	7.0±1.4
Subscapular	12.1±3.5	11.0±2.3	11.5±3.0	10.5±0.7	10.5±2.1	10.0±1.4
Suprailiac	11.3±5.8	9.7±5.0	10.3±4.5	10.0±4.2	9.0±1.4	8.8±0.4
Abdominal	14.1± 6.0	12.1±4.9	14.7±6.7	17.0±0.0	16.5±0.7	14.8±0.4
Thigh	13.7±4.9	13.0±3.7	15.6±5.1	10.0±1.4	8.8±1.1	8.1±3.0
Calf	9.3±3.0	8.4±3.2	10.3±3.0	5.0±1.4	8.5±0.7	6.8±0.4
Density, g/cm <sup>3</sup>	1.060±	1.062±	1.059±	1.069±	1.069±	1.071±
	0.015	0.013	0.012	0.002	0.002	0.003
%F	17.0±6.5	17.2±5.6	17.5±4.5	12.9±0.8	13.2±0.9	12.2±1.3
FM, kg	14.0±6.0	12.8±5.1	13.1±4.8	9.8±0.1	9.8±1.8	8.8±1.6
FFM, kg	62.5±5.6	61.3±5.6	60.6±4.6	66.2±5.6	64.2±6.7	63.2±4.0

TG: trekking group; NTG: No Trekking Group.

On average, in females (Table 4) TG lost 1 kg of FM and 2 kg of FFM, while NTG lost 0.4 kg of FM and 1.3 kg of FFM. Weight loss was therefore partitioned similarly as in males. TG lost less BM than NTG in males, in spite of the fact that a higher caloric expenditure may be supposed in TG, while the opposite happened in females.

BM loss was predominantly due to a reduction in FFM, in both TG and NTG, males and females. Body composition changes instead showed a greater percentage reduction of FM compared to FFM in males, both TG and NTG, and females TG. Only in females NTG percentage reduction was similar in both FM and FFM.

TABLE 4. EFFECTS OF TREKKING ON BODY COMPOSITION IN FEMALES DURING EXPEDITION

FEMALES Variables	TG n=5			NTG n=3		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
Height, cm	162.4±8.6	-	-	160.8±6.4	-	-
Weight, kg	60.7±12.7	58.5±13.0	57.9±11.1	54.3±6.7	54.2±6.8	52.7±6.4
BMI, kg/m <sup>2</sup>	23.3±6.1	22.4±6.2	22.2±5.4	21.0±1.5	20.9±2.1	20.4±2.3
Girths, cm						
Arm	25.2±3.9	25.1±3.7	25.3±4.4	24.4±1.6	23.9±2.3	24.1±2.4
Max. thoracic	88.8±6.4	89.2±8.0	87.1±6.8	86.3±5.8	88.0±7.8	84.9±4.3
Min. thoracic	81.9±7.7	82.0±6.5	80.6±7.0	81.6±6.6	81.2±7.7	79.1±4.5
Normal thoracic	84.0±6.7	84.5±7.9	82.3±6.3	83.1±5.5	83.8±8.5	82.1±4.1
Waist	68.4±9.6	67.6±11.5	68.0±9.9	65.7±5.5	65.6±5.5	66.4±2.8
Hip	97.5±10.1	94.9±10.0	93.5±10.2	92.0±1.5	87.0±3.8	88.7±2.0
Thigh	55.4±4.0	54.6±3.8	54.8±3.3	48.7±3.9	47.2±5.0	47.5±2.5
Calf	35.8±3.4	34.5±3.6	34.8±3.4	34.9±1.2	34.0±1.9	34.0±1.4
Skinfolds, mm						
Triceps	15.0±6.0	13.5±4.1	14.9±6.6	10.7±3.5	13.0±0.9	12.7±1.2
Subscapular	11.4±5.9	12.4±8.6	12.3±8.5	10.0±4.4	10.2±2.8	9.3±2.3
Suprailiac	12.0±7.0	10.8±6.2	12.1±7.0	10.0±3.6	7.7±2.8	6.8±2.4
Abdominal	13.8±5.8	13.1±7.4	13.4±7.8	11.0±1.7	10.0±5.0	11.0±1.0
Thigh	23.6±5.5	19.0±5.5	20.8±5.1	18.7±7.0	19.8±4.3	18.2±6.5
Calf	15.0±4.9	15.4±7.6	15.4±7.4	14.3±3.8	12.5±1.3	11.5±3.0
Density, g/cm <sup>3</sup>	1.043±	1.045±	1.044±	1.048±	1.047±	1.048±
	0.014	0.014	0.017	0.010	0.010	0.005
%F	24.7±6.4	23.8±6.5	24.1±7.9	22.4±4.7	22.9±4.3	22.5±2.4
FM, kg	15.6±7.6	14.5±7.7	14.6±7.5	12.3±3.9	12.9±3.8	11.9±2.8
FFM, kg	45.2±5.6	44.0±5.6	43.3±4.2	42.0±3.6	41.6±3.1	40.7±3.6

## 5.4 Discussion and conclusions

Subjects lost weight during the expedition and adaptive responses were quicker in males than in females, as in males the differences were already significant between the first and the second measurement, while in females only between the first measurement and the third one. This fact supports the hypothesis of greater eco-sensitivity in the male sex and a generally higher resistance of the female sex to adverse environmental conditions (Wolanski, 1975; Semproli and Gualdi-Russo, 2007). In males TG lost less BW than NTG, in spite of the fact that a higher caloric expenditure may be supposed. Trekking at HA seems to have a more intense BM reduction effect in females than in males, even if this result must be taken with caution because of the limited number of individuals in NTGs. The average BM loss was about 4.0% of the starting BM and was partitioned into 2/3 FFM and 1/3 FM on average in both males and females. These values are not different from changes in body composition observed by Boyer and Blume (1984).

In a study by Wagner (2010), climbers lost weight on two different expeditions, but the loss was more pronounced on the longer and higher Everest expedition. It has therefore been suggested that humans cannot maintain weight above 5000 m and the magnitude of weight loss is dependent on the amount of time spent at HA. Weight loss at HA may be related to the amount of FM before the expedition as suggested by the present study. A relationship between initial body fat content and degree of body weight loss was observed by Surks et al. (1966, p. 1745). The clarification of mechanisms leading to weight loss at HA might provide new tools for future treatment of obesity (Lippl et al. 2010).

Loss in BM has been attributed in varying proportions to reduced FM and FFM (Ermolao et al. 2011). The same results as the present study, that is 1/3 FM loss and 2/3 FFM loss, have been found by Rose et al. (1988). In their study, experienced mountain climbers have reported severe loss of muscle mass during expeditions. A review by Kayser (1994) confirms that weight loss at altitude is due to an initial loss of water and subsequently to loss of FM and muscle mass, probably because of malnutrition. If fat stores are reduced due to extensive precedent physical exercise, exposure to HA might cause loss of lean body mass, including muscle (Tschop and Morrison, 2001, p. 239; Hoppeler et al., 1990). Since HA exposure can lead to losses of muscle mass, these losses may also negatively influence exercise capacity. Tanner and Stager (1998) noted that weight loss appears to be predominately from FFM in studies conducted in laboratory chambers, but in field-based studies weight loss is largely due to a reduction in FM.

The methodology used to assess body composition is also likely to influence the results. The applicability of the adopted equations at high altitude may require further approval. Still, we consider the skinfold method better than multiple frequency bioelectric impedance analysis because of the variability of body impedance in different measurement conditions (Gualdi-Russo and Toselli, 2002). The hydration status of the subject affects multifrequency bioimpedance analysis accuracy, but it may also affect skinfold measurements because with dehydration the tissues become more compressible and so less thick. Unfortunately no information about hydration status of the subjects were available

Precise evaluation of body composition changes utilizing laboratory methods such as hydrostatic weighing or radiographic techniques is not always practical or possible in field conditions at HA (Fulco et al., 1985). Due to alterations in BW, water and protein balances, the use of predictive equations to describe body composition changes during and after a HA sojourn may not be valid, since subjects may be dissimilar from the population from which the equation were derived. This may be considered a limitation of the present research, as of similar ones, at HA.

During a mountain expedition, unlike a simulated ascent in hypobaric chamber, it is difficult to determine whether body weight loss is due to increased energy expenditure because of intense physical activity, cold environment, limited availability or palatability of food, dehydration, malabsorption, acute mountain sickness, or combinations of these

stresses (Rose et al. 1988). More research is needed to determine the influence of hypoxia on weight loss independent of physical effort, as suggested also by Wagner PD (2010).

The present study shows a similar pattern of fat mobilization from adipose tissue at HA as Bharadwaj (1972), since the sample had an increase in average triceps skinfold thickness and a reduction at trunk sites. While the cited study observed only males, the present one verified the same pattern in both males and females, even if in our sample changes were not significant.

Our investigation included female subjects and three repeated measurements: before, during and after expedition. These facts contributed to improve the current knowledge on body composition modifications and adaptations occurring during long exposures to HA in females, since most of the studies to date mainly included male subjects and consisted of follow-ups. The present paper highlights the importance of repeated measures, by means of which we could observe the different behavior in the two sexes. Accurate repeated measures were needed to track changes during stay at HA.

In conclusion, this study confirms that exposure at HA reduces BW - relatively more in terms of FM than FFM - and suggests different adaptation patterns in the two sexes.

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# 6. Fourth study: Anthropometric and biomechanical characteristics of a sample of sprinters

Athletics is one of the most ancient and popular sports in human history. Among its disciplines, sprinting is one of the most spectacular. Winning the 100 m dash at the Olympics is an extremely prestigious achievement in sport overall, earning the gold medalist fame and fortune. Sprinting requires different motor skills, like strength and speed, and top sprinters are superb athletes who have in common some typical physical traits, like a lean and muscular body. The following study describes the anthropometric and strength-related characteristics of a sample of Italian sprinters and their relationships to performance and health.

## 6.1 Introduction

Athletics – or *track-and-field*, as it is known in American English – comprises several sport disciplines, or *events*, most of which are part of the official Olympic program. Some of them have their roots in human pre-history, when physical activity was not performed for entertainment or competition purposes, but rather for hunting or fighting. In fact, speed, strength and endurance were necessary motor skills for surviving.

Modern athletics' events can be classified according to the following taxonomy:

- Running:
  - Sprints: up to 400 m.
  - Mid-distances: up to 3,000 m, including 3,000 m steeplechase<sup>6</sup>.
  - Long distances: up to the marathon (42,195 m) and beyond (but not at the Olympics), also including race-walking (20 km and 50 km).
- Jumping
  - Long jump.
  - Triple jump.
  - High jump.
  - Pole vault.
- Throwing:
  - Shot-put.
  - Discus.

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<sup>6</sup> According to different sources, middle distances may go up to 10,000 m. Usually though, the 5,000 m and the 10,000 m are considered long distances.

- Hammer.
- Javelin.

Running is performed on the track, while jumps and throws are performed on the field. Still, when a run-up is needed, as in jumps and in the javelin, the running surface is covered with the same material as the track. Some of these disciplines, like discus, long jump and sprint running, were practiced also in ancient Olympics.

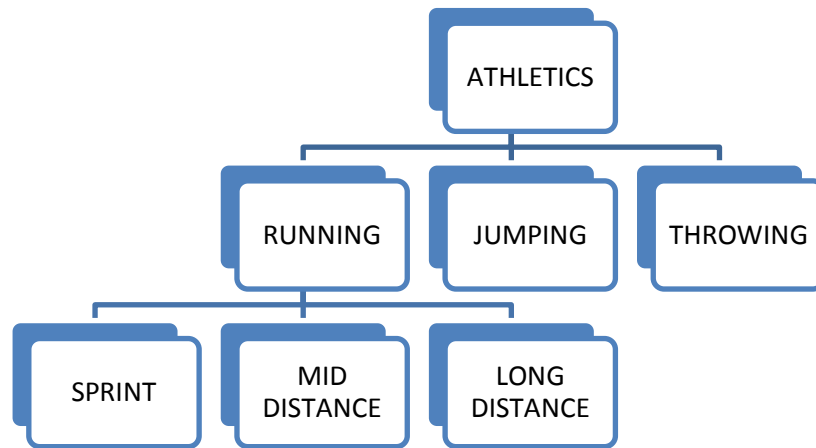


Fig. 1. Taxonomy of athletics' events.

Male outdoor sprint running traditionally includes the following:

- 100 m.
- 200 m.
- 400 m.
- 110 hs.
- 400 hs.
- 4 x 100 m relay race.
- 4 x 400 m relay race.

Indoor, both men and women perform the 60 m, instead of the 100 m, and the 60 hs instead of the 110 hs or the 100 hs. The indoor program is not part of the summer Olympics.

The time in the 100 m in the most important events has decreased constantly. In the last summer games, in 2012 in London, all the participants to the final finished the race in less than 10 seconds (Table 1), with the only exception of Asafa Powell, who was injured. The gold medal was won in 9.63 s by Jamaican sprinter Usain Bolt, who also holds the current world record (9.58 s). In 1992, 20 years earlier, at the Olympic Games in Barcelona, only the winner, Linford Christie (from GBR) ran the final in less than 10 s (precisely in 9.96 s) while the second, Frank Fredericks, finished in 10.02 s and the third, Dennis Mitchell in 10.04 s.

TABLE 1. 2012 OLYMPICS: 100 M MEN FINAL RANKING.

Final rank	Athlete	Country	Mark (s)
1	Usain Bolt	Jamaica	9.63
2	Yohan Blake	Jamaica	9.75
3	Justin Gatlin	USA	9.79
4	Tyson Gay	USA	9.80
5	Ryan Bailey	USA	9.88
6	Churandy Martina	Netherlands	9.94
7	Richard Thompson	Trinidad and Tobago	9.98
8	Asafa Powell	Jamaica	11.99

Source: IAAF<sup>7</sup> official web sites, [www.iaaf.org](http://www.iaaf.org).

Three out of eight athletes in the Olympic final were from Jamaica and one from Trinidad. Also the Dutch athlete Martina was of Caribbean origins, while the other three were African Americans. The predominance of black athletes in sprinting has been investigated from different points of view: anthropometric and biomechanical (Babel et al. 2005), demographic (Irving et al. 2013) and genetic (Deason et al. 2012, Eynon et al. 2013, Scott et al. 2010, Wang et al. 2013).

In the same edition of the Games, in the 200 m men final, the first 4 athletes finished in less than 20 s, with the winner, Usain Bolt again, finishing in 19.32 s (Table 2). In Barcelona 1992, none of the competitors in the final ran the 200 m in less than 20 s, with the winner, Michael Marsh (USA), finishing in 20.01 s. Frank Fredericks, second overall, ran in 20.13 s, and Michael Bates, third, in 20.38 s.

TABLE 2. 2012 OLYMPICS: 200 M MEN FINAL RANKING.

Final rank	Athlete	Country	Mark (s)
1	Usain Bolt	Jamaica	19.32
2	Yohan Blake	Jamaica	19.44
3	Warren Weir	Jamaica	19.84
4	Wallace Spearmon	USA	19.90
5	Churandy Martina	Netherlands	20.00
6	Christophe Lemaitre	France	20.19
7	Alex Quinonez	Ecuador	20.57
8	Anaso Jobodwana	RSA	20.69

Source: IAAF official web sites, [www.iaaf.org](http://www.iaaf.org).

The continuous improvements in the performances of sprinters have highlighted the prevalence of athletes with a low fat mass percentage, a large fat free mass and impressive amount of muscular strength, even in a lower and wider range of qualification levels.

<sup>7</sup> International Association of Athletics Federations, world athletics governing body.

In Figure 2 and 3 we can see the progression of the world record in the 100 m and the 200 m since the definite adoption of electronic timing in all the official IAAF competitions. In the former event, the incredible achievements of Usain Bolt a few years before the 2012 London Olympics are marked by a steep decline of the graph. In the latter event, the long-lasting record of Pietro Mennea (Italy), 19.72 s, set in 1979 results in a constant horizontal segment followed by a downward step, caused by Michael Johnson (USA) setting the new record at 19.66 s in 1996. In the two charts, the progressions in both the sprint events are evident, even if they followed different trends.

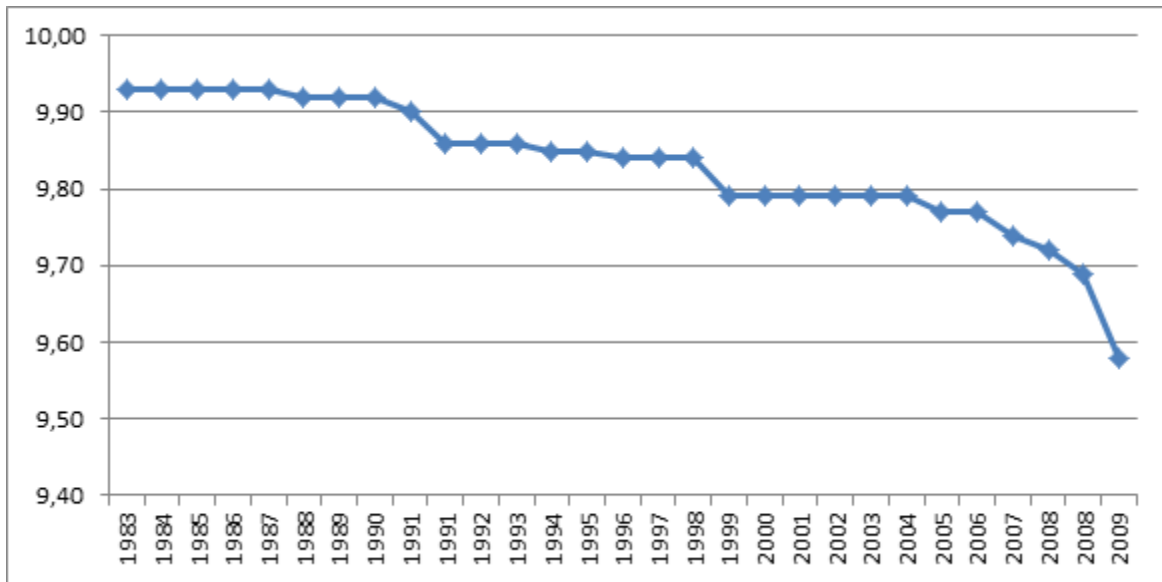


Fig. 2. 100 m men world record progression.

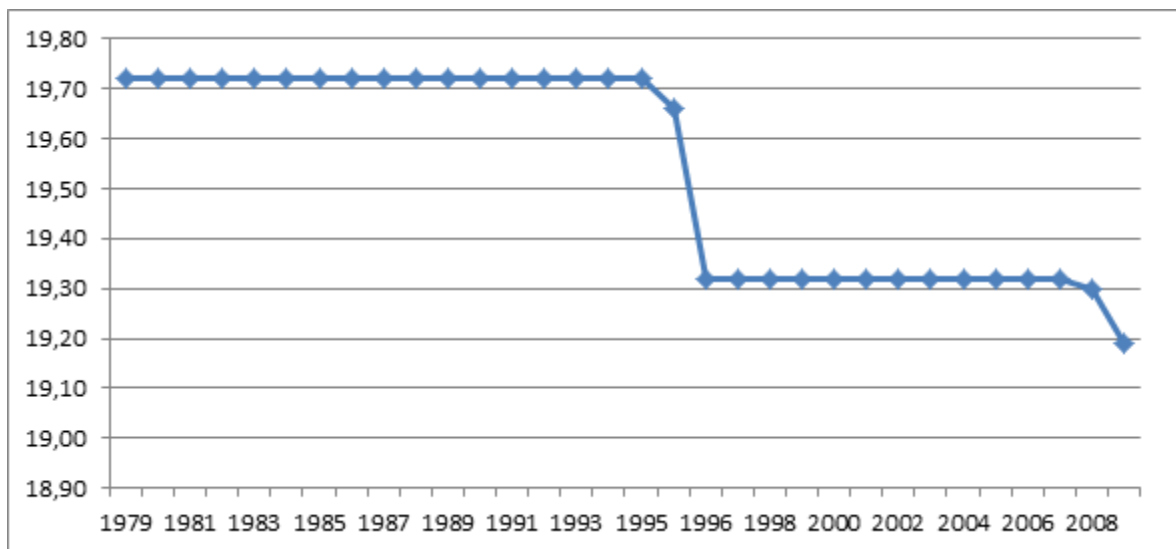


Fig. 3. 200 m men world record progression.

There are many factors which can contribute to performances in sport: muscle mass and strength, strength-to-body weight ratios, psychology, motor skills, efficient energy production systems, height, somatotype etc. Some of these factors are highly trainable, others are mainly genetic. Still, body shape plays an important role in sport, as it can be

inferred observing top athletes' physique. It is therefore possible to speak of morphological optimization: a narrow range of variation in physical traits of sport champions practicing the same discipline (O'Connor et al. 2007).

Several investigators are interested in assessing and evaluating the anthropometric traits of athletes and their somatotype in particular (Housh et al. 1984, Gualdi-Russo et al. 2001, Norton et al. 2004, Uth 2005, Vucetić et al. 2008, Abraham 2010, Abraham 2011, Barbieri et al. 2012, Watts et al. 2012, Massidda et al. 2013, Zillmann et al. 2013). Results can be used for early talent discovery, and in order to improve our understanding of what it takes to make a champion, or simply a volleyball player, a gymnast, a mountain climber, a runner etc.

However, there is a lack of focus on male sprinters and the possible correlations between anthropometry, sport-specific skills and performances. The aims of the present study are to assess anthropometrically and biomechanically a sample of active male Italian sprinters (competing in the 100 m and 200 m), and to analyze the potential correlations between anthropometric traits, muscular strength and performances.

## **6.2 Sample and methods**

The present cross-sectional study involved 73 Italian male sprinters, of diverse ethnic origins - but predominantly Caucasians - aged  $23.5 \pm 6.9$  (mean  $\pm$  standard deviation SD). The athletes - with different levels of qualification - volunteered for the research and were assessed by means of standard surface anthropometry after giving their written and informed consent. This study was approved by the Ethical Committee of the University of Ferrara.

### **6.2.1 Anthropometric assessment**

Measurements and personal data were collected on the field, on the occasion of some official FIDAL<sup>8</sup> competitions in 2012-2013. The following anthropometric measures were taken:

- Weight (W, kg)
- Stature (S, cm) and sitting stature (SS, cm)
- Biacromial (BA), bicrestiliac (BI), humerus and femur breadths
- Mid-thigh, calf, relaxed and contracted arm girths
- Skinfold thicknesses: triceps, thorax, sub-scapula, supra-iliac, mid-thigh and calf.

Breadths, girths and skinfold thicknesses were taken according to standardized anthropometric procedures (Lohman et al. 1988), on the left side of the body.

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<sup>8</sup> *Federazione Italiana Di Atletica Leggera*, Italian Athletics Federation.

From some of these measures, we have calculated the following anthropometric indices: the body-mass index (BMI, [kg/m<sup>2</sup>]) as a measure of nutritional status, the cormic index (CI=SS\*100/S) and the acromion-iliac index (AII=BI\*100/BA) as measures of body proportions.

Body density (BD) was calculated using Jackson and Pollock (1985) equation with three skinfolds (triceps, thorax and sub-scapula). Body fat percentage (%F) was calculated from BD using Siri equation (1956). Fat Mass (FM, kg) was calculated as (%F\*W)/100 and fat free mass (FFM, kg) as W-FM. Somatotype components (endomorph, mesomorph, ectomorph) were calculated by means of the anthropometric method, according to Heath and Carter (Carter 2002).

### 6.2.2 Sprint performance and strength assessment

By means of a questionnaire the following data were also collected: 100 m and 200 m personal best (PB) time and year, 100 m and 200 m seasonal best (SB) time. Performances were later checked on the official FIDAL website and updated in case. Results in the most common exercises used in sprinting to train and test muscular strength and power were also collected: 1 repetition maximum (1RM, the highest weight which can be lifted in a single repetition of the given exercise) in the squat, clean and snatch, and best performance achieved in the standing long jump test (Figure 4). Test results were reported by the athletes and not tested on the field.

### 6.2.3 Statistical analysis

Descriptive statistical analyses were performed on each variable, which were checked for distribution normality. Skinfolds were normalized by means of decimal logarithmic transformation. Correlation analysis was performed between anthropometry and performance, strength and performance, and anthropometry and strength. Significance was set at p=0.05. Statistica (ver. 11.0, StatSoft Italia srl, Padua, Italy) software package was used To perform all the statistical analyses.



Fig. 4. Standing long jump.

### 6.3 Results

Descriptive statistics of the main anthropometric traits are shown in Table 3. Mean BMI value was in the normal weight nutritional status. Mean CI value was in the metriocormic range. Mean AII value corresponds to trapezoidal trunk (according to Facchini 1988).

TABLE 3. SPRINTERS' MAIN ANTHROPOMETRIC TRAITS.

Trait	Mean	SD	Min	Max
W (kg)	71.8	7.7	56.0	93.5
S (cm)	176.3	6.9	160.5	191.1
BMI (kg/m <sup>2</sup> )	23.1	1.9	19.3	28.1
SS (cm)	91.9	3.7	83.7	99.6
CI	52.1	1.2	47.5	54.7
BA breadth (cm)	41.1	2.3	36.5	51.2
BI breadth (cm)	27.9	1.8	22.3	31.9
AII	67.9	3.6	59.3	77.2
Humerus breadth (mm)	67.7	5.9	41	77
Femur breadth (mm)	98.2	7.5	63	110
Relaxed arm girth (cm)	29.4	2.2	24.2	34.3
Contracted arm girth (cm)	32.3	2.5	25.6	37.8
Mid-thigh girth (cm)	54.4	3.2	48.5	63.0
Calf girth (cm)	38.1	2.3	34.3	45.0
Triceps skinfold (mm)	8.4	2.5	4.0	15.0
Thorax skinfold (mm)	5.5	1.9	4.0	13.0
Sub-scapular skinfold (mm)	9.0	2.2	5.0	17.0
Supra-iliac skinfold (mm)	6.2	2.2	3.0	14.0
Mid-thigh skinfold (mm)	9.5	3.1	5.0	19.0
Calf skinfold (mm)	6.5	1.8	3.0	11.0

In our sample, 13 athletes were overweight according to WHO cut-off point (BMI $\geq$ 25). At the same time, nobody was overfat, according to Gallagher et al. (2000) cut-off value for body fatness (%F $\geq$ 20). The dominant mean somatotype component was the mesomorphic one, having also the smallest variation coefficient (SD/mean). Endomorphy was the smallest mean component. Sprinters' body composition and somatotype descriptive statistics are summarized in Table 4.

TABLE 4. SPRINTERS' BODY COMPOSITION AND SOMATOTYPE.

	BD (g/ml)	%F	FM (kg)	FFM (kg)	Endo	Meso	Ecto
Mean	1.08	8.46	6.15	65.69	2.16	5.06	2.53
SD	0.01	2.57	2.27	6.62	0.60	1.21	0.90

The somatoplot of the mean somatotype, belonging to the balanced mesomorph category, is shown in Figure 5.

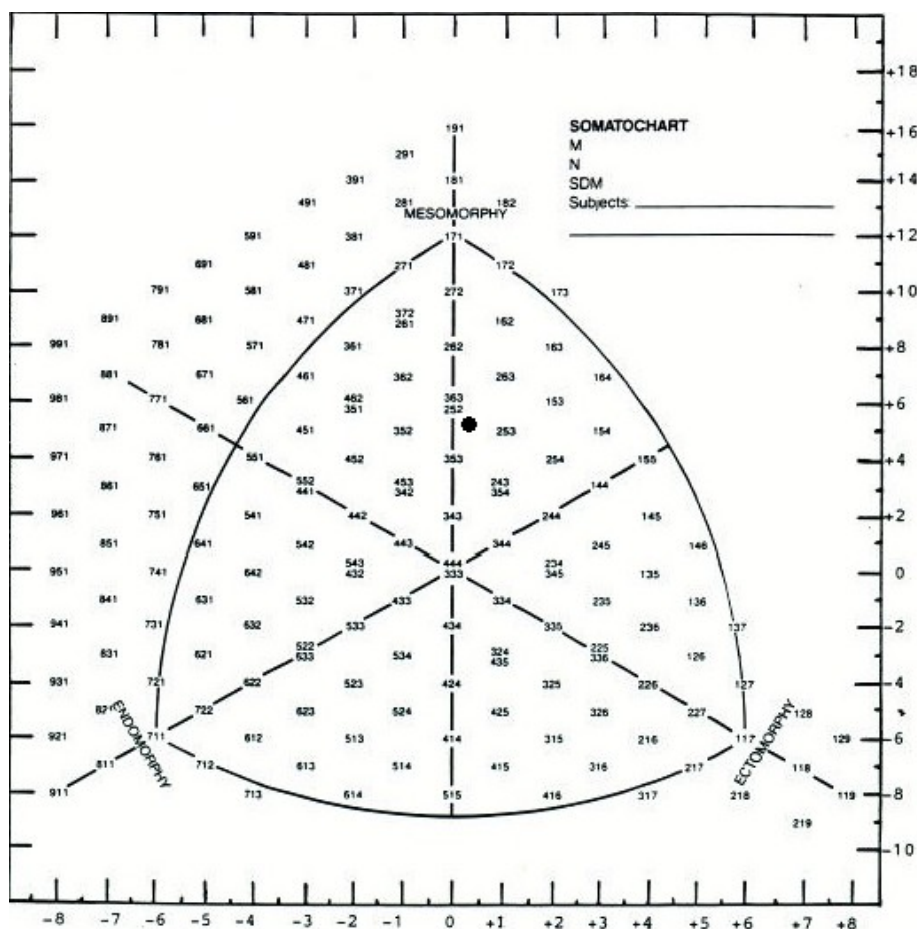


Figure 5. Mean somatotype of the athletes.

Reported sprint times are summarized in Table 5.

TABLE 5. SPRINT TIMES.

	100 m	100 m	200 m	200 m
	PB (s)	SB (s)	PB (s)	SB (s)
Mean	11.37	11.56	23.23	23.56
SD	0.54	0.60	1.31	1.41

Two different types of statistical data analysis were carried on: anthropometric and biomechanical, in order to describe the peculiar characteristics of the sample and to find possible correlations with performances. Significant correlations between anthropometric or biomechanical variables and running speed are negative, since performance is the inverse of the time on the chosen distance (the lower the time, the higher the performance).

Negative significant correlations were found between 100 m PB and the following variables: weight, relaxed and contracted arm girths, calf girth, FFM and BMI. Thigh girth approaches significance ( $p=0.056$ ). Negative significant correlations were found between



100 m SB and the following variables: relaxed and contracted arm girths. Age instead showed a significant positive correlation with 100 m SB time. Negative significant correlations were found between 200 m PB and relaxed and contracted arm girths. Negative significant correlations were found between 200 m SB and contracted arm girth. Again, a positive correlation was found between age and 200 m SB time. Results are shown in Table 6.

TABLE 6. CORRELATIONS BETWEEN 100 m PB AND ANTHROPOMETRIC TRAITS.

Trait	100 m PB		100 m SB		200 m PB		200 m SB	
	r	p	r	p	r	p	r	p
W (kg)	-0.247	0.042						
Relaxed arm (cm)	-0.410	0.001	-0.276	0.026	-0.246	0.045		
Contracted arm (cm)	-0.451	<0.001	-0.328	0.008	-0.340	0.005	-0.311	0.017
Calf (cm)	-0.261	0.032						
FFM (kg)	-0.248	0.042						
BMI (kg/m <sup>2</sup> )	-0.323	0.007						
Age (yrs)			0.350	0.004			0.293	0.026

Only significant results ( $p < 0.05$ ) are shown.

For what concern the somatotype, a significant positive correlation ( $r=0.273$ ,  $p=0.024$ ) was found between the ectomorphic component and 100 m PB (which implies a negative correlation with performance), but not with the SB, nor with any performance in the 200 m.

Absolute and relative strength descriptive statistics are shown in Table 7. Relative strength is defined as  $F_r = F_{\max}/BW$ , that is maximum force divided by body weight, where 1RM in the three basic exercises was taken as the most direct measure of  $F_{\max}$  in the lower limbs.

TABLE 7. ABSOLUTE AND RELATIVE STRENGTH.

	Squat	Clean	Snatch	Long jump	$F_r$	$F_r$	$F_r$
	1RM (kg)	1RM (kg)	1RM (kg)	(cm)	squat	clean	snatch
Mean	120.8	78.4	65.1	290.4	1.68	1.08	0.87
SD	33.0	20.2	12.3	22.0	0.41	0.26	0.15

Correlations between 100 m PB, 100 m SB, 200 m PB, 200 m SB, strength and relative strength are shown in Table 8.

TABLE 8. CORRELATIONS BETWEEN STRENGTH AND PERFORMANCES.

		F <sub>max</sub> squat	F <sub>r</sub> squat	F <sub>max</sub> clean	F <sub>r</sub> clean	F <sub>max</sub> snatch	F <sub>rel</sub> snatch	Long jump
100 m PB	r	-0.589	-0.527	-0.556	-0.515	-0.353	-0.322	-0.438
	p	0.000	0.000	0.001	0.002	0.044	0.068	0.002
100 m SB	r	-0.526	-0.460	-0.479	-0.456	-0.166	-0.203	-0.420
	p	0.000	0.001	0.005	0.008	0.373	0.273	0.005
200 m PB	r	-0.481	-0.417	-0.656	-0.628	-0.533	-0.545	-0.476
	p	0.000	0.003	0.000	0.000	0.001	0.001	0.001
200 m SB	r	-0.455	-0.414	-0.618	-0.603	-0.487	-0.530	-0.460
	p	0.002	0.006	0.000	0.000	0.009	0.004	0.003

In most cases correlations were highly significant ( $p < 0.01$ ). The snatch 1RM correlation with the 100 m PB was only significant. The snatch relative strength correlation with the 100 m PB approached significance, while both the snatch 1RM and the snatch relative strength correlations with the 100 m SB were not significant. This could be partially related to the fact that only a few athletes adopted this exercise (33 out of 68 among those who declared a valid 100 m PB and 31 out of 65 among those who declared a valid 100 m SB). If referred to performances in the 200 m, snatch absolute and relative strength correlations are highly significant.

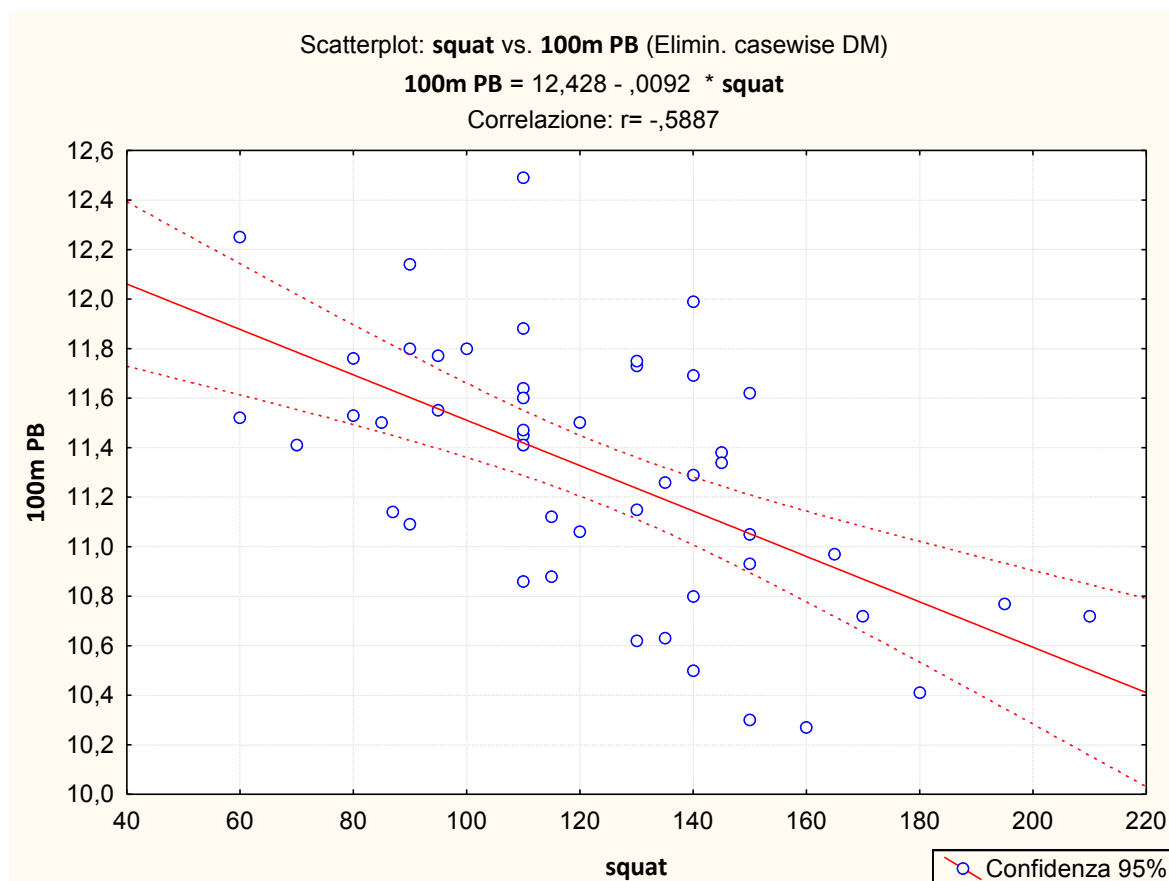


Figure 6. Correlation between squat and 100 m PB.

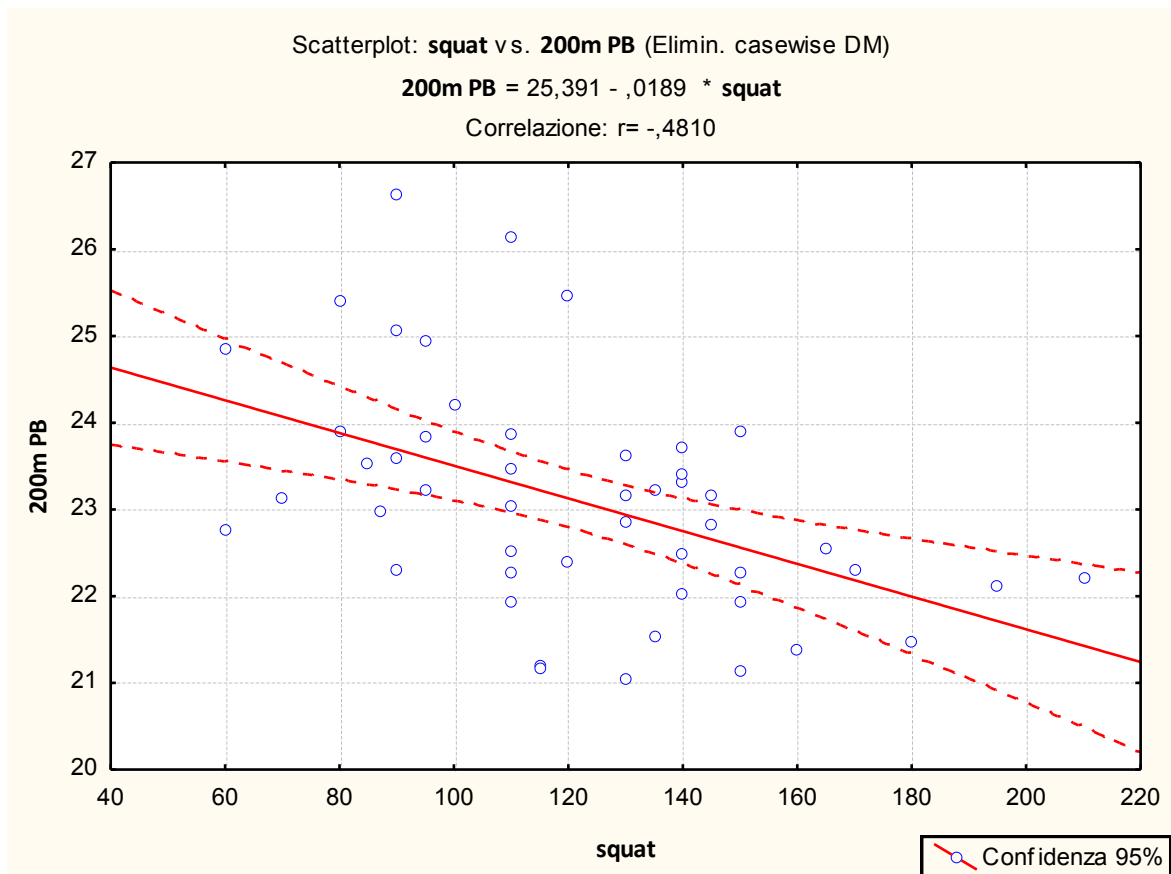


Figure 7. Correlation between squat and 200 m PB.

Squat is slightly more correlated to performance in the 100 m than in the 200 m (Fig. 6 and 7). The opposite is true for clean and snatch, which have stronger correlation to performance in the 200 m than in the 100 m (Fig. 8 and 9). Standing long jump instead is correlated to performance in the 100 m and in the 200 m in a similar way.

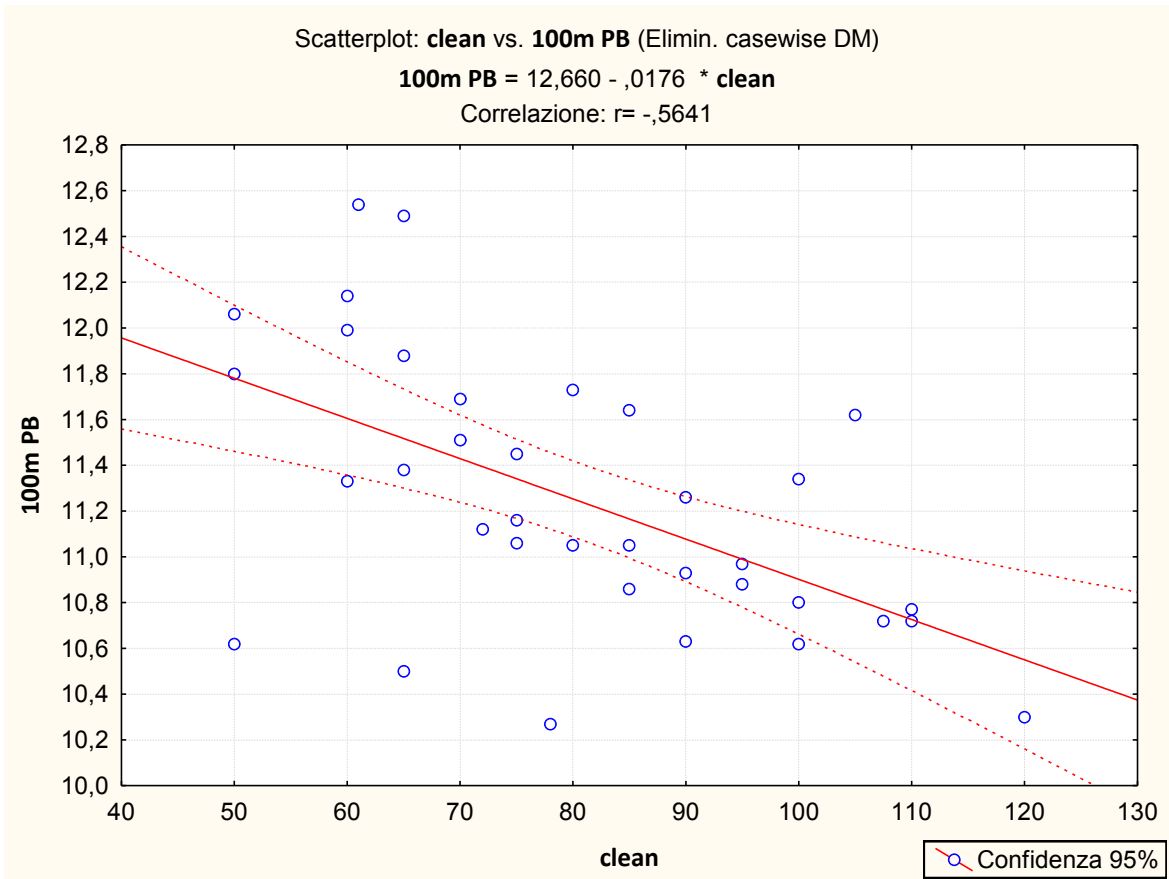


Figure 8. Correlation between clean 1RM and 100 m PB.

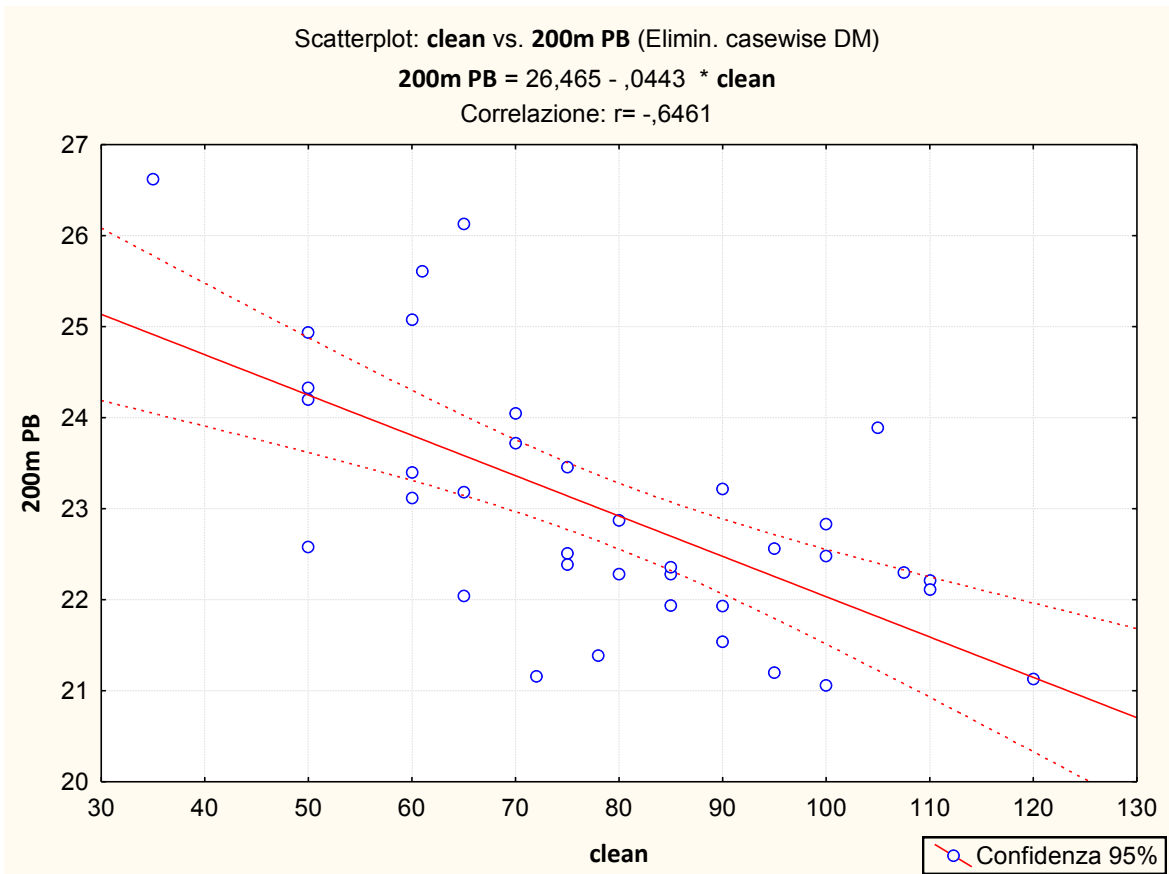


Figure 9. Correlation between clean 1RM and 200 m PB.

Given the significant correlations between indices of body mass - like BMI, W and FFM – and performance in the shortest and most power-oriented distance (100 m), a further analysis on the possible correlations between anthropometry and strength was carried on.

Highly significant positive correlations were found between BMI and the main indices of strength: squat, clean and snatch. Also correlation between W and squat is positive and highly significant, while correlations with snatch and with standing long jump are significant. Highly significant correlations were found between FFM and squat, FFM and standing long jump, while the correlation with snatch approaches significance. Results are shown in Table 9.

The correlation between BMI and squat relative strength is positive and highly significant ( $r=0.483$ ,  $p<0.001$ ). This finding would be consistent with the positive correlation between BMI and performances where strength-to-weight ratio is crucial, like in sprinting.

TABLE 9. CORRELATIONS BETWEEN ANTHROPOMETRY AND STRENGTH.

		$F_{\max}$ squat	$F_{\max}$ clean	$F_{\max}$ snatch	Long jump
BMI ( $\text{kg}/\text{m}^2$ )	r	0.653	0.464	0.451	0.194
	p	<0.001	0.003	0.006	0.184
W (kg)	r	0.442	0.286	0.354	0.288
	p	0.001	0.081	0.034	0.047
FFM	r	0.470	0.273	0.324	0.370
	p	<0.001	0.096	0.054	0.010

## 6.4 Discussion and conclusions

Compared to the general Italian male population ( $W=75.6\pm 10.1$  kg,  $S=171.6\pm 6.9$  cm, Masali 2013), our athletes are significantly lighter ( $p=0.002$ ) and taller ( $p<0.001$ ). On average sprinters have a smaller BMI.

Compared to a sample of Southern Indian male sprinters ( $S=172.1\pm 3.19$  cm,  $W=68.2\pm 2.97$  kg,  $\%F=6.23\pm 0.83$ , Abraham 2010) our athletes were significantly taller ( $p=0.035$ ) and heavier ( $p=0.007$ ), but with a similar BMI. Still, the Indian sprinters were significantly leaner ( $p<0.001$ ). In both groups, the dominant somatotype component is mesomorphy. Italians are significantly less endomorphic ( $p=0.009$ ) and ectomorphic ( $p=0.012$ ) but more mesomorphic ( $p=0.009$ ).

Top Croatian sprinters ( $W=72.58\pm 6.74$  kg,  $S=181.76\pm 5.21$  cm,  $\text{BMI}=21.95\pm 1.60$   $\text{kg}/\text{m}^2$ ,  $\%F=5.86\pm 2.21$ , Vucetić et al. 2008) are significantly heavier ( $p=0.045$ ) and taller ( $p=0.001$ ) than Italian sprinters, but they have a similar BMI. They are significantly leaner

( $p < 0.001$ ), which could be related to their higher level of qualification. They have similar endomorphic and ectomorphic components, but Croatians are significantly ( $p = 0.013$ ) less mesomorphic.

Relatively to standard cut-off values, our sprinters have a low %F but a relatively high BMI, which accounts for a lean body with a large muscle mass. Therefore, BMI must be taken with caution as an index of adiposity in sprinters, and more in general in power-oriented sports. The fact that athletes practicing short, intense efforts, like the 100 m and the 200 m, have such an optimal body composition - even if compared to runners covering much longer distances - must not be underestimated for health, fitness and body weight management purposes.

Traditionally, low-intensity, frequent, long-duration aerobic activities - like walking or cycling at low speed - have been consistently suggested by physicians and medical organizations connected to fitness, in order to maintain and promote physical health in general, and cardiovascular efficiency in particular. For example, in 1995 the American College of Sports Medicine suggested 30 minutes a day of moderate intensity physical activity (Pate et al. 1995), where “moderate” actually stands for the equivalent of a walk.

In 2007, the updated recommendations of the same organizations and of the American Heart Association slightly modified the previous position, suggesting a combination of moderate and vigorous intensity aerobic activity, where “vigorous” is exemplified by jogging at least 20 minutes for at least two days a week (Haskell et al. 2007). In the same paper though, the authors add that “In addition, every adult should perform activities that maintain or increase muscular strength and endurance a minimum of two days each week”. As stated by Prof. Jamie Timmons in an interesting lecture<sup>9</sup> he gave on the 6<sup>th</sup> December 2012 at Cardiff University, our understanding of the relationship between physical activity and human health is continuously evolving.

In sport practice, most disciplines involve short, intense and repeated efforts, like sprinting, jumping, hitting etc. with some (often incomplete) rest in between. This is especially true in team sports, like volleyball, soccer, American football, rugby, basketball and the like, where athletes either sprint or recover. Something similar can be observed in individual sports where the aerobic contribution to the overall effort is minimal or non-significant like tennis (Christmass et al. 1998, Fernandez et al. 2006, Ferrauti 2001), athletics (excluding middle and long distances), gymnastics and Olympic weightlifting.

Nonetheless, athletes practicing the above disciplines show very low levels of fat, having at the same time a significantly higher body mass and an average body fat percentage similar to or lower than middle or long distance runners (Vucetic et al. 2008, Abraham 2010), mainly because of a higher amount of muscles, i.e. metabolically active body mass (Spennst et al. 1993). According to Uth (2005), the BMI of top class male sprinters is  $23.7 \pm 1.5 \text{ kg/m}^2$ , which is higher than present study's athletes and only slightly

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<sup>9</sup> You can watch it here: <http://www.youtube.com/watch?v=E42TQNWhW3w>.

lower than that of the Danish normal population. The WHO sets to 25 kg/m<sup>2</sup> the cut-off point between normal weight and overweight, but adds that 23 kg/m<sup>2</sup> may be considered sufficient to take public health actions - in particular in Asian populations - in order to prevent diabetes and cardiovascular risks (WHO Expert Consultation 2004).

Advices on distances to be covered while engaging in some kind of aerobic activity for fitness purposes might have placed an excessive focus on the second factor of physical work's equation ( $W = \vec{F} \cdot \vec{d}$ ), that is displacement. Things may get even worse if advices rely solely on time, since in the equations of force, acceleration and velocity  $t$  is at the denominator, thus implying that - given a distance - longer time spent walking, jogging or cycling reduces the mechanical component of energy expenditure.

Beside purely mechanical considerations, these health-related advices seem to neglect human physiology. Several studies have demonstrated that the amount of performed work and resulting calories burnt while training do not account for total body weight or fat loss, because short, intense and repeated efforts increase total daily energy expenditure (Sevits et al. 2013). High intensity interval training (commonly known as HIIT) improves blood glucose in both diabetics and non-diabetics (Adams 2013) and several fitness-related aerobic and anaerobic variables like VO<sub>2</sub> max (the maximum volume of oxygen), peak power and recovery time (Bayati 2011).

A study by Hazel et al. (2012) showed that as little as two minutes of sprint interval training elicit body composition improvements to an extent similar to that of 30 minutes of continuous, moderate intensity, endurance training. The prolonged effects of sprint training resulted in a similar total oxygen consumption over 24 hours compared to endurance training, even if oxygen consumption was greater during the latter. The significant body-fat losses observed after sprint training are therefore partially due to an increase in metabolism post-exercise.

Sprinters are involved in workouts comprising lower training volumes (that is, distances) than their endurance counterparts, usually consisting in some form of sport-specific interval training. Even if there is no doubt that conventional recommendations can effectively improve general health - especially in sedentary people - it is questionable whether low intensity, long duration, high frequency sessions can be considered the most efficient and feasible way of tackling health issues and managing body fatness, not to mention the fact that not everyone may have the time or the will to train so often or so long.

The correlations between anthropometric traits and sprint performance in both the 100 m and 200 m in our sample have a common characteristic, that is arm girth, and in particular contracted arm girth. A significant correlation between upper arm girth and performance was also found by Knetchle et al. (2008) in ultra-endurance runners, where muscle mass may seem to be detrimental. More in general, other indices of muscle mass, as calf girth and FFM, seem to be correlated to performance, at least in the 100 m. Since it

is believed that a high strength-to-bodyweight ratio is crucial in sprinting, the correlation between body mass, BMI and running speed in the 100 m may seem contradictory, even if it has been found in other studies, e.g. in a sample of young Indian athletes (Abraham 2011).

In our sample, 13 athletes out of 73 resulted overweight according to BMI, while none was overfat according to %F. Correct and misclassifications are summed up in Table 10.

TABLE 10. CLASSIFICATION ACCORDING TO BMI AND %F.

	Overfat (%F $\geq$ 20)	Normal fat (%F<20)	Total
Overweight (BMI $\geq$ 25)	0	13	13
Normal weight (BMI<25)	0	60	60
Total	0	73	73

There were 13 false positives (FP, type I errors or false alarms). No false negatives (FN, type I errors or miss) were found. Sensitivity, the ability of BMI to correctly identify the fat athletes, or true positive rate  $TPR=TP/(TP+FN)$ , could not be determined because of the absence of overfat athletes ( $TP+FN=0$ ). Specificity, the ability to correctly identify the normal fat athletes, or true negative rate, was  $TNR=TN/(TN+FP)=60/(60+13)=0.82$ . The positive predictive value was  $PPV=TP/(TP+FP)=0/(0+13)=0$ . The negative predictive value was instead  $NPV=TN/(TN+FN)=60/(60+0)=1$ . These results confirms the lack of precision<sup>10</sup> of BMI as an index of adiposity in a sample of sprinters.

The hypothesis that BMI is associated with larger muscle mass rather than greater adiposity in athletes practicing high-intensity sports has been supported by other authors (Nevill and Holder 1995, Nevill et al. 2010). Therefore BMI can be an important anthropometric factor for success in both male and female sprinters.

Watts et al. (2012) suggested that the reciprocal ponderal index (RPI) could be a better predictor of performance, especially in female sprinters. RPI can be calculated as:

$$RPI = \frac{H}{\sqrt[3]{W}}$$

where H is stature in cm and W body weight in kg. Still, our study cannot support this hypothesis in male sprinters. Only one significant correlation between sprint time (specifically the 100 m PB) and RPI could be found, but it was positive ( $r=0.274$ ,  $p=0.024$ ) and therefore negative with performance. Also the ectomorphic somatotype component

<sup>10</sup> Precision is the proportion of true positives against all positive results. Accuracy is the proportion of true results (positive and negative) in the sample, which in this case is 0.82.



was negatively correlated with performance in the 100 m PB. These findings may support the hypothesis that ectomorphism and more in general slenderness are negatively correlated with acceleration and therefore shorter sprints up to 100 m (Norton et al. 2004).

If a high BMI may be considered an index of large muscle mass, in athletes involved in power-oriented sports, with a low %F, then it can be considered an index of absolute and relative strength (Perez-Gomez et al. 2008), since we can suppose that added lean muscle mass produce a larger force than its weight. This may be particularly true in sprinters (Maughan et al. 1983) because of their higher proportion of fast twitch fibers. The influence of FFM on muscle strength was described by Thorland et al. (1987) in a sample of young sprinters and middle distance runners at national level. A positive correlation between body mass and strength is given for granted in many other power-oriented sports, like Olympic weightlifting, powerlifting and wrestling, where weight classes exist. In general, the adoption of the BMI as an index of adiposity appears to be contradictory, especially in athletes.

Weyand and Davis (2005) compared athletes competing in distances from 100 m to 10,000 m. An inverse relationship between BMI and running distance was found. A similar trend was observed also by Khosla (1985) in a large sample of Olympic female runners from 100 m to the marathon. Well trained sprinters are lean and have a large muscle mass, since ground forces relative to body weight are a determinant of running speed (Weyand et al. 2000), while endurance runners have a limited body and muscle mass. Among runners of similar stature and F%, having a relatively larger body mass appears to improve sprinting performances. The authors conclusions are that running has a structural basis, which is in relationship with performance requirements.

A significant positive correlation between sprinting time and age was found in both 100 m and 200 m, if the SB was taken into consideration. In fact, we may suppose that athletes achieved their PB in their prime. Korhonen (2009) has demonstrated that decreasing running speed with aging is mainly due to reduced ground contact forces, in a much larger age range than the present sample, thus confirming the role of strength in sprinting performance.

After anthropometry, biomechanical variables potentially correlated to performance were taken into consideration. The squat, the clean and the snatch are very common exercises in the sprinters' community and they are usually adopted to train muscular strength. The maximal load (1RM) lifted in the three exercises is therefore used as a measure of maximum force. In order to clarify the semantic difference between strength and force in this study, we can say that strength is produced by muscles and it produces physical force. To measure the exerted force directly, a force platform is needed, which is usually quite unpractical and expensive. Also, force is a vector, even though within the scope of this research, only its module is taken into consideration.

The 1RMs in the clean and in the snatch and the long jump are usually considered measures of "speed-strength", as it is commonly referred to in the strength training jargon.

Conceptually, speed-strength is closely related to power. In fact, whenever a force is applied against a resistance in the form of a mass - as a barbell, subjected to gravitational acceleration - as in weight lifting, and the force overcomes it, mechanical power is produced, in proportion to the lifted weight and the velocity of the lift.

Power can be defined as the scalar product of force times velocity:  $P = \vec{F} \cdot \vec{v}$ . On average, the Olympic lifts produce a higher amount of power, compared to the squat or the deadlift, using a 1RM load (Newton 2002, p. 17), mainly because of higher lifting speed (Garhammer 1993). Great acceleration is needed in order to rack the barbell at shoulder height (as in the clean) or at lockout overhead (as in the snatch), which would not be possible if the weights were lifted at almost constant speed, as in non-ballistic movements like the squat or the deadlift. This is the reason why in strength training the Olympic lifts are usually adopted in order to train speed-strength.

Nonetheless, in our analysis only force measured as 1RM has been used, even if the possible correlation between power and performance is worth further investigation. In fact, sprinting can be primarily seen as an evidence of power – given the importance of displacement velocity, i.e. speed - rather than of force (produced by muscular strength) *per se*, even if the latter influences the former by definition. Similarly, great importance must be given to power compared to the athlete's body weight.

Correlation between leg strength and sprint performance has been extensively investigated, with significant results. Weyand et al. (2000) found that runners reach faster top speeds applying greater support forces to the ground, and not repositioning their legs more quickly. Still, most of the studies focus on short distances (<100 m) and starting speed, which are closely related to performances in field-based sports, like soccer, rugby, American football etc. Wisløff et al. (2004) found a strong correlation between maximum squat strength, jumping height and performance in short sprints (10 m and 30 m) in elite soccer players. Comfort et al. (2014) studied a sample of young soccer players and found a strong correlation between absolute maximal squat strength and sprint performance in the 5 m and jump height. Relative strength instead was more correlated to sprinting performance in the 20 m.

Cronin and Hansen (2005) found non-significant correlations between absolute strength and sprinting speed in a sample of professional rugby players. Significant correlations were instead found between jump heights, relative power and sprinting performance. The authors conclusions are that increasing power-to-weight ratio and plyometrics can be more effective than absolute strength training in improving speed in well-trained athletes. Cunningham et al. (2013) measured maximal leg strength by means of the squat and lower body power by means of the countermovement jump in a sample of professional rugby players. Both relative strength and relative power were significantly correlated with 10 m sprint performance, confirming the findings of the preceding study. Kirkpatrick and Comfort (2013) found similar results in sample of junior elite rugby

players: relative squat strength was significantly correlated to sprint performance in the 10 m, 20 m and 40 m.

McBride et al. (2009) found a significant correlation between 10 yard and 40 yard sprint times and relative leg strength, measured as squat 1RM/BW, in a sample of American football players. Similarly, Requena et al. (2011) found a significant correlation between relative squat strength (1RM/BW) and sprint performances in distances up to 80 m.

Young et al. (1995) found a correlation between several measures of absolute and relative strength and speed-strength in a sample of elite young track and field athletes. In particular, they found that the best predictor of starting speed (2.5 m time) was relative maximal strength, while absolute maximal strength was more correlated to running speed (50 m) than starting ability. Bret et al. (2002) found a significant correlation between maximal strength in the half squat, countermovement jump and 100 m performance in a sample of male sprinters. The half squat proved to be the better predictor. Mangine et al. (2013) found significant correlations between 30 m sprint time, peak and relative power (measured by means of a non-motorized treadmill) and peak vertical jump power in a sample of active individuals (men and women, non-professional athletes). According to Comfort et al. (2012), increases in both absolute and relative strength were reflected in improved running performances in short sprints up to 20 m.

The present study confirms the strong correlations between both absolute and relative strength and running speed, also in longer sprints (100 m and 200 m). However, a non-ballistic movement like the squat, allowing to lift heavy weights at low speed, seems to be more correlated to performance in the 100 m, where starting ability is crucial, than in the 200 m. Ballistic, high-speed Olympic lifts instead seem to be more correlated to performance in the 200 m, where flying speed is more relevant than in the 100 m. These findings needs further investigation.

In the cited studies, the correlation between jumping and sprinting was investigated only for vertical jumps (squat jump, countermovement jump and the like) as in Smirniotou et al. (2008), who found a strong correlation between jumping height and sprint performance in the 100 m. Dal Pupo et al. (2013) found a correlation between vertical jumps and longer sprints (200 m and 400 m). Correlation between sprinting speed and standing long jump was not investigated. One notable exception is Kale et al. (2009), who took into consideration the standing long jump as a predictor of sprint performance in the 100 m. Still, they found that drop jump height reflects maximum speed during sprint running more closely than other vertical and horizontal jump tests. The present study has found a highly significant correlation between standing long jump and performance in both 100 m and 200 m.

While the athletes' sprint performances were checked on the official Italian track-and-field web site and their anthropometric data were collected by qualified professionals on-the-spot, strength-related data were recorded on the basis of the athletes personal

declarations. This fact can be the main limitation of our research. Even without taking into consideration the conflicting needs of *ego* and *bona fide*, in some cases it can be difficult, out of an official competition, to assess the real 1RM of an exercise. In the squat for example, the depth of the lift can change significantly the outcome of the test. This should not be the case with the Olympic lifts, where weights are lifted from the ground to lockout position. Still, not all sprinters perform these lifts or focus on them equally. In some cases, the projected maximum was used, which was calculated by means of the relationship between a low number of repetitions and 1RM. Therefore, the real 1RM may slightly differ from the tested one.

Nonetheless, the present study confirms the strong relationship between strength and sprint performance, enhancing the understanding of the peculiarity of such correlation with the two main sprinting events. Also the relationship between jumping ability and running speed was addressed, taking into consideration the standing long jump – and not the more popular but less easy to assess vertical jump - as a fundamental measure of relative power, which proved to be a good predictor of sprinting ability in both the 100 m and the 200 m.

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## 7. Conclusions

The original researches presented in this dissertation have highlighted the importance of kinanthropometry in somatotyping and in the assessment of body composition, in particular of body fatness, relatively to sport performance or practice and health. Physical activity has proved to have a positive correlation with body composition and therefore with general health, especially for what concern cardiovascular- and metabolic-related parameters, like body fat percentage. While the prevalence of the mesomorphic somatotype component in the athletes assessed by the presented studies can be sport-related, the observed low levels of body fatness seem to be a pre-requisite for top performance in many disciplines and a consequence of dedicated training.

Anthropometric indices like BMI or WSR are easy, non-invasive and cheap to measure, and for these reasons they are popular means for the evaluation of adiposity. Nonetheless, they have demonstrated a low reliability. In particular, in the general population, BMI has low sensitivity (i.e. a high percentage of misses, overweight people who do not fall into the overweight category), while specificity (i.e. the percentage of overweight people who are actually overfat) is usually good. The opposite is true for the athletic - or simply physically active - population, where individuals with a large body mass, mainly because of muscle hypertrophy, can be classified as overweight by means of the BMI, while they are actually false positives (i.e. false alarms). In both active and general population, positive predictive value is poor.

This is evident at least when they are compared to other conventional indirect methods of body fatness assessment, like those based on skinfold thicknesses, which are more precise – even if not gold-standard - but more cumbersome, requiring specific training and skills. Therefore, further research is needed in order to find a proper replacement for the traditionally and most frequently adopted proxies of adiposity. In my opinion, any approach which cannot discriminate between fat and fat free mass, at least approximately, will not solve this problem.

The presented studies have explored the practice of disciplines involving strenuous efforts (as it often happens in sport practice), like weight lifting, mountaineering and sprint running. While it is obvious that any kind of physical activity will bring some benefits, at least when compared to a sedentary life style, athletes involved in repeated, intense physical efforts have shown very low levels of body fatness. Therefore, conventional advices on physical activity focusing on long, moderate and frequent endurance-oriented sessions seem to be less effective and efficient than intense, low volume, power-oriented forms of sport like body building and sprinting, especially when it comes to improved body composition, in terms of low fat mass and high fat free mass. It must be noted that most up-to-date medical and fitness organizations have already taken into consideration the opportunity for shorter, more intense efforts in their general advices on physical activity.

In conclusion, further research is needed in order to improve the assessment of body composition in a feasible way, and the understanding of the reciprocal interaction between physical activity, health and sport performances. Innovative kinanthropometric methods may help physicians – and general practitioners in particular – to easily and accurately assess the health status of their patients, at least for what concern their levels of adiposity. Further, kinanthropometry may help sport coaches to quantify the effects of training and physical characteristics for morphometric optimization. Focused biomechanics assessments may help personal trainers and fitness professionals to evaluate the real effects and benefits of physical activity on their athletes.