TESIS DOCTORAL EUROPEA / EUROPEAN DOCTORAL THESIS

# ESTUDIO DE LOS PERFILES ANTROPOMÉTRICO Y NUTRICIONAL EN DEPORTISTAS DE ELITE

# STUDY OF THE ANTHROPOMETRIC AND NUTRITIONAL PROFILES IN ELITE ATHLETES


DEPARTAMENTO DE EDUCACIÓN FÍSICA Y DEPORTIVA

FACULTAD DE CIENCIAS DEL DEPORTE

UNIVERSIDAD DE GRANADA

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**2015**

Editor: Universidad de Granada. Tesis Doctorales
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ISBN: 978-84-9125-392-1
URI: http://hdl.handle.net/10481/41559

*A mis padres, Antonio y Antonia, por vuestro continuo apoyo y esfuerzo desinteresado, muchas veces más allá de lo que cabría pensar y anteponiendo el desarrollo de vuestros hijos a vuestras propias necesidades. Ello me ha permitido llegar hasta aquí.*

*A mis hermanos, Adolfo y Mónica, porque a pesar de no pertenecer al ámbito académico y que en ocasiones no os haya sido fácil entender mis pasos a seguir, siempre he sentido vuestro apoyo.*

*GRACIAS POR ESTAR SIEMPRE AHÍ*

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CERTIFICA:

Que la Tesis Doctoral titulada "Estudio de los perfiles antropométrico y nutricional de deportistas de elite" que presenta D. **Cristóbal Sánchez Muñoz** ha sido realizada bajo mi dirección, habiendo concluido y reuniendo a mi juicio las condiciones de originalidad y rigor científicas requeridas, autorizo su presentación y defensa ante el Tribunal que designe la Universidad de Granada.

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CERTIFYS:

That the Doctoral Thesis entitled "Anthropometric and nutritional profiles study of elite athletes" presented by **Cristóbal Sánchez Muñoz** has been done under my tutelage. This Doctoral Thesis proves that the PhD candidate has gained expertise through the process in both the field work as well as reporting data in a scientific manner. Therefore, I firmly believe that Cristóbal Sánchez Muñoz is an excellent candidate for a PhD award.

Karen Williams

In Manchester, UK, October 16th 2015

El doctorando CRISTÓBAL SÁNCHEZ MUÑOZ y los directores de la Tesis Doctoral MIKEL ZABALA DÍAZ y KAREN WILLIAMS, garantizamos, al firmar el presente documento, que el trabajo ha sido realizado por el doctorando bajo la dirección de los directores de la tesis y hasta donde nuestro conocimiento alcanza, en la realización del trabajo, se han respetado los derechos de otros autores a ser citados, cuando se han utilizado sus resultados o publicaciones.

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# ESTUDIO DE LOS PERFILES ANTROPOMÉTRICO Y NUTRICIONAL EN DEPORTISTAS DE ELITE

## STUDY OF ANTHROPOMETRIC AND NUTRITIONAL PROFILES IN ELITE ATHLETES

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# RESÚMEN


El proceso de identificación de talentos deportivos y su desarrollo juegan un papel fundamental en la búsqueda de la excelencia deportiva. Los atletas se caracterizan por una combinación de características antropométricas, composición corporal y somatotipo que se cree que influyen en la probabilidad de éxito en un deporte determinado. Dada la importancia de estas variables corporales junto con la nutrición para el rendimiento y la salud del deportista en un deporte determinado, es necesario determinar los perfiles antropométricos y nutricionales de deportistas de elite con el fin de conocer y establecer un marco de referencia que ayude a los entrenadores a la identificación de talentos para una especialidad deportiva, así como para mejorar el rendimiento de los atletas a la vez que mantienen un estado saludable.

En este contexto, el objetivo general de esta Tesis Doctoral fue determinar las características antropométricas, la composición corporal y el somatotipo de deportistas de elite de algunas especialidades, así como establecer relaciones con determinados aspectos nutricionales relacionados con el rendimiento deportivo.

Los principales hallazgos y conclusiones fueron: a) se han utilizado una variedad de técnicas antropométricas en la identificación de talentos en diferentes tipos deportes; b) se han descrito las características antropométricas, la composición corporal y el somatotipo de los jugadores junior de tenis de elite; c) no se observaron diferencias significativas en ningún item medido entre los jugadores mejor clasificados y el resto, no siendo así en el caso de las tenistas; d) se ha establecido una tabla de perfil antropométrico para los jugadores de tenis de elite; e) se ha descrito el perfil antropométrico de los ciclistas de bicicleta de montaña Olímpica de diferentes niveles competitivos; f) existen diferencias físicas entre los ciclistas de bicicleta de montaña en función del nivel competitivo; g) Los hábitos alimentarios de los ciclistas de categorías cadete/junior de la selección española de bicicleta de montaña no son los más adecuados. Se requiere un mayor trabajo de formación, control y orientación nutricional, especialmente en los más jóvenes; h) se ha descrito la ingesta nutricional, la composición corporal y el perfil bioquímico de ciclistas profesionales durante una carrera de cuatro etapas; i) la ingesta de todos los micronutrientes durante la carrera de cuatro etapas excedieron las recomendaciones dietéticas, excepto en el caso del folato y del potasio; j) se observaron modificaciones en la composición corporal y en los parámetros bioquímicos de los ciclistas profesionales en una prueba de cuatro etapas.

## SUMMARY


Sport talent identification process and its development play a key role in the seek of sport performance excellence. Athletes are characterized by a combination of anthropometrical characteristics, body composition and somatotype, that are believed to affect success probability in specific sports.

Because of the importance of these body variables together with nutrition to get the best development of performance and health status in an specific sport, it is necessary to determine the anthropometrical and nutritional profiles in elite athletes with the aim of knowing and establishing a reference framework that could help the coaches in the talent identification process, as well as to improve athletes' performance and also to maintain their health status.

In this context, the general aim of this PhD dissertation was to determine the anthropometrical characteristics, body composition and somatotype of elite athletes in some sport specialties, as well as to establish relations with certain nutritional aspects related to sport performance.

The main findings and conclusions were: a) a variety of anthropometrical techniques have been used for talent identification in different sports; b) the anthropometric characteristics, body composition and somatotype of elite junior tennis players are presented; c) no significant differences were observed in any measured item for the males between the first and the lower ranked elite male junior tennis players, although his was not the case of the female in which significant differences were observed; d) anthropometric profile charts for elite junior tennis players are established; e) the anthropometric profiles of male Olympic cross country mountain bikers at different competitive levels are presented; f) physical differences in Olympic cross country mountain bikers have been observed according to their competitive levels; g) feeding habits of the cadet/junior cyclists of Spanish national mountain bike team are considered inadequate. It is recommended specific work on nutritional formation, control and orientation, especially with the youngest; h) the nutritional intake, body composition, and biochemical profile of the professional cyclists in a four-stage race are presented; i) intake of all micronutrients, except for folate and potassium, exceeded the recommended dietary allowances; j) variations in body composition and biochemical parameters were observed in a four stage professional cycling tour.

Con la evolución del deporte competitivo y la gran profesionalización en los últimos años, así como la búsqueda de la excelencia, el proceso de identificación de talentos deportivos y su desarrollo juegan un papel crucial, fundamentalmente en determinados deportes (gimnasia, natación,…) en los cuales es importante que el talento sea identificado de forma temprana en la carrera deportiva [5, 32]. Los elementos que forman parte del proceso de identificación de talentos y que se han reconocido para programas de éxito son los siguientes [2]: 1) el conocimiento de los aspectos importantes para el éxito en la competición; 2) la recogida de un conjunto de datos sobre un deportista; 3) la recopilación de un conjunto de datos normativos o comparativos; 4) el uso de estos datos para construir un perfil específico de un atleta y 5) la interpretación del perfil para guiar el proceso de selección o servir de base para un programa de entrenamiento en marcha.

Los programas de identificación de talentos suelen monitorizar varios aspectos, uno de los cuales se desarrolla mediante la cineantropometría, entendida como el estudio del tamaño humano, la forma, la proporción, la composición y la maduración para ayudar en la evaluación del crecimiento y de los efectos del ejercicio, el rendimiento y la nutrición [13]. Los atletas se caracterizan por una combinación de características de composición corporal / tamaño corporal que se cree que influyen en la probabilidad de éxito en un deporte determinado [36]. También está claro que el éxito en el deporte es multifactorial [35, 41] y que el valor de las medidas antropométricas para ayudar en la identificación del talento o predicción del éxito varía entre deportes [8, 9, 14] y dentro de un mismo deporte [27, 30, 45]. Por ello, es evidente que la medición cineantropométrica es una herramienta crucial en la búsqueda de información para asistir a los entrenadores y atletas en la obtención del éxito al más alto nivel en el deporte, sirviendo de referencia sobre el resultado del entrenamiento realizado (por ejemplo para comprobar si se aumentan o disminuyen fundamentalmente los componentes graso y/o muscular y en qué medida absoluta y/o relativa) [12, 16, 33].

Desde hace décadas, un gran número de estudios han determinado los perfiles antropométricos, físicos y motores de atletas de diferentes deportes [4, 23, 37, 42, 43], siendo relacionados algunos de ellos con parámetros de rendimiento con el fin de determinar los mejores predictores de rendimiento en dichas especialidades [3, 16, 21, 34]. Estos parámetros de rendimiento antropométricos deben ayudar a los entrenadores y preparadores físicos para definir una base objetiva para la identificación de talentos y ofrecer perspectivas de entrenamiento para la obtención del mejor desempeño. Por otro lado, estos valores criterios que determinan el rendimiento deberían permitir reorientar al atleta hacia una práctica deportiva en otra disciplina dentro del mismo deporte o incluso hacia otros deportes para los cuáles podría conseguir la excelencia. Por ello, es importante conocer cuáles son los atributos antropométricos, de composición corporal y del somatotipo predictores del rendimiento deportivo en determinadas especialidades investigadas en jóvenes deportistas (**Aportación I**), así como determinar aquellos perfiles de deportes que aún no han sido analizados (**Anexo**) o teniendo en cuenta el nivel de rendimiento (**Aportación II**).

Las primeras investigaciones del ámbito asociaron la naturaleza hereditaria de características fisiológicas, antropométricas y psicológicas con el rendimiento deportivo [10, 11]. Estos estudios determinaron las características antropométricas de los atletas olímpicos y se abogó por una estrecha relación entre las características físicas y eventos olímpicos específicos. De acuerdo con esta línea de trabajo es posible determinar los perfiles antropométricos, de composición corporal y del somatotipo de deportistas de elites adultos y relacionarlos con el nivel de rendimiento para conocer los predictores de rendimiento en el deporte participante (**Aportación III**). Estos perfiles también serán de ayuda a entrenadores y preparadores para la orientación del entrenamiento para alcanzar los valores óptimos en las variables predictores de la excelencia en el caso que sea posible y de interés en función del momento de la temporada deportiva.

Por otro lado, se ha demostrado que una nutrición adecuada, junto con la composición corporal, juega un papel clave en la optimización del rendimiento deportivo y en el mantenimiento de la salud [24, 28, 39]. El conocimiento y la evaluación precisa de los hábitos alimentarios y de la ingesta dietética de los atletas en los diferentes deportes durante el entrenamiento y la competición es necesario para comparar la energía ingerida, los nutrientes y la hidratación con las recomendaciones para el deporte en cuestión [7, 19] y proporcionar un asesoramiento y planteamiento nutricional adecuado. Para ello, numerosos estudios han evaluado y determinado el perfil nutricional de los atletas de diferentes actividades deportivas [6, 15, 18, 20, 26, 44], siendo necesario investigar lo que ocurre en otros grupos de atletas para optimizar el rendimiento deportivo en el entrenamiento (**Aportación IV**) y la competición (**Aportación V**), para así mantener el estado de salud y que el mejor rendimiento deportivo pueda ser alcanzado. Las propuestas nutricionales para deportistas de alto rendimiento se deben realizar utilizando los resultados de investigaciones llevadas a cabo en circunstancias similares a las de entrenamiento y competición de estos deportistas, dependiendo las necesidades nutricionales y la ingesta calórica en función del momento de la temporada en la que se encuentre o los tipos de entrenamiento o competición a desarrollar. Existen diferentes métodos para evaluar el estado nutricional de un individuo, entre las que se encuentra la valoración de la composición corporal, así como un consenso de que debido a su complejidad, la combinación de diferentes métodos asegura una obtención de datos útiles y fiables para saber cómo proceder en la intervención dietética y nutricional [29].

Por último, la composición corporal es un factor que puede influir en el rendimiento deportivo y en la salud del deportista [1], con lo cual es de gran interés para los atletas y entrenadores. En cuanto al rendimiento, en muchos deportes el peso corporal y la composición corporal son variables de rendimiento cruciales, fundamentalmente en los deportes gravitacionales y de resistencia, donde el exceso de peso corporal se asocia con una desventaja competitiva [22, 31, 40]. Lo mismo ocurre en aquellos deportes en los que las categorías de competición se determinan en base al peso corporal de los deportistas [38]. En el ámbito de la salud, un bajo peso y/o baja grasa corporal son factores de riesgo para la salud de los deportistas, más aún cuando se combinan con una dieta extrema y trastornos de la alimentación. Además, los deportistas que mantienen una baja ingesta de energía durante un tiempo pueden tener deficiencias de nutrientes, fatiga crónica y un mayor riesgo de infecciones y enfermedades, lo cual favorece un potencial daño para la salud y una reducción del rendimiento. Por ello, por un lado es importante saber cómo varían los diferentes componentes de la composición corporal con la edad, el sexo, el estado de madurez, así como conocer la influencia del entrenamiento sistemático y el momento de la temporada, siendo muy importante tener la capacidad de evaluar la composición corporal del atleta con exactitud, precisión y fiabilidad.

Desde principios de la década de 1980, se han propuesto una gran variedad de técnicas y métodos para estimar la composición corporal, pero todas tienen algunos problemas inherentes, ya sea en la metodología de medición, en la interpretación de los datos o en los supuestos que las fundamentan, no existiendo a día de hoy una metodología de aplicación universal. Uno de los métodos de valoración de la composición corporal más usados es el método antropométrico, debido a su bajo costo, a su relativa facilidad en la toma de datos y a la posibilidad de realizar la toma de datos en el lugar de entrenamiento o competición [1]. Es un método práctico y requiere un equipo limitado, dependiendo su mayor fiabilidad del correcto entrenamiento de los técnicos y que los protocolos estén bien estandarizados, como es el caso del protocolo cada vez más utilizado y globalizado de la ISAK (Sociedad

Internacional para el Avance de la Cineantropometría) [25]. El error de medición se debe en parte al instrumental utilizado y a la ecuación utilizada para determinar la densidad corporal, a través de la cual se estima el porcentaje de grasa corporal. Además, uno de los mecanismos para reducir el error de medición es el uso de los datos en bruto como los pliegues cutáneos individuales, la suma de los pliegues cutáneos o ratios de pliegues cutáneos. Existen otros métodos de laboratorio para la evaluación de la composición corporal, pero el costo y las limitaciones técnicas de la metodología necesaria a menudo limitan su aplicabilidad en el ámbito deportivo.

## INTRODUCTION

The evolution of competitive sport and the professionalization reached in the latest years, as well as the seek of performance excellence, the process of talent identification in sport and its development, play a crucial role especially in some sports (gymnastics, swimming…) in which it is very important that this talent identification is done the sooner possible [5, 32]. The elements that are part of talent identification and that have been recognized in successful programs are the following [2]: 1) knowledge of the most important factors associated with success in sport competitions; 2) collection of data of the athlete; 3) collection of a database that are normative and reference; 4) the use of data to build a specific profile of an athlete; 5) the interpretation of the reached profile to guide the process of selection or to serve as the base for a training program going on.

Talent identification programs use for monitoring various aspects, one of them is the one developed by kineanthropometry, as the study of the human size, form, proportion, composition and maturity to help in the assessment of the growth and the effects of exercise, performance, and nutrition [13]. Athletes are characterized by a combination of characteristics of body composition/size that are believed to affect the probability of success in a specific sport [36]. It is also clear that sport success is multifactorial [35, 41] and that the value of anthropometrical measurements that can help in talent identification or to predict sport success may vary among sports [8, 9, 14] and within a specific sport [27, 30, 45]. So, it is evident that kineanthropometrical measurement is a crucial tool to assess and assist coaches and athletes in the seek of sport success at the highest level, serving as a reference of the result of developed training (for example to analyse if there has been an increase or decrease of fat and/or mass components and in which absolute and/or relative quantity) [12, 16, 33].

Decades ago, a great number of studies have determined anthropometrical, physical and motor profiles of athletes of different sports [4, 23, 37, 42, 43], being those related to other performance-related parameters with the aim of determining the best predictors of the best performance in each sport or discipline [3, 16, 21, 34]. These anthropometrical parameters should help the coaches and physical trainers on defining objectively talent identification and offering training perspectives to obtain the best result. Also, these values and information that determine performance should allow the athlete to be directed to a specific sport practice or another discipline within the same sport, or even to a completely different sport in which the athlete could apply his/her more suitable potential characteristics that theoretically would match better with the sport requirements. So, it is important to know which are the anthropometrical characteristics, body composition and somatotype as predictors of sport success among specific sports in young athletes (**Contribution I**), as well as to determine those profiles in sports that have not been studied in the past (**Annex**), or taking into account performance level (**Contribution II**).

The pioneer investigations in the matter associated hereditary characteristics such as those physiological, anthropometrical, and psychological, to sport performance and success [10, 11]. Those studies determined anthropometrical characteristics of Olympic athletes suggesting there was a close relationship between them and specific Olympic events. In agreement with this, it is possible to determine anthropometrical, body composition and somatotype profiles of elite adult athletes to know the predictors of sport performance and success in specific sports (**Contribution III**). These profiles would be helpful also for coaches and physical trainers in their training orientation process to reach the optimal values in the predictor variables of excellence (in the case this is possible), and of interest in relation to the specific moment of the season.

On the other hand, it has been demonstrated that an appropriate nutrition, together with a body composition assessment, plays a key role in the optimization of sport performance and in the maintenance of health status [24, 28, 39]. The knowledge and precise evaluation of the feeding patterns and food ingestion of the athletes in different sports during training and competition, is necessary to check energy intake, nutrients, and hydration recommended for the specific sport and specific athlete [7, 19] to guide the best nutritional program possible. For this purpose, several studies have evaluated and determined the specific nutritional profile in varying sports [6, 15, 18, 20, 26, 44], showing that it is necessary to investigate what is going on in other sports and athletes to improve sports performance during training (**Contribution IV**) and competition (**Contribution V**), so that health status can be maintained and the better performance can be reached. Nutritional proposals for high performance athletes should be done using the previous research developed in similar circumstances to those during training and competition for these kind of athletes, depending on nutritional requirements and calorie intake on the base of the moment of the season in which training load and content during training and/or competitions is being done. There are several methods to assess nutritional status of an individual, among we highlight body composition assessment, and the consensus that, because of its complexity, the combination of different methods guarantees a useful and reliable data collection to know how to proceed in the nutritional intervention [29].

Finally, body composition is a factor that may affect sport performance and also athlete's health status [1], so this variable it is of great interest for athletes and coaches. Regarding sport performance, in many sports body weight and body composition are crucial performance variables, mainly in those sports in which gravity and endurance take part, where a higher body weight is associated with a performance disadvantage [22, 31, 40]. Also, it is of great interest in those sports in which competing categories are decided taking into account body weight [38]. In the field of health, too low body weight and/or body fat are risk factors of their health, especially in combination with an extreme diet and/or eating disorder. Also, athletes that maintain a low energy ingestion among time could have deficiencies of nutrients, chronic fatigue, and a higher risk of illness or infection process. So, it is important to know how body composition components vary with age, sex, maturity, as well as to know how the effect of a systematic training among the season, being very important to know how to evaluate body composition of the athlete with validity, reliability, and precision.

Since the 1980s, a great variety of techniques and methods to estimate body composition have been proposed, but all present inherent problems in measurement methodology, data interpretation, or in the foundations that sustain them, so that there is no nowadays a single and universal methodology. In this regard, one of the most used methods to assess body composition is the anthropometrical method, because of its low cost, relative easy data collection, and the possibility to repeat measurements as many times required and in the place that athletes train or compete -almost anywhere- [1]. This is a practical method that requires a few and relatively cheap tools, which reliability depends more in the appropriate training of the observers and the use of the standardized protocols like the one of ISAK (International Society for the Advance of Kineanthropometry) that is taken as the globalized “gold standard” [25]. Also the error of measurement in part could be due to the tools used, and later to the equation used to calculate body density that is used to estimate the percentage of body fat. Also, one of the mechanisms to reduce the measurement error is the use of the raw data like each skinfold, the sum of skinfolds or the ratio of skinfolds. There are other laboratory methods to assess body composition, but the cost and technical limitations of the methodology needed is many times a problem to apply them in the sport context.

**General:**

El objetivo general de esta Tesis Doctoral fue conocer las características antropométricas, la composición corporal y el somatotipo de deportistas de elite de algunas especialidades, así como establecer relaciones con determinados aspectos nutricionales relacionados con el rendimiento deportivo.

**Específicos:**

- Exponer algunas de las técnicas cineantropométricas que se utilizan en la identificación de talentos con alguna evidencia de cómo han sido utilizadas en una variedad de deportes (**Aportación I**).

- Describir las características antropométricas, la composición corporal y el somatotipo de jugadores junior de tenis de elite (masculinos y femeninos) (**Aportación II**).

- Comparar los datos antropométricos, la composición corporal y el somatotipo de los 12 primeros jugadores de tenis de elite en el ranking con los ranqueados más bajos (**Aportación II**).

- Establecer una tabla de perfil antropométrico para jugadores de tenis de elite (**Aportación II**).

- Describir el perfil antropométrico de los ciclistas de bicicleta de montaña olímpica (**Aportación III**).

- Comparar las características antropométricas, la composición corporal y el somatotipo de ciclistas de bicicleta de montaña olímpica de diferentes niveles competitivos, con el fin de determinar alguna variable predictor del rendimiento (**Aportación III**).

- Determinar los hábitos alimentarios de los ciclistas de la selección española de bicicleta de montaña (**Aportación IV**).

- Describir la ingesta de alimentos, la composición corporal y el perfil bioquímico de ciclistas profesionales durante una carrera de cuatro etapas (**Aportación V**).

- Evaluar la adecuación de la ingesta de nutrientes en relación con las recomendaciones actuales para los atletas de resistencia (**Aportación V**).

- Analizar los cambios corporales y bioquímicos de ciclistas profesionales en una carrera de cuatro etapas (**Aportación V**).

## AIMS

### Overall:

The overall aim of this PhD Thesis was to determine the anthropometric characteristics, body composition and somatotype of elite athletes in some sport specialties, as well as to establish relations with certain nutritional aspects related to sport performance.

### Specific:

- To cover some of the kinanthropometry techniques that are used in the talent identification with some evidence of how they have been used in a variety of sports (**Contribution I**).
- To describe the anthropometric characteristics, body composition and somatotype of elite male and female junior tennis players (**Contribution II**).
- To compare the anthropometric data, body composition and somatotype of the first 12 elite junior tennis players on the ranking with the lower ranked players (**Contribution II**).
- To establish an anthropometric profile chart for elite junior tennis players (**Contribution II**).
- To describe the anthropometric profile of male Olympic cross country mountain bikers (**Contribution III**).
- To compare the anthropometric characteristics, body composition and somatotype of male Olympic cross country mountain bikers at different competitive levels, with the aim of determining anthropometric predictor variables of performance (**Contribution III**).
- To determine the feeding habits of the cyclists of the Spanish mountain bike national team (**Contribution IV**).
- To describe the food intake, body composition, and biochemical profile of professional cyclists during a four-stage race (**Contribution V**).

- To evaluate the adequacy of nutrient intake in relation to the current recommendations for endurance athletes (**Contribution V**).

- To analyze body and biochemical changes of professional cyclists in a four-stage race (**Contribution V**).

## REFERENCIAS [References]


1. Ackland TR, Lohman TG, Sundgot-Borgen J, Maughan RJ, Meyer NL, Stewart AD, Müller W. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc research working group on body composition health and performance, under the auspices of the I.O.C. Medical Commission. Sports Med 2012; 42(3):227-249.
2. Ackland TR. Built for success: homogeneity in elite athlete morphology. In: Marfell-Jones M, Olds T, Stewart A, editors. *Kinanthropometry IX: Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry*. London: Routledge; 2006. p. 26-34.
3. Alcaraz PE, Abraldes JA, Ferragut C, Vila H, Rodríguez N, Argudo FM. Relationship between characteristics of water polo players and efficacy indices. J Strength Cond Res 2012; 26(7):1852-1857.
4. Alejandro V, Santiago S, Gerardo VJ, Carlos MJ, Vicente GT. Anthropometric characteristics of Spanish professional basketball players. J Hum Kinet 2015; 46:99-106.
5. Allen SV, Vandenbogaerde TJ, Pyne DB, Hopkins WG. Predicting a nation's olympic-qualifying swimmers. Int J Sports Physiol Perform 2015; 10(4):431-435.
6. Alves CR, Pasqua L, Artioli GG, Roschel H, Solis M, Tobias G, Klansener C, Bertuzzi R, Franchini E, Lancha Junior AH, Gualano B. Anthropometric, physiological, performance, and nutritional profile of the Brazil National Canoe Polo Team. J Sports Sci 2012; 30(3):305-311.
7. American College of Sports Medicine, Rodriguez NR, Di Marco NM, Langley S. American College of Sports Medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc 2009; 41(3):709-731.
8. Bayios IA, Bergeles NK, Apostolidis NG, Noutsos KS, Koskolou MD. Anthropometric, body composition and somatotype differences of Greek elite female basketball, volleyball and handball players. J Sports Med Phys Fitness 2006; 46(2):271-80.
9. Brunkhorst L, Kielstein H. Comparison of anthropometric characteristics between professional triathletes and cyclists. Biol Sport 2013; 30(4):269-273.
10. Carter JEL. Physical Structure of Olympic Athletes. Part I: The Montreal Olympic Games Anthropological Project. Basel: Karger; 1982.
11. Carter JEL. Physical Structure of Olympic Athletes. Part II: Kinanthropometry of Olympic Athletes. Basel: Karger; 1984.

12. Duthie GM, Pyne DB, Hopkins WG, Livingstone S, Hooper SL. Anthropometry profiles of elite rugby players: quantifying changes in lean mass. Br J Sports Med 2006; 40(3):202-207.
13. Eston R, Reilly T. Kinanthropometry and exercise physiology laboratory manual: test, procedures and data. Oxon: Routledge; 2009.
14. Gabbett T, Georgieff B, Domrow N. The use of physiological, anthropometric and skill data to predict selection in a talent-identified junior volleyball squad. J Sports Sci 2007; 25(12):1337-1344.
15. García-Rovés PM, Fernández S, Rodríguez M, Pérez-Landaluce J, Patterson AM. Eating pattern and nutritional status of international elite flatwater paddlers. Int J Sport Nutr Exerc Metab 2000; 10:182-198.
16. Gilinsky N, Hawkins KR, Tokar TN, Cooper JA. Predictive variables for half-Ironman triathlon performance. J Sci Med Sport 2014; 17(3):300-305.
17. Hammami MA, Ben Abderrahmane A, Nebigh A, Le Moal E, Ben Ounis O, Tabka Z, Zouhal H. Effects of a soccer season on anthropometric characteristics and physical fitness in elite young soccer players. J Sports Sci 2013; 31(6):589-596.
18. Iglesias-Gutiérrez E, García-Rovés PM, Rodríguez C, Braga S, García-Zapico P, Patterson AM. Food habits and nutritional status assessment of adolescent soccer players. A necessary and accurate approach. Can J Appl Physiol 2005; 30(1):18-32.
19. Jeukendrup AE. Nutrition for endurance sports: marathon, triathlon, and road cycling. J Sports Sci 2011; 29 Suppl 1:S91-S99.
20. Juzwiak CR, Amancio OM, Vitalle MS, Pinheiro MM, Szejnfeld VL. Body composition and nutritional profile of male adolescent tennis players. J Sports Sci 2008; 26(11):1209-1217.
21. Kerr RM, Spinks W, Leicht AS, Sinclair W. Predictors of 1000-m outrigger canoeing performance. Int J Sports Med 2008; 29(8):675-678.
22. Legaz Arrese A, González Badillo JJ, Serrano Ostáriz E. Differences in skinfold thicknesses and fat distribution among top-class runners. J Sports Med Phys Fitness 2005; 45(4):512-517.
23. Lovera M, Keogh J. Anthropometric profile of powerlifters: differences as a function of bodyweight class and competitive success. J Sports Med Phys Fitness 2015; 55(5):478-487.
24. Lukaski HC. Vitamin and mineral status: effects on physical performance. Nutrition 2004; 20:632-644.

25. Marfell-Jones M, Olds T, Stewart A, Carter L, editors. International standars for anthropometric assessment. Potchefstroom, South Africa: ISAK; 2006.
26. Martínez S, Pasquarelli BN, Romaguera D, Arasa C, Tauler P, Aguiló A. Anthropometric characteristics and nutritional profile of young amateur swimmers. J Strength Cond Res 2011; 25(4):1126-1133.
27. Menaspà P, Rampinini E, Bosio A, Carlomagno D, Riggio M, Sassi A. Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. Scand J Med Sci Sports 2012; 22(3):392-398.
28. Meyer NL, Sundgot-Borgen J, Lohman TG, Ackland TR, Stewart AD, Maughan RJ, Smith S, Müller W. Body composition for health and performance: a survey of body composition assessment practice carried out by the Ad Hoc Research Working Group on Body Composition, Health and Performance under the auspices of the IOC Medical Commission. Br J Sports Med 2013; 47(16):1044-10553.
29. Mielgo-Ayuso J, Maroto-Sánchez B, Luzardo-Socorro R, Palacios G, Palacios Gil-Antuñano N, González-Gross M. Evaluation of nutritional status and energy expenditure in athletes. Nutr Hosp 2015; 31 Suppl 3:227-236.
30. Milanese C, Piscitelli F, Lampis C, Zancanaro C. Anthropometry and body composition of female handball players according to competitive level or the playing position. J Sports Sci 2011; 29(12):1301-1309.
31. Olds TS, Norton KI, Lowe EL, Olive S, Reay F, Ly S. Modeling road-cycling performance. J Appl Physiol 1995; 78(4):1596-1611.
32. Pion J, Lenoir M, Vandorpe B, Segers V. Talent in female gymnastics: a survival analysis based upon performance characteristics. Int J Sports Med 2015; 36(11):935-940.
33. Pyne DB, Anderson ME, Hopkins WG. Monitoring changes in lean mass of elite male and female swimmers. Int J Sports Physiol Perform 2006; 1(1):14-26.
34. Reilly T, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. J Sports Sci 2000;18(9):669-683.
35. Reilly T, Williams AM, Nevill A, Franks A. A multidisciplinary approach to talent identification in soccer. J Sports Sci 2000;18(9):695-702.
36. Robertson S, Woods C, Gastin P. Predicting higher selection in elite junior Australian Rules football: the influence of physical performance and anthropometric attributes. J Sci Med Sport 2015; 18(5):601-606.

37. Singh S, Singh M, Rathi B. Kinanthropometric and performance characteristics of elite and non-elite female softball players. J Sports Med Phys Fitness 2013; 53(6):628-634.
38. Sundgot-Borgen J, Garthe I. Elite athletes in aesthetic and Olympic weight-class sports and the challenge of body weight and body compositions. J Sports Sci 2011; 29 Suppl 1:S101-114.
39. Sundgot-Borgen J, Meyer NL, Lohman TG, Ackland TR, Maughan RJ, Stewart AD, Müller W. How to minimise the health risks to athletes who compete in weight-sensitive sports review and position statement on behalf of the Ad Hoc Research Working Group on Body Composition, Health and Performance, under the auspices of the IOC Medical Commission. Br J Sports Med 2013; 47(16):1012-1022.
40. Swain DP. The influence of body mass in endurance bicycling. Med Sci Sports Exerc. 1994; 26(1):58-63.
41. Vaeyens R, Lenoir M, Williams AM, Philippaerts RM. Talent identification and development programmes in sport : current models and future directions. Sports Med 2008; 38(9):703-714.
42. Vernillo G, Schena F, Berardelli C, Rosa G, Galvani C, Maggioni M, Agnello L, La Torre A. Anthropometric characteristics of top-class Kenyan marathon runners. J Sports Med Phys Fitness 2013; 53(4):403-408.
43. Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B. Anthropometry of young competitive sport rock climbers. Br J Sports Med 2003; 37(5):420-424.
44. Zalcman I, Guarita HV, Juzwiak CR, Crispim CA, Antunes HK, Edwards B, Tufik S, de Mello MT. Nutritional status of adventure racers. Nutrition. 2007; 23(5):404-411.
45. Zillmann T, Knechtle B, Rüst CA, Knechtle P, Rosemann T, Lepers R. Comparison of training and anthropometric characteristics between recreational male half-marathoners and marathoners. Chin J Physiol 2013; 56(3):138-146.

Los apartados “Material y métodos”, “Resultados” y “Discusión” se presentan a continuación en cada una de las aportaciones que componen la memoria de la presente Tesis Doctoral.

# MATERIAL, MÉTHODS, RESULTS AND DISCUSSION

Sections “Material and methods”, “Results” and “Discussion” are presented below for each contribution that constitutes the present Doctoral Thesis.

I

# ANTHROPOMETRIC VARIABLES AND ITS USAGE TO CHARACTERISE ELITE YOUTH ATHLETES

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**In: Preedy VR, editor. Handbook of Anthropometry: Physical Measures of Human Form in Health and Disease. Vol 3, Parts 15-21. New York: Springer; 2012. p. 1865-1888**

# Chapter 114
# Anthropometric Variables and Its Usage to Characterise Elite Youth Athletes

Cristóbal Sánchez-Muñoz, Mikel Zabala, and Karen Williams

**Abstract** Talent identification programs usually monitor several parameters, once of which is kinanthropometry. There are a variety of anthropometric techniques that are used in talent identification. With respect to youth sport performance, the focus of this chapter was upon the use of techniques to assist with talent identification and performance within the adolescent (from 8–18 years for girls and 10–22 years for boys) phase of growth as competitive sport is not a regular occurrence in children <8 years old. Using evidence from a variety of studies, information has been provided about how sports have used kinanthropometry for talent identification purposes taking into consideration physical growth and maturation, absolute size and proportionality, somatotyping and body composition. The sports covered include individual sports (cycling, figure skating, gymnastics, rock climbing, track and field), field sports (cricket, hockey, soccer), contact team sports (American football, Australian rules football, rugby), court sports (badminton, basketball, handball, netball, tennis, volleyball), weight classified sports (judo, taekwondo, sumo wrestling, weightlifting) and water sports (rowing, sprint kayaking, swimming). Athletes are characterised by a combination of body composition/body size traits which are believed to influence the chance of success in any given sport therefore it is suggested that the measurement of kinanthropometry is a crucial tool in the search for information to assist coaches and athletes in the quest for success at the highest level in sport.

**Abbreviations**

| | |
|---|---|
| ADP | Air displacement plethysmography |
| ARF | Australian Rules Football |
| BIA | Bioelectrical impedance analysis |
| BMI | Body mass index |
| % BF | Percentage body fat |
| % MM | Percentage muscle mass |
| $C_s$ | Swimming economy |

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V.R. Preedy (ed.), *Handbook of Anthropometry: Physical Measures of Human Form in Health and Disease*, DOI 10.1007/978-1-4419-1788-1_114,

DXA Dual-energy X-ray absorptiometry
FFM Fat free mass
H-C Heath-Carter method
SK Skinfold

## 114.1 Introduction

Ackland (2006) has written extensively about the talent identification process and has identified the following elements for successful programmes: (1) understanding the important aspects for success in competition, (2) recording a set of data on an athlete, (3) gathering a set of normative or comparative data, (4) using these data to construct a profile of an athlete and (5) interpreting the profile to guide the selection process or provide the basis for an ongoing training program.

Talent identification programs usually monitor several parameters, once of which is kinanthropometry. This is the study of human size, shape and form and how those characteristics relate to human movement and sporting performance (Eston and Reilly 2009). Ackland (2006) believes that the elements outlined above have not always been used in the most effective manner, with some talent identification programs running a large battery of tests without the importance of the selected parameters being taken into consideration. It is thought that, in certain situations, it may be better to measure fewer, but more discriminatory, variables. This is an approach which should be considered in the measure of anthropometrical measures, given the depth and breadth of techniques available. The aim of this chapter is to cover some of the kinanthropometry techniques that are used in the talent identification with some evidence of how they have been used in a variety of sports. For the purposes of its relation to youth sport and performance, the focus will be upon the techniques used within the adolescent (from 8 to 18 years for girls and 10 to 22 years for boys) phase of growth as competitive sport is not a regular occurrence in children <8 years old (Barker et al. 2009) (Table 114.1).

**Table 114.1** Key features of Kinanthropometry

1. Kinanthropometry is the study of human size, shape, proportion, composition and maturation to assist in the evaluation of growth and of the effects of exercise, performance and nutrition.
2. Kinanthropometry utilises a combination of anatomy and movement from which data are collated and body composition predictions applied to the measurement and description of the human physique.
3. Growth is a reference to the increase in size of the body as a whole or the size attained by the specific parts of the body.
4. Maturation is the process of achieving a fully mature biological state.
5. There is a possibility that training for sport can accelerate growth and maturation; however, there are also concerns about the possible negative effects of rigorous training on growth and maturation, particularly in females compared to males.
6. Size and proportionality can play a fundamental role in selection, particularly when considering height and weight.
7. Talent ID generally monitors morphological and skeletal maturation status in young athletes; however, there are a number of growth spurts and plateaus which can affect both selection and performance.
8. The shape and proportions of an athlete are an important feature in talent identification; therefore, to increase the chance of success in sport, children should be directed towards sports for which they are physically suited. This is referred to as “morphological optimisation.”

## 114.2 Physical Growth and Maturation

Growth is a reference to the increase in size of the body as a whole or the size attained by the specific parts of the body. The growth of the whole body is usually measured by assessment of changes in stature or by assessment of the specific parts of the body using appropriate anthropometric techniques (Beunen 2009). Maturation is the process of achieving a fully mature biological state. The predominant types of maturation that are monitored during talent identification are morphological and skeletal. The rate of development can differ significantly between individuals; however, selection bias of early maturers is a common occurrence in selection for sport based upon chronological age (Helsen et al. 2005). Rowley (1987) believed that, to be successful in sport at an international level, intensive training must begin before puberty. What must be considered, however, is the average age of elite competition. For example, gymnasts normally peak in their performance around 16 years of age compared to weightlifters who tend to peak around 30 years of age. This will affect the intensity and volume of training from a young age and can affect selection. It is believed that training for sport is important to support normal growth and maturation, although it has also been suggested that training for sport can accelerate growth and maturation (Malina et al. 2004). Moreover, there is concern about the possible negative effects of rigorous training on growth and maturation, particularly in females compared to males.

## 114.3 Size and Proportionality

With respect to success in specific sports, proportionality can play a fundamental role in selection. Height and body mass are two of the main discriminatory factors in selection for sport and subsequent success for both individual and team sports (see Tables 114.2–114.4). When considering height, there are two factors to consider. The first is success at sport during childhood, whereby, in the majority of sports, taller athletes are generally the more successful, although there are exceptions to this, such as in gymnastics, where a shorter stature is regularly a discriminatory factor (Malina et al. 2004). The second factor is prediction of adult height for talent identification. During adolescence, which is the growth phase we are concentrating on for this chapter, growth is fairly unstable. There are a number of growth spurts and plateaus which can affect both selection and performance. To attempt to overcome these, predictions of adult height have been developed and used through the years (Lowery 1978; Sherar et al. 2005).

**Table 114.2** Key features of Somatotyping

1. Somatotyping is a method whereby the body is described in terms of a number of traits that have a relation to body shape and composition.
2. It is a classification of three empirically determined and visually rated extremes of body build.
3. A somatotype of an athlete consists of a three-numeral rating, which describes the current morphological representation of an individual.
4. The three numerals represent the three components of the physique, endomorphy, mesomorphy and ectomorphy.
5. Endomorphy is a general indicator of an individual's adiposity level or "roundness."
6. Mesomorphy refers to the level of muscularity of an individual.
7. Ectomorphy is considered to be an indicator of linearity of an individual.
8. The higher the rating of each component, the more prevalent it is in an individual.
9. The results of somatotyping can be plotted on a somatochart, which allows the comparison between individuals and/or sports.

**Table 114.3** Somatotype scores for a variety of sports in youths

| Sport/position | *n* | Level | Age (y) | Endomorphy | Mesomorphy | Ectomorphy | Method | Reference |
|---|---|---|---|---|---|---|---|---|
| Individual sports | | | | | | | | |
| *Men* | | | | | | | | |
| Figure skating | 12 | Sub-elite | 18.2 ± 3.6 | 1.7 ± 0.3 | 5.0 ± 0.9 | 2.9 ± 0.6 | H-C | Ross et al. (1977) |
| Track and field: Hammer throwers | 5 | Elite | 19.0 ± 1.7 | 3.1 ± 0.4 | 6.0 ± 1.0 | 1.2 ± 0.8 | H-C | Kidd and Winter (1983) |
| *Women* | | | | | | | | |
| Figure skating | 18 | Sub-elite | 15.7 ± 1.6 | 2.6 ± 0.7 | 3.8 ± 0.6 | 3.0 ± 0.9 | H-C | Ross et al. (1977) |
| | 46 | Elite | 17.7 ± 2.2 | 3.3 ± 0.1 | 3.8 ± 0.1 | 2.7 ± 0.1 | H-C | Monsma and Malina (2005) |
| Track and field: Long-distance runners | 28 | Elite | 13.4 ± 1.7 | 2.1 ± 0.7 | 1.4 ± 0.8 | 4.5 ± 1.1 | H-C | Wilmore et al. (1977) |
| Field team sports | | | | | | | | |
| *Men* | | | | | | | | |
| Soccer | 16 | Elite | 16.4 | 2.1 ± 0.5 | 4.0 ± 0.9 | 2.9 ± 0.9 | H-C | Reilly et al. (2000) |
| Forwards | 56 | Sub-elite | 17.6 ± 2.6 | 2.2 ± 0.5 | 4.5 ± 1.0 | 2.9 ± 1.0 | H-C | Gil et al. (2007) |
| Midfielders | 79 | Sub-elite | 17.2 ± 2.4 | 2.6 ± 1.0 | 4.4 ± 1.0 | 2.8 ± 0.9 | H-C | |
| Defenders | 77 | Sub-elite | 17.3 ± 2.7 | 2.5 ± 0.8 | 4.4 ± 1.0 | 2.8 ± 1.1 | H-C | |
| Goalkeepers | 29 | Sub-elite | 17.6 ± 2.4 | 2.7 ± 0.7 | 4.4 ± 0.9 | 2.8 ± 0.8 | H-C | |
| Contact team sports | | | | | | | | |
| *Men* | | | | | | | | |
| Rugby | 45 | Sub-elite | 10 | 2.6 ± 1.3 | 4.5 ± 1.0 | 3.6 ± 1.4 | H-C | Pienaar et al. (1998) |
| Court sports | | | | | | | | |
| *Men* | | | | | | | | |
| Badminton | 6 | Elite | 17.5 ± 0.5 | 2.0 ± 0.9 | 5.2 ± 1.0 | 3.8 ± 1.3 | H-C | Amusa et al. (2001) |
| Netball | 17 | Elite | 19 | 4.1 ± 0.7 | 3.7 ± 0.4 | 3.4 ± 0.9 | H-C | Bale and Hunt (1986) |
| | 68 | Elite | 14.8 ± 0.4 | 4.2 ± 1.0 | 3.4 ± 1.1 | 2.5 ± 0.9 | H-C | Hopper (1997) |
| Tennis | 170 | Sub-elite | 10–11 | 2.4 ± 1.1 | 4.3 ± 0.8 | 3.4 ± 1.1 | H-C | Elliot et al. (1989) |
| | 208 | Sub-elite | 12–13 | 2.4 ± 1.1 | 4.1 ± 1.0 | 3.8 ± 1.3 | H-C | |
| | 116 | Sub-elite | 14–15 | 2.1 ± 1.0 | 3.8 ± 1.0 | 4.2 ± 1.1 | H-C | |
| | 22 | Sub-elite | 16–17 | 2.2 ± 0.9 | 4.1 ± 0.6 | 3.9 ± 1.1 | H-C | |
| | 17 | Elite | 11 | 2.2 ± 0.8 | 4.1 ± 0.7 | 3.9 ± 1.0 | H-C | Elliot et al. (1990) |
| | 57 | Elite | 16.2 ± 0.4 | 2.4 ± 0.7 | 5.2 ± 0.8 | 2.9 ± 0.7 | H-C | Sánchez-Muñoz et al. (2007) |
| | 17 | Sub-elite | 12.6 ± 0.9 | 2.2 ± 0.8 | 4.1 ± 0.7 | 3.9 ± 1.0 | H-C | Juzwiak et al. (2008) |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Volleyball | | | | | | | | |
| Setters | | Elite | 17.0 ± 0.5 | 2.6 ± 0.9 | 1.9 ± 1.1 | 5.3 ± 1.2 | H-C | Duncan et al. (2006) |
| Hitters | | Elite | 17.0 ± 0.5 | 2.4 ± 0.5 | 2.6 ± 0.6 | 4.6 ± 0.8 | H-C | |
| Centres | | Elite | 17.0 ± 0.5 | 2.2 ± 0.8 | 3.9 ± 0.4 | 3.6 ± 0.7 | H-C | |
| Opposites | | Elite | 17.0 ± 0.5 | 2.3 ± 0.8 | 2.5 ± 1.0 | 5.1 ± 1.1 | H-C | |
| | 19 | Sub-elite | 15.5 ± 1.0 | 2.3 ± 0.8 | 2.5 ± 1.0 | 5.1 ± 1.1 | H-C | Gabbett et al. (2007) |
| *Women* | | | | | | | | |
| Badminton | 8 | Elite | 17.2 ± 1.1 | 4.2 ± 1.6 | 4.9 ± 0.6 | 2.9 ± 1.6 | H-C | Amusa et al. (2001) |
| Tennis | 103 | Sub-elite | 10–11 | 3.2 ± 1.2 | 3.9 ± 0.8 | 3.3 ± 1.0 | H-C | Elliot et al. (1989) |
| | 140 | Sub-elite | 12–13 | 3.4 ± 1.4 | 3.6 ± 0.9 | 3.6 ± 1.2 | H-C | |
| | 89 | Sub-elite | 14–15 | 4.0 ± 1.5 | 3.3 ± 1.1 | 3.4 ± 1.3 | H-C | |
| | 18 | Sub-elite | 16–17 | 4.2 ± 1.1 | 3.4 ± 1.0 | 3.1 ± 1.2 | H-C | |
| | 13 | Elite | 11 | 3.4 ± 1.3 | 3.7 ± 0.9 | 3.7 ± 1.4 | H-C | Elliot et al. (1990) |
| | 16 | Elite | 13 | 2.9 ± 0.8 | 2.9 ± 1.0 | 4.3 ± 1.0 | H-C | |
| | 15 | Elite | 15 | 3.9 ± 1.0 | 3.2 ± 1.0 | 3.4 ± 1.2 | H-C | |
| | 66 | Elite | 15.9 ± 0.6 | 3.8 ± 0.9 | 4.6 ± 1.0 | 2.4 ± 1.0 | H-C | Sánchez-Muñoz et al. (2007) |
| | 27 | Sub-elite | 16.4 ± 1.1 | 2.2 ± 0.8 | 4.1 ± 0.7 | 3.9 ± 1.0 | H-C | Juzwiak et al. (2008) |
| Weight-classified sports | | | | | | | | |
| *Men* | | | | | | | | |
| Weightlifters | | | | | | | | |
| Weight class: 52 kg | 5 | Elite | 15–16.9 | 2.0 ± 0.5 | 5.1 ± 0.6 | 3.1 ± 0.5 | H-C | Orvanova (1990) |
| | 5 | Elite | 17–18.9 | 2.0 ± 0.2 | 5.2 ± 0.3 | 3.2 ± 0.7 | H-C | |
| Weight class: 56 kg | 5 | Elite | 15–16.9 | 2.6 ± 0.3 | 5.5 ± 0.8 | 2.7 ± 0.7 | H-C | |
| | 3 | Elite | 17–18.9 | 2.3 ± 0.1 | 5.2 ± 1.1 | 3.6 ± 0.8 | H-C | |
| Weight class: 60 kg | 9 | Elite | 15–16.9 | 2.5 ± 0.7 | 5.4 ± 1.0 | 2.9 ± 1.2 | H-C | |
| | 4 | Elite | 17–18.9 | 2.6 ± 0.6 | 6.1 ± 0.3 | 2.0 ± 0.6 | H-C | |
| Weight class: 67.5 kg | 7 | Elite | 15–16.9 | 3.1 ± 1.0 | 5.7 ± 0.7 | 2.5 ± 0.8 | H-C | |
| | 12 | Elite | 17–18.9 | 3.1 ± 1.0 | 5.9 ± 0.9 | 1.9 ± 0.8 | H-C | |
| Weight class: 75 kg | 11 | Elite | 15–16.9 | 2.6 ± 0.6 | 6.5 ± 0.8 | 2.0 ± 0.7 | H-C | |
| | 14 | Elite | 17–18.9 | 3.1 ± 0.7 | 6.2 ± 1.2 | 1.8 ± 0.9 | H-C | |
| Weight class: 82.5 kg | 3 | Elite | 15–16.9 | 4.7 ± 1.6 | 7.0 ± 0.4 | 0.8 ± 0.3 | H-C | |
| | 7 | Elite | 17–18.9 | 3.0 ± 0.5 | 6.2 ± 1.2 | 1.6 ± 0.7 | H-C | |
| Weight class: 90 kg | 2 | Elite | 15–16.9 | 5.9 ± 0.4 | 6.6 ± 1.5 | 0.5 ± 0.4 | H-C | |
| | 8 | Elite | 17–18.9 | 4.0 ± 1.3 | 7.3 ± 0.7 | 1.0 ± 0.5 | H-C | |
| Weight class: 100 kg | 10 | Elite | 17–18.9 | 2.8 ± 0.6 | 7.9 ± 0.9 | 0.8 ± 0.4 | H-C | |
| Weight class: 110 kg | 7 | Elite | 17–18.9 | 5.8 ± 1.1 | 7.9 ± 0.4 | 0.2 ± 0.0 | H-C | |
| Weight class: >110 kg | 3 | Elite | 17–18.9 | 8.7 ± 0.2 | 9.7 ± 0.3 | 0.0 ± 0.0 | H-C | |

**Table 114.4** Key features of body composition

1. Body composition is defined as the division of the relative percentages of body weight into several compartments, according to definable tissues.
2. Usually, body composition is expressed as a two-compartment model in which the body is divided into fat and fat-free compartments. A four-compartment model divides the body into a fat portion, and further subdivides the fat-free portion into bone, muscle and the remainder (organs, nerves, blood, vessels and fluids).
3. Body composition measurements are applied regularly in a variety of fields including medicine, anthropology, ergonomics, human growth and sport performance.
4. Body composition techniques on athletes have been largely directed towards estimating the amount of fat in the body.
5. Assessment of body composition and the resulting computation of relative fatness contribute significant information to determine an athlete's training and nutritional programmes. Body composition estimates provide important information about an athlete's physical profile and affect the athletes' training.
6. Estimates of the body composition can only be made at present by indirect laboratory and field techniques due to the only direct method of quantifying the different compartments or tissues being cadaver dissection.
7. Traditional laboratory procedures for the estimation of body fat, such as hydrostatic weighing and total body water, are comparatively cumbersome, expensive and not always readily available, whereas more expedient methods, such as anthropometry, suffer from concerns about validity and accuracy. The technique used most often for assessing body fat in athletes has been skinfolds, although recent technological advances offer a variety of new methods for body composition assessment.

Of considerable interest is the gender differences that exist that may influence performance. Peak height velocity (PHV) is the maximum rate of growth occurring during the adolescent growth spurt (Baxter-Jones and Sherar 2007). Girls usually begin their growth spurt between 8 and 10 years, which is two years before boys usually begin their growth spurt (at 10–12 years). This may present a transitory advantage until boys begin to progress through their PHV phase by which point they have already had two years additional pre-PHV growth than girls. The time frame for PHV is also longer in boys, with the resultant height advantage in boys compared to girls measuring approximately 13 cm. Growth in the lower extremities is evident in the early phase of the growth spurt for both boys and girls; however, gender differences exist in regional muscle mass development (Malina et al. 2004). Still, there may be as much as five years' difference in the occurrence of PHV between genders; therefore, the chronological age can differ significantly compared to biological age. This is important since, during adolescence, selection for sports is likely to be influenced significantly by biological age as evidenced by the early maturers having an advantage (Helsen et al. 2005).

The shape and proportions of an athlete is an important feature in talent identification since it has been suggested that children should be directed towards sports for which they are physically suited (Bloomfield 1992). This process of "morphological optimisation" (Norton et al. 1996) is particularly useful for sports where height and body mass are important performance predictors.

## 114.4 Somatotyping

Somatotyping is a method whereby the body is described in terms of a number of traits that have a relation to body shape and composition. Sheldon et al. (1940) introduced the method from studies of Kretschmer's (1921) classification of three empirically determined and visually rated extremes of body build and Viola's (1933) ratio of trunk and limb measures. Heath and Carter (1967) developed this further with the Heath–Carter somatotype method, which is now the most universally applied of the available methods and is the method we have focussed on in this chapter. A somatotype of an athlete consists of a three-numeral rating, always recorded in the same order, which describes the current morphological representation. The three numbers, expressed as 2-5-1, for example, describe the value of each component – endomorphy, mesomorphy and ectomorphy – of the physique.

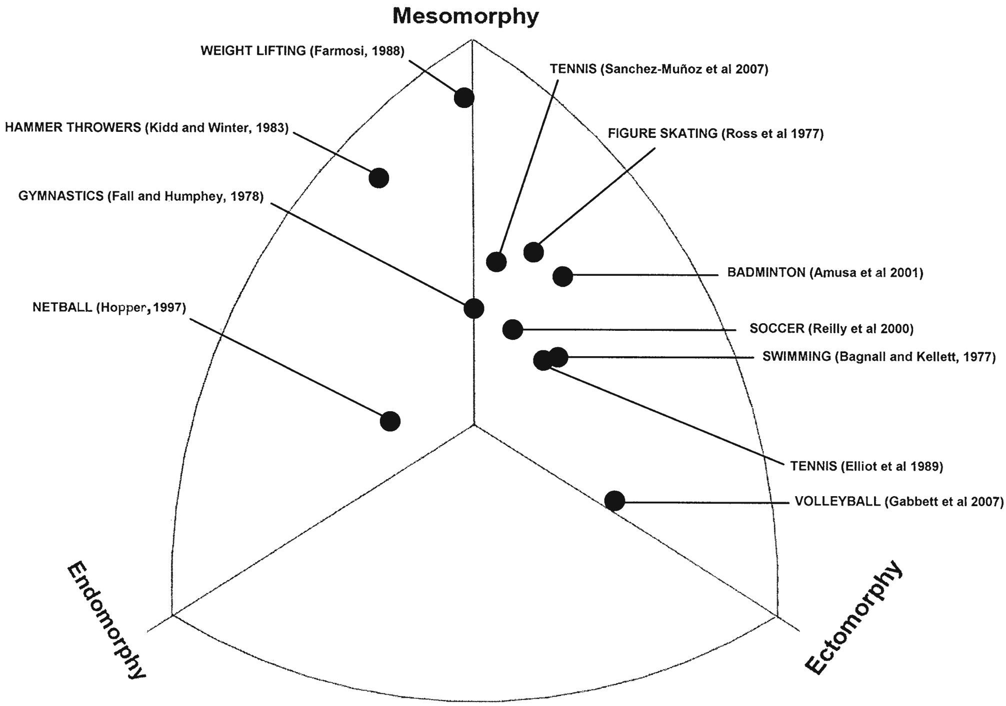


**Fig. 114.1** Somatotype distribution of mean somatotypes for various youth male sports

The higher the rating of each component, the more prevalent it is in an individual. The results of somatotyping can be plotted on a somatochart, which also allows the comparison between individuals or sports (see Table 114.1 and Figs. 114.1 and 114.2).

### 114.4.1 Components

The first component, endomorphy, describes the relative amount of adiposity of an individual's body. It does not take into consideration the distribution. Endomorphy also provides descriptors of physical aspects, such as roundness, relative volume and the distal tapering of the limbs. Mesomorphy is the second component and describes the level of muscularity of an individual. It also refers to the descriptors of physical aspects, such as robustness, the relative volume of the trunk and other muscle mass within an individual. The measures of endomorphy and mesomorphy are considered to be an anatomical model of body composition. Ectomorphy is the third component and is a description of the linearity of the body. It also describes physical aspects of slenderness in the absence of muscle or fat mass. The category that an individual will be placed in is dependent upon the dominant component, with an indication of their secondary component. For example, a rating of 3-5-1 would suggest that an individual is an endomorphic mesomorph as they have a high mesomorphic value (5) as the primary trait and a relatively high (3) value on the endomorphic scale. If an individual has equal values in two of their ratings, they are considered to be a balanced body type as dictated by the dominant components. For example, a 1-5-1 would be considered to be a balanced mesomorph as the values for endomorphy and ectomorphy are equally low compared to the high value for mesomorphy.

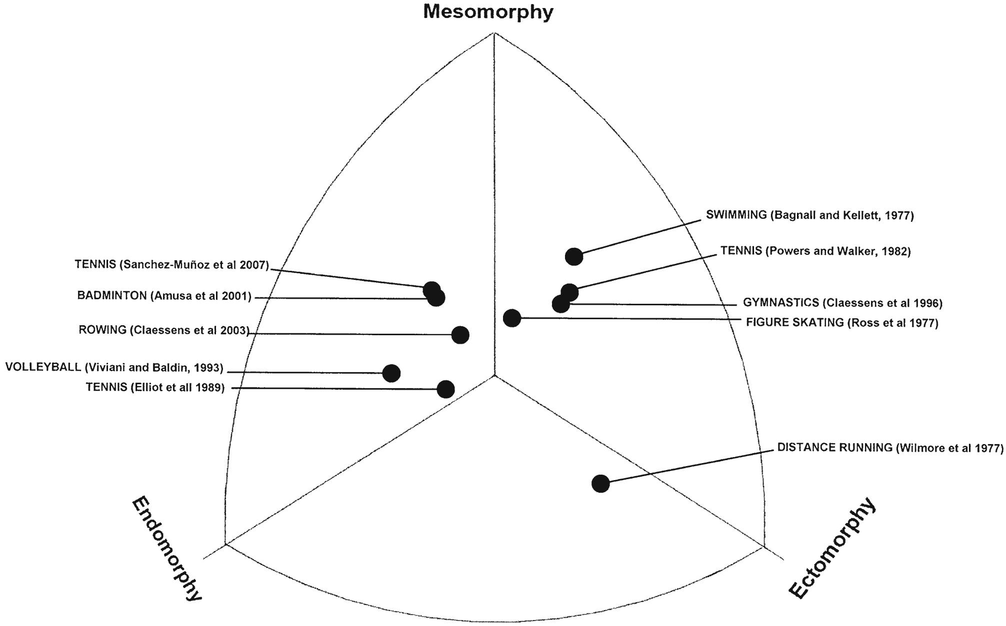


**Fig. 114.2** Somatotype distribution of mean somatotypes for various youth female sports

A somatotype is an indication of the physique as a whole. It allows the assessment of the body as a whole, taking into consideration levels of adiposity, muscularity and linearity. Its application in sport and performance has been significant with the ability to compare body types across a huge range of sports and at all levels of competition. With respect to youth sport, somatotyping allows the monitoring of training, growth and maturation over time. Additionally, there is evidence to suggest that the physique characteristics of young athletes in a variety of sports are consistent with those of adult athletes in the respective sports (Heath and Carter 1990), which is potentially a useful tool in talent identification.

## 114.5 Body Composition

Techniques for the measurement of body composition give a more accurate indicator of what makes up an individual's shape, thereby allowing further selection criteria to be identified. There are a number of techniques available for the measurement of body composition, which range from simple to in-depth. One of the simplest estimates of body composition is body mass index (BMI); however, there are issues surrounding its accuracy, particularly in adolescent boys where the increase in body mass between 11 and 16 years may be more to do with an increase in muscle mass than adipose tissue, therefore giving an incorrect estimate of relative obesity. If BMI is used, then, an attempt to classify young people against age- and gender-specific cutoff points should be made (Cole et al. 2000). The usefulness of BMI is greater in sports that do not rely on high power/weight ratios, such as field and court sports, as opposed to sports, such as gymnastics or cycling, where body composition can have a large impact upon a height/weight ratio value (see Tables 114.1–114.3).

In addition to BMI, there are a number of techniques available to assess body composition, such as skinfolds, bioelectrical impedance analysis (BIA), hydrodensitometry, air displacement plethysmography (ADP) and dual-energy X-ray absorptiometry (DXA). Some of these techniques, such as hydrodenistometry or DXA, require a high level of technical expertise and expensive equipment and can be quite timely to administer. One of the most used methods for the estimation of percentage body fat is skinfolds and body density. What must be taken into consideration is the effect of growth on the concepts associated with estimation of body density (Armstrong and Welsman 1997), since the water content of a child's fat-free mass and the increases seen in bone density during adolescence will affect those assumptions. Where an estimation of percentage body fat is attempted, child-specific equations should be used (Lohman 1992). To attempt to overcome this, some sports have opted to use the sum of skinfolds as an indicator of adiposity, which can also be used longitudinally. In sports, where rapid movements as well as movement of the body mass must occur, or in weight-classified sports, minimal body fat and a lean body shape is a distinct advantage (Tittel 1978). Such sports could include track and jumping sports, or combat sports. Talent identification in these types of sports should consider using a more in-depth estimation of body composition, such as skinfolds.

When considering team sports, positional differences should be accounted for, as different roles within a squad will have different energy requirements. For example, a midfielder in soccer will require a lower body fat than the goalkeeper due to the movement patterns of that position. Whilst body composition is an important element of the talent identification process, it is only one of the many factors that will contribute to success. Athletes can still perform at the highest level in the absence of the most favourable body composition, due to their excellence in other areas, such as physiology, tactics, technique and psychological approaches.

The factors outlined earlier have potential to affect performance prediction, the extent of which will depend upon a number of factors, such as the requirements and level of the sport, the application and the correct selection of techniques upon performance and their role in performance prediction. The use of the techniques in specific sports is outlined below and in Tables 114.5–114.7, with an attempt to compare the data to reference where possible. An effort to only use data from high-level youth sport had been made.

**Table 114.5** Anthropometric measures of individual, field team and contact team sports in youths

| Sport/Position | *n* | Level | Age (y) | Height (cm) | Body mass (kg) | BMI (kg/cm$^2$) | Reference |
|---|---|---|---|---|---|---|---|
| Individual Sports | | | | | | | |
| *Men* | | | | | | | |
| Artistic Gymnastics | 65 | Elite | 16.0±0.7 | 168.1±7.6 | 60.3±8.0 | – | Faria & Faria, 1989 |
| | 10 | Elite | 16.9±0.6 | 165.4±7.3 | 62.1±7.8 | – | |
| | 10 | Elite | 15.3±0.7 | 168.6±7.1 | 58.2±7.8 | – | |
| Cycling (Road) | 15 | Elite | 15.0±1.7 | 179.2±1.1 | 69.0±8.4 | – | Faria et al 1989 |
| Figure Skating | 12 | Sub-elite | 18.2±3.6 | 164.4±7.3 | 56.5±8.2 | – | Ross et al 1977 |
| Rock climbing | 52 | Elite | 13.5±3.0 | 162.2±15.6 | 51.5±13.6 | 19.1±2.2 | Watts et al 2003 |
| Track & Field | | | | | | | |
| Runners | 13 | Sub-elite | 11.7±1.1 | 147.0±6.8 | 36.6±4.1 | – | Unnithan et al 1995 |
| Runners | 11 | Sub-elite | 16.6±0.7 | 169.5±7.7 | 53.8±8.1 | 18.6±1.5 | Larsen et al 2004 |
| Runners | 11 | Sub-elite | 16.6±0.8 | 170.4±7.9 | 53.3±5.3 | 18.4±1.6 | |
| Runners: Sprint/ Hurdles | 14 | Sub-elite | 19.8±1.3 | 179.1±6.6 | 72.8±4.8 | – | Hollings & Robson, 1991 |
| Runners: Middle/ Long distance | 10 | Sub-elite | 19.6±1.3 | 178.1±2.8 | 66.8±4.2 | – | |
| Jumpers: long, triple, high, pole vault | 7 | Sub-elite | 19.3±0.9 | 181.6±8.1 | 75.5±6.3 | – | |
| Throwers: discus, shot, put, javelin | 7 | Sub-elite | 19.9±1.7 | 184.6±5.3 | 105.2±11.6 | – | |

(continued)

**Table 114.5** (continued)

| Sport/Position | *n* | Level | Age (y) | Height (cm) | Body mass (kg) | BMI (kg/cm²) | Reference |
|---|---|---|---|---|---|---|---|
| *Women* | | | | | | | |
| Artistic Gymnastics | 46 | Elite | 9.7±2.4 | 135.2±12.7 | 29.4±8.3 | – | Claessens & Lefevre, 1998 |
| | 14 | Sub-elite | 11.6±1.3 | 143.0±10.0 | 35.6±8.0 | 17.1±2.0 | Courteix et al 1999 |
| Figure Skating | 18 | Sub-elite | 15.7±1.6 | 156.8±5.0 | 48.6±6.0 | – | Ross et al 1977 |
| Rhythmic Gymnastics | 8 | Elite | 14.7±2.2 | 165.0±3.0 | 47.9±3.4 | 17.3±1.4 | Di Cagno et al 2008 |
| | 15 | Elite | 13.4±1.6 | 151.1±9.5 | 35.6±5.5 | | Douda et al 2008 |
| Rock climbing | 38 | Elite | 13.5±3.0 | 151.3±11.9 | 40.6±9.6 | 17.5±2.1 | Watts et al 2003 |
| Field Team Sports | | | | | | | |
| *Men* | | | | | | | |
| Cricket | 48 | Sub-elite | 14.8±1.3 | 175.7±9.8 | 65.8±12.9 | – | Pyne et al 2006 |
| Field Hockey | 21 | Elite | 13.2±1.3 | 169.0±1.0 | 55.1±8.7 | – | Elferink-Gemser et al 2004 |
| | 17 | Elite | 13.2±1.3 | 165.0±1.0 | 54.9±8.1 | – | |
| | 21 | Elite | 13.9±1.4 | 169.0±1.0 | 55.1±8.7 | – | Elferink-Gemser et al 2004 |
| | 15 | Elite | 16.0±1.0 | 176.0±8.0 | 64.4±8.0 | – | Elferink-Gemser et al 2007 |
| | 15 | Elite | 15.7±1.0 | 166.0±5.0 | 57.1±6.4 | – | |
| Soccer | 16 | Elite | 16.4 | 171.0±5.0 | 63.1±1.1 | – | Reilly et al 2000 |
| Forwards | 56 | Sub-elite | 17.6±2.6 | 174.8±6.8 | 68.4±9.1 | 22.2±2.2 | Gil et al 2007 |
| Midfielders | 79 | Sub-elite | 17.2±2.4 | 174.6±7.6 | 68.5±9.7 | 22.4±2.2 | |
| Defenders | 77 | Sub-elite | 17.3±2.7 | 175.5±7.6 | 68.9±9.1 | 22.3±2.2 | |
| Goalkeepers | 29 | Sub-elite | 17.6±2.4 | 179.5±5.9 | 74.0±7.9 | 22.9±1.7 | |
| | 16 | Elite | 13.4±0.4 | 165.2±10.5 | 52.5±9.9 | – | Le Gall et al 2010 |
| | 56 | Elite | 13.6±0.4 | 165.0±8.8 | 53.8±9.5 | – | |
| | 16 | Elite | 14.4±0.4 | 171.5±9.4 | 59.3±10.3 | – | |
| | 54 | Elite | 14.5±0.4 | 170.8±8.0 | 60.3±9.2 | – | |
| | 16 | Elite | 15.4±0.4 | 176.1±7.5 | 65.3±8.8 | – | |
| | 57 | Elite | 15.4±0.4 | 175.3±8.2 | 66.0±8.2 | – | |
| *Women* | | | | | | | |
| Field Hockey | 17 | Elite | 13.9±1.3 | 165.0±1.0 | 54.9±8.1 | – | Elferink-Gemser et al 2004 |
| Contact Team Sports | | | | | | | |
| *Men* | | | | | | | |
| American Football | | | | | | | |
| All | 18 | Sub-elite | 16.2±0.8 | 180.6±2.3 | 89.1±13.4 | – | Williford et al 1994 |
| Backs | 8 | Sub-elite | 16.1±0.6 | 180.1±5.3 | 80.5±7.6 | – | |
| Linemen | 10 | Sub-elite | 16.3±0.8 | 180.9±2.5 | 96.0±4.6 | – | |
| All | 65 | Sub-elite | 18.4±1.2 | 189.0±7.0 | 107.0±22.0 | 29.8±4.7 | Kaiser et al 2008 |
| Offensive line | 12 | Sub-elite | 18.4±1.2 | 196.9±3.8 | 137.0±9.8 | 35.3±2.8 | |
| Tight end | 3 | Sub-elite | 18.4±1.2 | 194.7±5.3 | 112.0±2.5 | 29.6±1.6 | |
| Defensive line | 10 | Sub-elite | 18.4±1.2 | 193.7±3.3 | 127.0±12.6 | 33.9±4.0 | |
| Quarterback | 4 | Sub-elite | 18.4±1.2 | 188.6±2.4 | 92.0±4.0 | 25.9±1.3 | |
| Linebacker | 9 | Sub-elite | 18.4±1.2 | 188.4±3.7 | 104.0±6.3 | 29.4±6.1 | |
| Kicker | 2 | Sub-elite | 18.4±1.2 | 188.0±7.2 | 88.0±14.1 | 24.7±2.3 | |
| Wide receiver | 6 | Sub-elite | 18.4±1.2 | 186.3±3.7 | 88.0±8.4 | 25.4±2.3 | |
| Defensive back | 13 | Sub-elite | 18.4±1.2 | 181.5±2.9 | 84.0±6.6 | 25.6±1.7 | |
| Running back | 6 | Sub-elite | 18.4±1.2 | 180.8±3.3 | 99.0±16.6 | 30.4±4.1 | |
| Australian Rules Football | 29 | Elite | 15.9±0.8 | 180.2±7.2 | 74.6±8.3 | – | Keogh, 1999 |
| Rugby | 45 | Sub-elite | 10 | 146.6±5.8 | 36.4±5.6 | – | Pienaar et al 1998 |
| All | 28 | Elite | 16.0±0.2 | 178.0±5.9 | 77.5±10.0 | – | Gabbett et al 2009 |
| Hip-up forwards | 28 | Elite | 15.9±0.4 | 180.9±6.7 | 87.0±11.1 | – | |
| Adjustables | 28 | Elite | 16.0±0.2 | 175.5±4.9 | 73.0±6.2 | – | |
| Outside backs | 28 | Elite | 16.0±0.2 | 178.8±5.5 | 74.9±7.6 | – | |

**Table 114.6** Anthropometric measures of court and weight-classified sports in youths

| Sport/position | *n* | Level | Age (years) | Height (cm) | Body mass (kg) | BMI (kg/cm²) | Reference |
|---|---|---|---|---|---|---|---|
| Court sports | | | | | | | |
| *Men* | | | | | | | |
| Badminton | 6 | Elite | 17.5 ± 0.5 | 171.0 ± 4.7 | 54.8 ± 3.0 | 18.7 ± 0.8 | Amusa et al. (2001) |
| Basketball | | | | | | | |
| Point guard | 28 | Elite | 15.4 | 177.9 ± 5.3 | 68.1 ± 0.6 | – | Hoare (2000) |
| Off/shooting guard | 25 | Elite | 15.4 | 180.5 ± 4.6 | 71.3 ± 8.6 | – | |
| Small/shooting guard | 31 | Elite | 15.4 | 186.1 ± 5.7 | 76.4 ± 8.3 | – | |
| Power/forward | 25 | Elite | 15.4 | 191.3 ± 3.7 | 83.8 ± 10.1 | – | |
| Centre | 16 | Elite | 15.4 | 194.6 ± 4.4 | 84.5 ± 9.2 | – | |
| Handball | 34 | Elite | 13.1 ± 0.5 | 157.0 ± 9.0 | 45.1 ± 8.3 | – | Mohamed et al. (2009) |
| | 47 | Elite | 15.0 ± 0.6 | 174.0 ± 8.0 | 61.3 ± 9.4 | – | |
| | 18 | Elite | 15.0 ± 0.6 | 179.0 ± 4.0 | 67.1 ± 6.4 | – | |
| Netball | 17 | Elite | 19 | 172.9 ± 4.8 | 65.5 ± 3.9 | – | Bale and Hunt (1986) |
| | 68 | Elite | 14.8 ± 0.4 | 169.1 ± 6.1 | 59.0 ± 6.2 | – | Hopper (1997) |
| Tennis | 170 | Sub-elite | 10–11 | 142.0 ± 6.2 | 35.0 ± 6.2 | – | Elliot et al. (1989) |
| | 208 | Sub-elite | 12–13 | 151.1 ± 7.4 | 40.4 ± 7.0 | – | |
| | 116 | Sub-elite | 14–15 | 163.4 ± 9.4 | 49.3 ± 8.8 | – | |
| | 22 | Sub-elite | 16–17 | 172.6 ± 6.5 | 59.5 ± 8.2 | – | |
| | 17 | Elite | 11 | 142.40 ± 5.7 | 33.5 ± 4.0 | – | Elliot et al. (1990) |
| | 27 | Elite | 13 | 153.4 ± 7.7 | 41.1 ± 6.3 | – | |
| | 13 | Elite | 15 | 169.6 ± 8.3 | 54.0 ± 8.8 | – | |
| | 57 | Elite | 16.2 ± 0.4 | 176.8 ± 6.4 | 69.9 ± 6.8 | 22.3 ± 1.4 | Sánchez-Muñoz et al. (2007) |
| | 17 | Sub-elite | 12.6 ± 0.9 | 159.0 ± 10.0 | 49.2 ± 7.0 | 19.4 ± 1.6 | Juzwiak et al. (2008) |
| | 27 | Sub-elite | 16.4 ± 1.1 | 177.0 ± 10.0 | 67.0 ± 9.5 | 21.5 ± 2.2 | |
| Volleyball | | | | | | | |
| Setters | | Elite | 17.0 ± 0.5 | 191.0 ± 5.0 | 71.2 ± 9.3 | – | Duncan et al. (2006) |
| Hitters | | Elite | 17.0 ± 0.5 | 193.0 ± 4.5 | 77.9 ± 8.4 | – | |
| Centres | | Elite | 17.0 ± 0.5 | 187.0 ± 3.6 | 77.6 ± 5.9 | – | |
| Opposites | | Elite | 17.0 ± 0.5 | 190.0 ± 5.9 | 71.3 ± 9.2 | – | |
| | 19 | Sub-elite | 15.5 ± 1.0 | 184.0 ± 8.0 | 71.1 ± 9.6 | – | Gabbett et al. (2007) |
| *Women* | | | | | | | |
| Badminton | 8 | Elite | 17.2 ± 1.1 | 159.5 ± 5.6 | 51.2 ± 6.1 | 20.2 ± 2.7 | Amusa et al. (2001) |
| Basketball | | | | | | | |
| Point guard | 32 | Elite | 15.2 | 166.2 ± 5.2 | 57.8 ± 6.6 | – | Hoare (2000) |
| Off/shooting guard | 30 | Elite | 15.2 | 169.4 ± 3.4 | 61.6 ± 6.0 | – | |
| Small/shooting guard | 17 | Elite | 15.2 | 173.5 ± 5.3 | 64.1 ± 6.7 | – | |

(continued)

**Table 114.6** (continued)

| Sport/position | *n* | Level | Age (years) | Height (cm) | Body mass (kg) | BMI (kg/cm²) | Reference |
|---|---|---|---|---|---|---|---|
| Power/ forward | 25 | Elite | 15.2 | 177.4 ± 3.6 | 69.4 ± 7.3 | – | |
| Centre | 19 | Elite | 15.2 | 181.6 ± 3.8 | 70.5 ± 6.9 | – | |
| Tennis | 103 | Sub-elite | 10–11 | 141.5 ± 6.2 | 34.9 ± 6.1 | – | Elliot et al. (1989) |
| | 140 | Sub-elite | 12–13 | 153.4 ± 8.4 | 43.3 ± 8.2 | – | |
| | 89 | Sub-elite | 14–15 | 162.8 ± 7.5 | 52.5 ± 7.2 | – | |
| | 18 | Sub-elite | 16–17 | 165.1 ± 5.2 | 56.2 ± 8.1 | – | |
| | 13 | Elite | 11 | 145.1 ± 5.8 | 36.4 ± 5.3 | – | Elliot et al. (1990) |
| | 16 | Elite | 13 | 159.0 ± 7.9 | 44.9 ± 6.6 | – | |
| | 15 | Elite | 15 | 164.5 ± 7.5 | 54.2 ± 6.8 | – | |
| | 66 | Elite | 15.9 ± 0.6 | 165.4 ± 6.3 | 59.9 ± 6.2 | 21.9 ± 1.7 | Sánchez-Muñoz et al. (2007) |
| Volleyball | 29 | Sub-elite | 14.3 ± 1.3 | 169.0 ± 8.0 | 59.6 ± 8.2 | 20.9 ± 2.5 | Melrose et al. (2007) |
| | 14 | Sub-elite | 13.1 ± 0.6 | 167.0 ± 9.0 | 56.1 ± 8.5 | 20.1 ± 2.6 | |
| | 15 | Sub-elite | 15.5 ± 0.6 | 170.0 ± 7.0 | 62.8 ± 6.6 | 21.6 ± 2.1 | |
| Weight-classified sports | | | | | | | |
| *Men* | | | | | | | |
| Judo | 17 | Elite | 14.7 ± 0.9 | 165.6 ± 10.4 | 55.5 ± 13.4 | – | Little (1991) |
| | 9 | Elite | 17.3 ± 0.8 | 175.3 ± 8.8 | 67.2 ± 7.2 | – | |
| Weightlifting | | | | | | | |
| Weight class: 52 kg | 5 | Elite | 15–16.9 | 160.1 ± 1.8 | 50.7 ± 1.2 | – | Orvanova (1990) |
| | 5 | Elite | 17–18.9 | 161.3 ± 3.8 | 51.6 ± 0.3 | – | |
| Weight class: 56 kg | 5 | Elite | 15–16.9 | 163.4 ± 3.5 | 55.8 ± 0.4 | – | |
| | 3 | Elite | 17–18.9 | 167.9 ± 3.8 | 55.7 ± 0.3 | – | |
| Weight class: 60 kg | 9 | Elite | 15–16.9 | 166.3 ± 6.0 | 58.4 ± 1.1 | – | |
| | 4 | Elite | 17–18.9 | 163.7 ± 2.8 | 60.3 ± 1.8 | – | |
| Weight class: 67.5 kg | 7 | Elite | 15–16.9 | 170.1 ± 3.6 | 64.5 ± 1.3 | – | |
| | 12 | Elite | 17–18.9 | 168.5 ± 4.6 | 66.4 ± 1.3 | – | |
| Weight class: 75 kg | 11 | Elite | 15–16.9 | 174.4 ± 4.7 | 73.2 ± 2.4 | – | |
| | 14 | Elite | 17–18.9 | 173.9 ± 5.3 | 74.2 ± 1.7 | – | |
| Weight class: 82.5 kg | 3 | Elite | 15–16.9 | 171.7 ± 3.3 | 80.5 ± 1.6 | – | |
| | 7 | Elite | 17–18.9 | 177.0 ± 3.7 | 79.7 ± 2.7 | – | |
| Weight class: 90 kg | 2 | Elite | 15–16.9 | 173.9 ± 3.2 | 88.0 ± 1.1 | – | |
| | 8 | Elite | 17–18.9 | 177.6 ± 4.6 | 87.0 ± 3.6 | – | |
| Weight class: 100 kg | 10 | Elite | 17–18.9 | 180.6 ± 4.4 | 97.1 ± 2.2 | – | |
| Weight class: 110 kg | 7 | Elite | 17–18.9 | 182.1 ± 2.5 | 105.4 ± 4.1 | – | |
| Weight class: >110 kg | 3 | Elite | 17–18.9 | 181.2 ± 2.7 | 126.3 ± 5.1 | – | |
| | 25 | Elite | 17.4 ± 1.4 | 170.0 ± 2.8 | 67.6 ± 11.8 | – | Conroy et al. (1993) |
| | 20 | Elite | 14.8 ± 2.3 | 165.5 ± 11.7 | 67.3 ± 10.4 | 24.1 ± 3.2 | Fry et al. (2006) |
| *Women* | | | | | | | |
| Judo | 9 | Elite | 15.5 ± 0.7 | 163.0 ± 4.7 | 58.1 ± 10.0 | – | Little (1991) |

**Table 114.7** Anthropometric measures of water sports in youths

| Sport/position | n | Level | Age (years) | Height (cm) | Body mass (kg) | BMI (kg/cm$^2$) | Reference |
|---|---|---|---|---|---|---|---|
| Water sports | | | | | | | |
| *Men* | | | | | | | |
| Rowing | 383 | Elite | 17.8 ± 0.7 | 187.4 ± 5.8 | 82.2 ± 7.4 | – | Bourgois et al. (2000) |
| | 48 | Sub-elite | 12.9 ± 0.6 | 164.7 ± 8.0 | 57.0 ± 10.7 | – | Mikulic and Ruzic (2008) |
| Sprint Kayak | 15 | Elite | 13–14 | 184.0 ± 4.0 | 86.8 ± 5.2 | – | Aitken and Jenkins (1998) |
| Swimming | | | | | | | |
| Freestyle: short distance | 31 | | 12–13 | 169.4 ± 8.0 | 58.2 ± 5.6 | – | Avlonitou (1994) |
| Backstrokers | 30 | | 12–13 | 169.4 ± 8.6 | 56.7 ± 8.8 | – | |
| Breaststrokers | 27 | | 12–13 | 163.2 ± 7.2 | 49.7 ± 7.5 | – | |
| Fliers | 12 | | 12–13 | 161.4 ± 9.6 | 57.6 ± 8.8 | – | |
| Freestyle: long distance | 12 | | 12–13 | 160.0 ± 6.9 | 47.0 ± 6.0 | – | |
| Freestyle: 100 m | 178 | Sub-elite | 12.8 ± 0.1 | 165.5 ± 0.7 | 54.1 ± 0.7 | – | Geladas et al. (2005) |
| | 15 | Sub-elite | 11.9 ± 0.3 | 154.9 ± 7.5 | 42.5 ± 7.0 | 17.5 ± 1.9 | Jürimäe et al. (2007) |
| | 15 | Sub-elite | 14.3 ± 1.4 | 172.9 ± 7.9 | 61.3 ± 10.6 | 20.3 ± 2.1 | |
| *Women* | | | | | | | |
| Rowing | 220 | Elite | 17.5 ± 0.8 | 174.5 ± 6.2 | 69.5 ± 6.2 | – | Bourgois et al. (2000) |
| Sweep rowers | 108 | Elite | 17.5 ± 0.8 | 176.3 ± 5.4 | 71.6 ± 5.6 | – | |
| Scullers | 111 | Elite | 17.5 ± 0.8 | 173.5 ± 6.5 | 67.4 ± 6.1 | – | |
| Sprint Kayak | 10 | Elite | 13–14 | 171.0 ± 3.0 | 67.5 ± 3.5 | – | Aitken and Jenkins (1998) |
| Swimming | | | | | | | |
| Freestyle: Short distance | 29 | | 12–13 | 167.2 ± 7.2 | 57.9 ± 6.3 | – | Avlonitou (1994) |
| Backstrokers | 28 | | 12–13 | 164.4 ± 7.6 | 53.2 ± 6.2 | – | |
| Backstrokers | 29 | | 12–13 | 162.7 ± 5.8 | 52.7 ± 6.4 | – | |
| Fliers | 19 | | 12–13 | 155.4 ± 2.6 | 50.6 ± 5.4 | – | |
| Freestyle: Long distance | 14 | | 12–13 | 159.5 ± 5.2 | 49.5 ± 7.9 | – | |
| Freestyle: 100 m | 85 | Sub-elite | 12.7 ± 0.1 | 161.2 ± 0.6 | 48.3 ± 0.6 | – | Geladas et al. (2005) |

## 114.6 Individual Sports

### *114.6.1 Cycling*

Track cyclists are known to be more powerful than road cyclists, especially those involved in the shorter distances, although there are similarities across both groups. Road versus track cycling should also be taken into consideration. Faria et al. (1989) indicated that youth cyclists were notably taller, heavier and leaner than non-athletes and when compared to junior swimmers and runners, and they were found to be similar to endurance athletes. Measures of body composition revealed a high correlation between estimated percentage fat, triceps skinfold and suprailium skinfold, which suggests that these are the most appropriate skinfold measurements for this homogeneous population.

### 114.6.2 Figure Skating

The importance of morphological characteristics for most optimal performance in aesthetic sports has been noted. Monsma and Malina (2005) demonstrated that elite skaters had shorter leg lengths than pre-elite skaters; however, this may be due to maturation levels, as pre-elites are generally younger and in an earlier phase of their adolescent growth spurts. Additionally, lower-level test stream skaters had greater skinfold values than both pre-elite and elite skaters, suggesting an effect of level on kinanthropometry. Ross et al. (1977) demonstrated that, compared to Mexican Olympic athletes, Canadian Olympic skaters (senior and junior men and ladies) were ectomorphic/mesomorphic on the scales and that they closely resembled gymnasts in size, being relatively small, lean and only slightly less muscular.

### 114.6.3 Gymnastics

Success in gymnastics relies on attaining the highest score during competition. It is claimed that anthropometrics are the greatest predictor of performance in rhythmic gymnastics (Douda et al. 2008), accounting for 41% of the success in performances of basic body elements of difficulty, whereas non-adipose voluminosity accounts for 26% of rhythmic-gymnastics-specific manipulations with the apparatus (Miletic et al. 2004). Rhythmic gymnastics relies in part upon the ability to leap and hop. It was found that height accounted for 16% of variance in hopping height. Elite rhythmic gymnasts were taller and had significantly longer thigh lengths and higher values of FFM than sub-elites (Di Cagno et al. 2008), therefore supporting the use of these parameters to select gymnasts in the early stages of development.

When attempting to predict the best independent predictors of annual changes in bone mineral density (BMD) for total body, lumbar, spine, trochanter and femoral neck sites of highly trained gymnasts, Courteix et al. (1999) found that variations in lean mass, bone age and fat mass were the greatest independent predictors. With respect to male gymnasts, it was found that top male class II gymnasts were significantly leaner than class I and lower class II gymnasts. Additionally, class II gymnasts, when compared to other classes, were characterised as shorter in stature, were leaner and possessed more muscle mass (Faria and Faria 1989). The length of the arms with respect to trunk length and percentage body fat are key factors due to their potential impact on achieving skill at the highest level and should therefore be included in the talent identification process of high-level gymnasts.

### 114.6.4 Rock Climbing

The popularity of climbing continues to grow, with normative data on adult climbers beginning to emerge regularly. In evaluations of young competitive rock climbers, significant differences in height, mass, ratio of arm span to height, biiliocristal/bi-acromial ratio, sum of skinfolds and estimated percentage fat were found compared to age-matched controls. Watts et al. (2003) suggested that young competitive climbers have general characteristics similar to adult climbers, although young climbers appearing to be more linear with narrow shoulders relative to hips. Continued monitoring of youth climbers is useful to form normative databases both for selection for elite levels and for comparison to adult climbers.

### *114.6.5 Track and Field*

There is a plethora of data relating to kinanthropometry of runners of differing distances and a variety of ages. The data of Graves et al. (1987) showed that elite female runners had smaller girths than gymnasts, body builders and normative references. Male Kenyan runners had measures of BMI, height and mass that were smaller than age-matched Scandinavian athletes. This suggests that there may be an affect of race on performance (Larsen et al. 2004). Hollings and Robson (1991) indicated that, in a cohort of field and track athletes including throwers, sprinters, middle-distance runners and jumpers, throwers were a distinct group as far as body build was concerned. They were taller, heavier and had higher levels of subcutaneous fat than the other groups. Throwers had a low ponderal index with their limbs appearing as a series of relatively short levers, which would assist them in performance. Middle-distance runners were lighter than the other groups, whereas the sprinters and jumpers were similar to each other, suggesting that anthropometric variables can differentiate between groups of events in track and field athletes and should be considered for talent selection.

## 114.7 Field Team Sports

### *114.7.1 Cricket*

Cricket is a sport which requires all players to field and bat and is supported by a set of skills that defines a player's role which will contribute to the success of the team. One of the aspects of crickets that can affect the potential for success is peak bowling speed (Stuelcken et al. 2007). A study of the anthropometric and strength correlates in junior cricketers revealed multiple predictors of success in achieving peak bowling speed, which included height, body mass and estimated percentage muscle mass. From these measures, it was found that body mass and estimation of percentage muscle mass were considered to be the most useful anthropometric predictors of peak velocity in junior bowlers (Pyne et al. 2006); therefore, they should be used as part of a battery of tests for talent detection in youth players.

### *114.7.2 Hockey*

Field hockey requires intermittent running, accelerations and decelerations, requiring a high level of effort. Differences in anthropometric measures have been reported in players of differing levels (Ready and Van der Merwe 1986). A study of female players demonstrated that higher-level regional players had significantly lower skinfold thickness values and estimated percentage fat than the lower-level club players, suggesting that talent identification programmes should potentially use these anthropometric measures as part of the selection process (Keogh et al. 2003). A study of elite and sub-elite male and female junior players over three seasons demonstrated that elite male and female players increased in height and mass. Males also reduced estimated percentage body fat over time. Elite players appear to score better than their sub-elite counterparts in a number of characteristics and it is suggested that players should be tracked into adulthood (Elferink-Gemser et al. 2004).

### *114.7.3 Soccer*

Soccer is intermittent in nature and is multifactorial in terms of the elements required for success. A talent identification study by Reilly et al. (2000) demonstrated that elite-level junior players had significantly lower endomorphy scores than lower-level players. Additionally, elite-level players were leaner than lower-level players when considering both sum of skinfolds and estimated percentage fat. The sum of skinfolds also more clearly distinguished between the groups than did estimated percentage fat. With respect to positions, Gil et al. (2007) demonstrated that forwards were the leanest players, presenting the highest level of muscle. By contrast, the goalkeepers were found to be the tallest and heaviest players, with the largest skinfold values and the highest percentage fat values. For midfielders, height was one of the anthropometric discriminants of selection. Le Gall et al. (2010) demonstrated that graduate players from an elite youth academy were taller and heavier than amateurs. The findings of these studies suggest that anthropometric measures should be taken into consideration when attempting to detect talented for soccer.

## 114.8 Contact Team Sports

### *114.8.1 American Football*

American football players are thought to have a morphological profile similar to rugby players due to the similarities in playing profiles involving discontinuous bouts of intensive exercise with high levels of tackling. Research indicated that BMI values of collegiate players were classified as overweight or obese; however, average body fat percentage estimations placed them into the acceptable age- and gender-referenced normal ranges (Kaiser et al. 2008). With respect to positional differences, morphology of the players in the study was consistent with the positional specialisation requirements. For example, positions specialised for the line-off scrimmage blocking and tackling were taller and heavier than players at other positions. The positions specialised for sprinting and dynamic agility demonstrated lower height, weight, body fat percentages and BMI compared to the overall group (Kaiser et al. 2008). It was also suggested that, as the level of competition increases, so do weight, height and fat-free mass (FFM) (Williford et al. 1994), highlighting the importance of monitoring body composition at all levels of development.

### *114.8.2 Australian Rules Football (ARF)*

Like other contact field sports, ARF requires players to cover the majority of distances during a game at submaximal speeds, with shorter bursts of speed interspersed with longer periods of recovery. One of the main anthropometrical attributes for success is considered to be height, especially for key positions, such as forwards. A study to predict selection in an elite youth ARF team found that height and mass were anthropometric measures that could be used in a discriminant analysis to predict selection, with height considered to be one of the two most important discriminators for selection in elite under-18 ARF players. Additionally, selected players were shown to be significantly taller and heavier than non-selected players (Keogh 1999). Selected junior players appear to be relatively similar to senior players in terms of height (Douge 1988), but not in terms of body mass, although anthropometric measurements, such as girths and body mass, increase significantly as teenage males mature (Housh et al. 1997), signifying that under-18 ARF players are still maturing physically, which is required if players are to compete at the senior level. Anthropometric measures should be monitored at junior through to senior levels to maximise the chance of selection of optimal body types for ARF.

### *114.8.3 Rugby*

Rugby league is a collision sport that is intermittent in nature. The positions can be broadly classified into forwards or backs. Forwards are involved in significantly more collisions and tackles than backs and have a higher activity ratio of high:low intensity. Forwards also cover a larger distance than backs during a match. Studies of senior rugby league players have shown significant differences between positions in measures of height, body mass and skinfold thickness (O'Connor 1996). Research on junior elite rugby league players indicates that forwards are taller, heavier and have greater skinfold thicknesses than backs. When discriminating between starters and non-starters, elite starters were taller and heavier than non-starters, whereas sub-elite starters were taller than sub-elite non-starters (Gabbett et al. 2009). In a study attempting to identify and develop rugby talent, calf and upper-arm girths as well as humerus and femur diameters showed practical significance (Pienaar et al. 1998). The findings of the studies earlier indicate that physical characteristics of junior rugby players should be taken into account in talent identification models and should therefore be a consideration when setting realistic junior performance standards.

## 114.9 Court Sports

### *114.9.1 Badminton*

Badminton is considered to be an agility sport, which requires movements to be executed by the upper extremities, although performance is multifactorial. A study by Amusa et al. (2001) showed that height, weight and arm span are the most important indicators for performance in junior national players. Somatotype measures indicated that, in male players, mesomorphic ectomorph was the predominant measure, whilst endomorphic mesomorph was the main measure for females. It was also suggested that, to allow free movement around the court, lower weight athletes with low BMI values would have an advantage.

### *114.9.2 Basketball*

Basketball is an agility-based, intermittent sport that partially relies on jumping ability. Morphological proportions to support those activities is key; therefore; height is one of the key determinants of success, so are long limb lengths for defending, passing and shooting. In junior elite players, arm span was considered to be a predictor of overall success. When positions are considered, the best male point guards were taller than the rest, though the best power forwards were significantly taller and had a longer arm span than the rest. The best small forward players were also taller than the rest of the players in that position (Hoare 2000). In female players, positional differences existed between centres and point guards demonstrating lower levels of FFM and smaller arm span values. In best versus rest tests, the best females had proportionally longer legs than the rest of the cohort. Since significant differences exist in certain anthropometric measures in young players, monitoring anthropometric attributes appears to be a successful tool for predicting success alongside other factors related to basketball performance (Hoare 2000).

### 114.9.3 Handball

Handball is a dynamic sport characterised by speed, agility, reaction speed, explosive power, endurance, strength and coordination. In handball, absolute size of the body is an important factor in handball for both youth and adults. It is also suggested that the size of the hand is an important factor when selection criteria for players are set. This is due to hand size and finger length being useful for throwing accuracy. In a study of male youth players for talent detection purposes, significant differences were seen between the elite and non-elite players for body mass, arm length, relative arm length, arm span and both upper limb muscle circumferences (stretched and flexed). For the long-term development of talented players, a careful follow-up of the maturation process, including growth of the most important body segments, is considered necessary. In a discriminant analysis, height was considered an important determinant for performance and corresponds well with characteristics suggested as essential in youth and adult handball (Mohamed et al. 2009).

### 114.9.4 Netball

Netball is a court sport that is intermittent in nature with agility and jumping two of the key skills for success. Bale and Hunt (1986) demonstrated that elite players were heavier, significantly taller and had significantly smaller femur bone widths than players classified as good. Elite players showed total skinfold and estimated fat levels which suggested a larger muscle mass but lower levels of adiposity in relation to their height. Somatotype analysis showed most players were of the mesomorphic endomorph type or balanced mesomorphs (Hopper 1997). With respect to positions, centres were significantly shorter, lighter and had less fat than attackers and defenders. Attackers and defenders were the tallest and heaviest of the players, whereas central players were more mesomorphic than the attackers and defenders who tended to show more ectomorphic traits. There are several parameters that should be monitored to assess ability, of which body composition is one.

### 114.9.5 Tennis

Tennis is characterised by explosive activities interspersed with intermittent bouts over a long period of time. A high lean body mass/height ratio is thought to be an advantage. A study of adolescent junior players found the BMI and estimated percentage fat of players to be in the recommended range for young athletes (Juzwiak 2008), whereas, in a study by Elliot et al. (1990), it was indicated that, in male players, estimated percentage fat was lower in high-level players across age groups. The cohort of players were also shown to be more linear, expressing high ectomorphy levels, which is line agreement with the findings of Copley (1980), who suggested that ectomesomorphy is a required characteristic for successful tennis performance at the professional level.

For females, body composition was considered an important indicator of tennis performance from 11 to 15 years. Higher level players were leaner than the controls in both endomorphy levels and sum of skinfolds. Copley (1980) also showed that professional female players were more endomesomorphic than amateur players, although height and mass were not thought to discriminate between higher level and control subjects. A study by Sanchez-Muñoz et al. (2007) demonstrated that significant differences were observed in height and humeral and femoral breadths when comparing the first 12 and the lower ranked female players. The first 12 players were significantly taller than the lower ranked players, providing evidence for the use of talent identification in junior tennis.

### *114.9.6 Volleyball*

Volleyball is an intermittent sport that requires players to participate in frequent short bouts of high-intensity exercise, followed by periods of low-intensity activity. Thissen-Milder and Mayhew (1991) demonstrated that height and weight were two of the anthropometric characteristics measured in high-school players that could discriminate amongst starters and non-starters. Data from Melrose (2007) suggested that lean body mass and shoulder, hip and thigh girths are the key anthropometric physical determinants of performance in adolescent female volleyball players. In measures of junior national and state players, significant differences were detected between levels for height, standing-reach height and skinfold thickness. Male players were found to be taller, heavier and leaner and with greater standing-reach height than female players. A study of somatotypes in elite players showed positional differences, with setters tending to be endomorphic ectomorphs, hitters and opposites tending to be balanced ectomorphs, and centres tending to be ectomorphic mesomorphs (Duncan et al. 2006). The analysis of performance standards for junior volleyball highlights the importance of some characteristics as the level of playing increases.

## 114.10 Weight-Classified Sports

### *114.10.1 Judo*

Successful participation in Judo is thought to depend upon appropriate levels of technical skill, supported by a number of physical characteristics. In a study of junior males and female judokas, Little (1991) demonstrated that the estimated percentage body fat for junior males and females was less than the normative reference value. Given that the nature of Judo is to continuously grip your opponent whilst actively trying to remove them from a balanced stable position, it would seem that biological maturity would have an impact on performance and chance of success and performance differences, especially in junior males of the same chronological age, but contrasting maturity status, the difference of which is most apparent between the ages of 13 and 16 (Malina et al. 2004). This indicates the importance of monitoring maturity in junior judokas.

### 114.10.2 Sumo Wrestling

Sumo wrestlers are well known for their very large bodies, which has often raised questions about their health status. The anthropometric dimensions of sumo wrestlers, such as stature, body weight, length and circumference of the limbs and trunk have been reported previously. A study of wrestlers in the higher leagues demonstrated larger bodies than those who belong to the lower leagues (Nishizawa et al. 1976; Hattori et al. 1999). In college-level sumo wrestlers, BMI and estimated percentage fat was very high compared to non-athletes and all were characterised as obese, although further measures of body composition also demonstrated that the wrestlers had excessive fat-free mass values. To monitor the health status as well as the talent detection element, accurate methods should be used to estimate body composition in junior sumo wrestlers.

### 114.10.3 Taekwondo

Taekwondo is a weight-classified combat sport using a variety of kicking and punching movements. Fleming and Costarelli (2007) showed that following an analysis of skinfold measurements, a cohort of international standard athletes were very lean, with low levels of fat mass and high levels of muscle mass. Measures of BMI were high, which may be due to their lean body mass/height ratio as opposed to their level of obesity. Evidence from other combat sports suggests that athletes regularly compete at 5–10% below their natural body weight (Filaire et al. 2001), highlighting the importance of body composition.

### 114.10.4 Weightlifters

Somatotyping by Orvanova (1990) indicated that the athletes at the higher levels showed greater levels of mesomorphy and lower levels of endomorphy. Depending upon their pubertal growth spurt, young lifters have varying levels of mesomorphy and ectomorphy. When separated into weight groups, the lighter athletes showed higher levels of mesomorphy, whereas the heavier athletes demonstrated higher levels of endomorphic mesomorphy. Ectomorphy decreases, whereas mesomorphy and endomorphy were shown to increase with weight class. Comparison of age groups revealed that the younger lifters in each weight class had higher endomorphy and lower mesomorphy levels than the adult lifters. Ectomorphy was found to be higher in the youngest lifters, but only below the weight class of 82.5 kg. All age and weight classes of weightlifters demonstrated greater mesomorphy and lower ectomorphy than non-athletes and the differences tended to increase with weight class. Measures of bone mineral density revealed that it is found to be much higher in junior weightlifters due to the influence of the chronic overloads experienced with training for that sport (Conroy et al. 1993). When attempting to predict performance, Fry et al. (2006) showed that body mass and relative fat are two of the five screening tools that should be utilised for detection in junior weightlifters.

## 114.11 Water Sports

### *114.11.1 Rowing*

Extensively studied, anthropometric data from both males and females have emphasised the importance of body mass (Secher and Vaage 1983) and body size (Rodriguez et al. 1986) in rowing. In a cohort of youth rowers, from a selection of anthropometric measures, thigh girth and lean body mass, when entered into a regression table, were significant predictors of 1-km rowing performance (Mikulic and Ruzic 2008). Bourgois et al. (2000) also showed that male junior rowers had increased bicep, thigh and calf girths compared to reference data, whereas female junior rowers had increased biceps thigh, and calf compared to references and non-finalists. Of the rowers who reached the finals, all had larger measures in the biceps and thigh than the non-finalists. Therefore, anthropometric measures should be considered for performance prediction measures in rowing events for both males and females, as clear differences between athletes and reference data exist.

### *114.11.2 Sprint Kayak*

Sprint kayaking requires the athlete to propel themselves predominantly using the upper body. Aitken and Jenkins (1998) showed differences in body mass, biceps girth, upper arm length, forearm length, thigh length, lower leg length and biliocristal breadth between elite kayakers and controls. The elite female paddlers had greater mass and bicep girths than the female controls. With respect to key determinants of performance in male paddlers, those who had greater bi-acromial breadth and extremity lengths demonstrated greater improvements following training. Additionally, the morphological proportions of kayakers who performed at Olympic level revealed that elite paddlers had distinct characteristics compared to the general population, which included a greater than average thigh length, shoulder and chest breadths along with proportionally large upper body girths (arm and chest girth) and proportionally narrow hips in males and lean physiques as demonstrated by low skinfold scores (Ackland et al. 2003). The data from previous studies clearly indicate that anthropometric measures can be useful in the selection of individuals for high-level performance and should therefore be considered in athlete monitoring protocols.

### *114.11.3 Swimming*

Training for high-level swimming begins at an early age. Due to the large number of swimming events, research has attempted to classify the variety of characteristics which help to distinguish which event an individual should select and train for. Analysis of youth data for the prediction of 100-m freestyle performance suggested that upper extremity length was a significant predictor of 100-m freestyle performance, whereas body height, upper extremity and hand length were all significantly related to 100-m freestyle time (Geladas et al. 2005). In a variety of swimming events, Avlonitou (1994) showed that sprint and back swimmers were the tallest and heaviest among the events for both sexes. This group also had the highest values for upper and lower limbs and hand and foot lengths. The long-distance group was the shortest and lightest group for males and the lightest group for females. The female fly group had the lowest values for height, upper and lower limb lengths as well as hip width. Significant correlations were obtained between performance and somatometric variables. For swimmers participating in different events, variation in body size and form is already present at an early age. Analyses of swimming performance including body composition measures found significant relationships between the energy cost of swimming ($C_s$) and body mass, FFM and body mass in prepubertal and pubertal swimmers, suggesting that body composition parameters have a significant impact on $C_s$ (Jürimäe et al. 2007). It was also shown that, of the anthropometric measures, arm span was the best predictor of swimming performance. Swimming is clearly influence by anthropometrics; therefore, every effort should be made to clarify which anthropometric measures distinguish between events, thus allowing a talent identification option available for all events.

## 114.12 Practical Application to Sport and Performance

The data from these studies suggest that participants are characterised by a combination of body composition/body size traits which are believed to influence the chance of success in any given sport. It is also clear that success in sport is multifactorial and that the value of anthropometric measures in assisting with talent identification or predicting success is varied between and within sports. It is, however, clear that the measurement of kinanthropometry is a crucial tool in the search for information to assist coaches and athletes in the quest for success at the highest level in sport.

### Summary Points

- Talent identification programmes usually monitor several parameters, once of which is kinanthropometry.
- For talent identification purposes, measurements of kinanthropometry take into consideration physical growth and maturation, absolute size and proportionality, somatotyping and body composition as measured by a variety of methods.
- Athletes are characterised by a combination of body composition/body size traits which are believed to influence the chance of success in any given sport.
- It is thought that, in certain situations, it may be better to measure fewer but more discriminatory variables for potential athlete selection purposes.
- Success in sport is multifactorial; therefore, the value of anthropometric measures in assisting with talent identification or predicting success is varied between and within sports.

**Acknowledgements** The authors would like to take this opportunity to thank their respective Universities, Liverpool John Moores University and University of Granada, for the continued support during the writing of this chapter.

## References

Ackland TR. In: Marfell-Jones A, Stewart A, Olds T, editors. Kinanthropometry IX. Potchefstroom: ISAK; 2006.
Ackland TR, Ong KB, Kerr DA, Ridge B. J Sci Med Sport. 2003;6(3):285–94
Aitken DA, Jenkins DG. J Sports Sci. 1998;16:539–43
Amusa LO, Toriola AL, Dhaliwal HS, Mokgwathi MM. J Hum Movement Stud. 2001;40:115–28
Armstrong N, Welsman J. Young people and physical activity. Oxford: Oxford University Press; 1997

Avlonitou E. J Sports Med Phys Fitness. 1994;34:185–91
Bale P, Hunt S. Aus J Sci Med Sports. 1986;18(4):16–9
Barker A, Boreham C, Van Praagh E, Rowlands AV. In: Eston R, Reilly T, editors. Kinanathropometry and exercise physiology laboratory manual: tests, procedures and data. Oxon: Routledge; 2009. p. 197–230
Baxter-Jones ADG, Sherar LB. In: Armstrong N, editors. Paediatric exercise physiology: Advances in sport and exercise series (Spurway N, MacLaren, eds.). London: Elsevier; 2007. p. 1–26
Beunen G. In: Eston R, Reilly T, editors. Kinanathropometry and exercise physiology laboratory manual: Tests, procedures and data. Oxon:Routledge 2009. p. 73–100
Bloomfield J. In: Bloomfield J, Fricker PA, Fitch K, editors. Text-book of science and medicine in sport. Melbourne:Blackwell Scientific; 1992.
Boileau RA, Lohman TG, Slaughter MH. J Sport Sci. 1985;7:17–27
Bourgois J, Claessens AL, Vrijens J, Philippaerts R, Van Renterghem B, Thomis M, Janssens M, Loss R, Lefevre J. Br J Sports Med. 2000;34:213–7
Brozek J, Grande F, Anderson JT, Keys A. Ann NY Acad Sci. 1963;110:113–40
Cole TJ, Bellizzi MC, Flegal KM, Dietz WH. Br Med J. 2000;320:1240–3
Conroy BP, Kraemer WJ, Maresh CM, Fleck SJ, Stone MH, Fry AC, Miller PD, Dalsky GP. Med Sci Sports Exerc. 1993;25(10):1103–9
Copley BB. South Afr J Res Sports Phys Educ Rec. 1980;3(2):33–44
Graves JE, Pollock ML, Sparling B. Int J Sports Med. 1987;8:96S–102S
Courteix D, Lespessailles E, Jaffre C, Obert P, Benhamou CL. Acta Paediatr. 1999;88:803–8
Di Cagno A, Baldari C, Battaglia C, Brasili P, Merni F, Piazza M, Toselli S, Ventrella AR, Guidetti L. J Sports Med Phys Fitness. 2008;48:341–6
Douda HT, Toubekis AG, Avloniti AA, Tokmakidis SP. Int J Sports Physiol Perform. 2008;3:41–54
Douge B. In: Reilly T, Lees A, Davids K, Murphy WJ, editors. Science and football. London: E & FN Spon 1988. p. 3–19
Drinkwater DT. An anatomically derived method for the anthropometric estimation of human body composition. Ph.D. thesis, Burnaby, BC: Simon Fraser University; 1984
Drinkwater DT, Ross WD. In: Ostyn M, Beunen G, Simons J, editors. Kinanthropometry II. Baltimore, MD: University Park Press, 1980. p. 177–89
Duncan MJ, Woodfield L, Al-Nakeeb Y. Br J Sports Med. 2006;40:649–51
Durnin JVGA, Womersley J. Br J Nutr. 1974;32:77–97
Elferink-Gemser MT, Visscher C, Lemmink KAPM, Mulder T. J Sports Sci. 2004;22:1053–63
Elliot BC, Ackland TR, Blanksby BA, Hood KP, Bloomgield J. Aus J Sci Med Sport. 1989;21(3):14–21
Elliot BC, Ackland TR, Blanksby BA, Bloomfield J. Aus J Sci Med Sport. 1990;22(4):87–92
Eston R, Reilly T. Kinanthropometry and exercise physiology laboratory manual: Tests, procedures and data. In: Eston R, Reilly T, editors. Oxon: Routledge, 2009
Faulkner JA. In: Falls H, editors. Human exercise physiology. Baltimore, MD: Academic Press; 1968. p. 87–95
Faria IE, Faria EW. J Sports Med. 1989;29(4):369–78
Faria IE, Faria EW, Roberts S, Yoshimura D. Res Q Exerc Sport. 1989;60(4):388–95
Filaire E, Maso F, Degoutte F, Jouanel P, Lac G. Int J Sports Med. 2001;22(6):454–9
Fleming S, Costarelli V. Nutr Food Sci. 2007;37(5):358–66
Fry AC, Ciroslan D, Fry MD, Leroux CD, Schilling BK, Chiu LZF. J Strength Cond Res. 2006;20(4):861–6
Gabbett T, Georgieff B, Domrow N. J Sports Sci. 2007;25(12):1337–44
Gabbett T, Kelly J, Ralph S, Driscoll D. J Sci Med Sport. 2009;12:215–22
Geladas ND, Nassis GP, Pavlicevic S. Int J Sports Med. 2005;26:139–44
Gil SM, Gil J, Ruiz F, Irazusta A, Irazusta J. J Strength Cond Res. 2007;21(2):438–45
Hattori K, Kondo M, Abe T, Tanaka S, Fukunaga T. Ann Hum Biol. 1999;26:179–84
Heath BH, Carter JEL. Am J Phys Anthropol. 1967;27:57–74
Heath BH, Carter JEL. Somatotyping: development and applications. Cambridge: Cambridge University Press; 1990
Helsen WF, Van Winckel J, Williams AM. J Sports Sci. 2005;23(6):629–36
Hoare DG. J Sci Med Sport. 2000;3(4):391–405
Hollings SC, Robson GJ. J Sports Med Phys Fitness. 1991;31:178–82
Hopper DM. Br J Sports Med. 1997;31(3):197–9
Housh TJ, Evotovich TK, Stout JR, Housh DJ, Johnson GO, Briese MC, Perry SR. J Strength Cond Res. 1997; 11(3):159–62
Jürimäe J, Haljaste K, Cicchella A, Lätt E, Purge P, Leppik A, Jürimäe T. Pediatr Exerc Sci. 2007;19:70–81
Juzwiak C, Amancio OMS, Vitalle MSS, Pinheiro MM, Szejnfeld VL. J Sports Sci. 2008;26(11):1209–17
Kaiser GE, Womack JW, Green JS, Pollard B, Miller GS, Crouse SF. J Strength Cond Res. 2008;22(1):243–9
Katch F, Michael ED, Horvath SM. J Appl Physiol. 1967;23:811–3
Keogh J. J Sci Med Sport. 1999;2(2):125–33

Keogh JWL, Weber CL, Dalton CT. Can J Appl Physiol. 2003;28(3):397–409
Kidd D, Winter EM. Br J Sports Med. 1983;17(4):152–3
Kretschmer E. Körperbau und Charakter. Berlin Springer Verlag 1921
Larsen HB, Christensen DL, Nolan T, Sondergaard H. Ann Hum Biol. 2004;31(2):159–73
Le Gall F, Carling C, Williams M, Reilly T. J Sci Med Sport 2010;13(1): 90–95
Little NG. J Sports Med Phys Fitness. 1991;31(4):510–20
Lohman TF. Advances in body composition assessment. Current issues in exercise science series (monograph number 3) Champaign, IL:Human Kinetics, 1992
Lowery, G. Growth and development of children. 7th ed. Chicago, IL: Year Book Medical; 1978
Malina RM, Bouchard C, Bar-Or O. Growth, maturation, and physical activity. Champaign, IL: Human Kinetics; 2004
Matiegka J. Am J Phys Anthropol. 1921;4:223–30
Meleski BW, Shoup RF, Malina RM. Hum Biol. 1982;54(3):609–25
Melrose DR, Spanil FJ, Bohling ME, Bonnette RA. J Strength Cond Res. 2007;21(2):481–86
Mikulic P, Ruzic L. J Sci Med Sport. 2008;11(2):218–26
Miletic D, Katic R, Males B. Coll Antropol. 2004;28:727–37
Mohamed H, Vaeyens R, Matthys S, Multael M, Lefevre J, Lenoir M, Philippaerts. J Sports Sci. 2009;27(3):257–66
Monsma EV, Malina RM. J Sports Med Phys Fitness. 2005;45:491–500
Nishizawa T, Akaoka I, Nishida Y, Kawaguchi Y, Hayashi E, Yoshimura T. Am J Clin Nutr. 1976;29:1167–74
Norton KI, Olds TS, Olive SC, Craig NP. In: Norton KI, Olds TS, editors. Anthropometrica. Sydney: UNSW Press, 1996
O'Connor D. Strength Cond Coach. 1996;4:21–6
Orvanova E. Somatotypes of weight lifters. J Sports Sci. 1990;8:119–37
Pienaar AE, Spamer MJ, Steyn HS. J Sports Sci. 1998;16:691–9
Poortmans JR, Boisseau N, Moraine JJ, Moreno-Reyes R, Goldman S. Med Sci Sports Exerc. 2005;37:316–22
Pyne DB, Duthie GM, Saunders PU, Petersen CA, Portus MR. J Strength Cond Res. 2006;20(3):620–26
Ready AE, Van der Merwe M. Aust J Sci Med Sport. 1986;18:13–8
Reilly T, Williams AM, Nevill, Franks A. J Sports Sci. 2000;18:695–702
Rodriguez FA. In: Reilly T, Watkins J, Borms J, editors. Kinanthropometry III. London: E & FN Spon; 1986. p. 255–61
Ross WD, Brown SR, Yu JW, Faulkner RA. Sports Med. 1977;17:195–205
Rowley S. J Child Psychol Psychiatry. 1987;28:371–7
Sánchez-Muñoz C, Sanz D, Zabala M. Br J Sports Med. 2007;41:793–9
Secher NH, Vaage O. Eur J Appl Phys. 1983;52:88–93
Siri WE. Body composition from fluid spaces and density. Berkeley, CA: Doner Laboratory of Medical Physics, University of California; 1956
Siri WE. In: Brozek J, Henschel A, editors. Techniques for measuring body composition. Washington, DC: National Academy of Sciences, 1961. p. 223–44
Sheldon WH, Stevens SS, Tucker WB. The varieties of human physique. New York: Harper and Brothers; 1940
Sherar LB, Mirwald RL, Baxter-Jones AD, Thomis M. J Pediatr. 2005;147(4):508–14
Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, Bemben DA. Hum Biol. 1988;60:709–23
Stuelcken M, Pyne D, Sinclair P. J Sports Sci. 2007;25(14):1587–97
Thissen-Milder M, Mayhew JL. J Sports Med Phys Fitness. 1991;31:380–4
Tittel K. In: Landry F, Orban WA, editors. Biomechanics of sport and Kinanthropometry. Miami: Symposia Specialists Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B. Br J Sports Med. 2003;37:420–424
Viola G. La constituzione individuale. Bologna: Cappelli; 1933
Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B. Br J Sports Med. 2003;37:420–4
Williford HN, Kirkpatrick J, Scharff-Olson M, Blessing DL, Zhen Wang N. Am J Sports Med. 1994;22(6):859–62
Wilmore JH, Brown CH, Davis JA. Ann N Y Acad Sci. 1977; 301:764–76

II

# ANTHROPOMETRIC CHARACTERISTICS, BODY COMPOSITION AND SOMATOTYPE OF ELITE JUNIOR TENNIS PLAYERS

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**Br J Sports Med 2007; 41:793-799**

ORIGINAL ARTICLE

# Anthropometric characteristics, body composition and somatotype of elite junior tennis players

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*Br J Sports Med* 2007;**41**:793–799. doi: 10.1136/bjsm.2007.037119

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Accepted 7 July 2007

**Objectives:** The aims of this study were to describe the anthropometric characteristics, body composition and somatotype of elite male and female junior tennis players, to compare the anthropometric data, body composition and somatotype of the first 12 elite junior tennis players on the ranking with the lower ranked players, and to establish an anthropometric profile chart for elite junior tennis players.
**Methods:** A total of 123 (57 males and 66 females) elite junior tennis players participated in this study. The athletes were divided into two groups, the first 12 and the lower ranked players, according to gender. A total of 17 anthropometric variables were recorded of each subject.
**Results:** There were no significant differences in height and weight between the first 12 and the lower ranked boys, while the first 12 girls were significantly taller than the lower ranked girls ($p = 0.009$). Significant differences were found for humeral and femoral breadths between the first 12 and the lower ranked girls ($p = 0.000$; $p = 0.004$, respectively). The mean (SD) somatotype of elite male junior tennis players could be defined as ectomesomorphic (2.4 (0.7), 5.2 (0.8), 2.9 (0.7)) and the mean (SD) somatotype of elite female junior tennis players evaluated could be defined as endomesomorphic (3.8 (0.9), 4.6 (1.0), 2.4 (1.0)). No significant differences were found in somatotype components between the first 12 and the lower ranked players of both genders.
**Conclusions:** When comparing the first 12 and the lower ranked elite junior tennis players of both genders, no significant differences were observed in any measured item for the boys. By contrast, significant differences were observed in height and humeral and femoral breadths between the first 12 and the lower ranked girls, whereby the first 12 were taller and had wider humeral and femoral breadths than the lower ranked players. These differences could influence the playing style of junior female players.

The interest in anthropometric characteristics, body composition and somatotype from different competitive sports has increased over the last decades. It has been well described that there are specific physical characteristics in many sports, such as the anthropometric profile, that indicate whether the player would be suitable to compete at the highest level in a specific sport.[1–8] The quantification of morphological characteristics of elite athletes can be a key point in relating body structure to sports performance.

During the past two decades, great changes have taken place in tennis with respect to technique and tactics, and even more so with respect to the physical performance of the players. Nowadays, tennis is one of the most popular sports in the world and is extensively studied. Most of the scientific literature has focused on physiological[9–17] and biomechanical variables,[18–29] physical performance,[30–33] and prevention and treatment of injuries.[34–40] At present, there is little data on the physical characteristics of young[41–44] and adult[45] tennis players.

Therefore, the purpose of this study was to determine the anthropometric characteristics, body composition and somatotype of elite junior tennis players, in order to use this for training and for the detection and identification of talented players.

## METHODS

### Subjects

The sample consisted of 123 elite junior tennis players (57 males and 66 females) from 28 national teams that competed at the 2005 and 2006 Davis Junior Cup and Fed Junior Cup (a team competition where the best players in the world from the under 16 category take part). The subjects were grouped according to gender and results; the first 12 players and the lower ranked players. The latter difference was made in order to separate the sample according to playing level, as even though all the tennis players studied had been training for more than 6 years at 16 h/week (tables 1 and 2), at the international level there are still differences between the best teams and the lower ranked teams in number of training hours per week or number of competitions carried. We aimed to separate the teams at the highest position in the final classification (quarter final, semifinal and final) from the lower ranked players. Therefore, the first 12 subjects studied were a representative sample of the best junior players of the world, and the best in the individual rankings.

The mean (SD) somatotype of elite male junior tennis players evaluated could be defined as ectomesomorphic (2.4 (0.7), 5.2 (0.8), 2.9 (0.7)), ranging from 1.4–3.9 for endomorphy, 3.0–7.5 for mesomorphy and 1.5–5.2 for ectomorphy. The mean (SD) somatotype of elite female junior tennis players evaluated could be defined as endomesomorphic (3.8 (0.9), 4.6 (1.0), 2.4 (1.0)), ranging from 2.4–5.7 for endomorphy, 2.6–6.8 for mesomorphy and 0.7–4.6 for ectomorphy. No significant differences were found in somatotype components between the first 12 and the lower ranked players of both genders. Figures 1 and 2 illustrate the somatotypes for all the studied elite male and female junior tennis players.

Tables 3 and 4 give the anthropometric profile charts of elite male and female junior tennis players. The scores for 17 anthropometric dimensions are located on the chart together with the corresponding percentile values.

**Abbreviations:** DEXA, dual *x* ray absoptiometry; ISAK, International Society for the Advancement of Kinanthropometry; TEM, technical error of measurement

**Table 1** Descriptive anthropometric characteristics for male junior tennis players (mean (SD) and range), and differences among the first 12 and the lower ranked players

| | All male junior tennis players (n = 57) | | First 12 players (n = 12) | | Lower ranked players (n = 45) | | |
|---|---|---|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range | Mean (SD) | Range | p Value |
| Age (years) | 16.2 (0.4) | 14.8–16.7 | 16.4 (0.2) | 16.0–16.7 | 16.1 (0.4) | 14.8–16.7 | NS |
| Height (cm) | 176.8 (6.4) | 163.2–195.2 | 176.9 (7.1) | 166.3–192.4 | 176.7 (6.3) | 163.2–195.2 | NS |
| Weight (kg) | 69.9 (6.8) | 51.4–86.3 | 70.4 (6.1) | 60.9–82.3 | 69.8 (7.0) | 51.4–86.3 | NS |
| BMI ($kg/m^2$) | 22.3 (1.4) | 19.3–26.0 | 22.5 (0.8) | 21.6–24.1 | 22.3 (1.5) | 19.3–26.0 | NS |
| Breadth (cm) | 182.1 (6.7) | 165.1–197.6 | 182.4 (6.6) | 174.8–197.6 | 182.1 (6.8) | 165.1–196.5 | NS |
| Triceps skinfold (mm) | 9.5 (2.7) | 5.3–15.9 | 8.8 (1.9) | 6.1–12.3 | 9.6 (2.9) | 5.3–15.9 | NS |
| Biceps skinfold (mm) | 4.3 (1.2) | 2.8–7.9 | 4.0 (0.7) | 3.0–5.5 | 4.4 (1.3) | 2.8–7.9 | NS |
| Subscapular skinfold (mm) | 8.3 (1.7) | 5.4–14.1 | 7.7 (1.1) | 6.5–10.5 | 8.5 (1.8) | 5.4–14.1 | NS |
| Suprailiac skinfold (mm) | 12.9 (4.5) | 6.4–24.6 | 12.4 (3.1) | 7.5–18.0 | 13.0 (4.9) | 6.4–24.6 | NS |
| Supraspinal skinfold (mm) | 7.6 (2.7) | 4.5–16.6 | 7.1 (1.0) | 5.3–9.3 | 7.9 (2.9) | 4.5–16.6 | NS |
| Abdominal skinfold (mm) | 11.3 (4.5) | 5.8–25.2 | 9.8 (1.7) | 6.9–12.6 | 11.7 (4.9) | 5.8–25.2 | NS |
| Thigh skinfold (mm) | 10.7 (2.7) | 6.6–17.3 | 10.1 (2.0) | 7.5–13.4 | 10.9 (2.8) | 6.6–17.3 | NS |
| Calf skinfold (mm) | 8.2 (2.3) | 5.1-17.0 | 7.9 (1.9) | 5.5–10.9 | 8.3 (2.4) | 5.1–17.0 | NS |
| Upper arm girth (cm) † | 28.7 (1.7) | 23.9–32.1 | 28.9 (1.0) | 27.3–30.5 | 28.7 (1.8) | 23.9–32.1 | NS |
| Upper arm girth (cm)†† | 30.7 (1.8) | 26.9–34.4 | 30.6 (0.9) | 29.4–32.6 | 30.7 (1.9) | 26.9–34.4 | NS |
| Thigh girth (cm) | 51.2 (2.5) | 44.0–56.3 | 51.9 (2.0) | 49.1–56.3 | 51.0 (2.6) | 44.0–56.1 | NS |
| Calf girth (maximum) (cm) | 37.3 (1.8) | 33.0–41.3 | 37.6 (1.7) | 34.8–40.8 | 37.2 (1.8) | 33.0–41.3 | NS |
| Humeral breadth (cm) | 7.2 (0.4) | 6.4–8.0 | 7.2 (0.4) | 6.4–7.9 | 7.2 (0.3) | 6.6–8.0 | NS |
| Femoral breadth (cm) | 10.4 (0.5) | 9.4–11.7 | 10.4 (0.6) | 9.4–11.5 | 10.4 (0.5) | 9.7–11.7 | NS |
| Sum of 3 skinfolds (mm) | 30.6 (8.0) | 17.5–47.8 | 28.9 (5.3) | 21.1–39.2 | 31.1 (8.6) | 17.5–47.8 | NS |
| Sum of 6 skinfolds (mm) | 65.6 (18.0) | 36.7–111.2 | 61.2 (9.5) | 47.3–81.1 | 66.8 (19.5) | 36.7–111.2 | NS |
| Sum of 8 skinfolds (mm) | 78.1 (20.3) | 45.0–125.9 | 73.0 (10.9) | 56.0–96.1 | 79.4 (22.0) | 45.0–125.9 | NS |
| % Body fat[48] | 15.8 (3.6) | 8.9–22.2 | 15.2 (2.4) | 11.1–19.8 | 16.0 (3.9) | 8.9–22.2 | NS |
| % Muscle mass[50] | 46.7 (1.9) | 42.0–51.9 | 47.0 (1.7) | 44.3–49.2 | 46.6 (2.0) | 42.0–51.9 | NS |
| Endomorphy | 2.4 (0.7) | 1.4–3.9 | 2.2 (0.4) | 1.7–2.9 | 2.5 (0.7) | 1.4–3.9 | NS |
| Mesomorphy | 5.2 (0.8) | 3.0–7.5 | 5.3 (0.4) | 4.6–5.8 | 5.2 (0.9) | 3.0–7.5 | NS |
| Ectomorphy | 2.9 (0.7) | 1.5–5.2 | 2.8 (0.6) | 1.6–3.8 | 2.9 (0.8) | 1.5–5.2 | NS |
| Total years playing tennis | 7.9 (1.6) | 7.0–9.0 | 8.3 (0.9) | 7.0–9.0 | 7.5 (1.4) | 7.0–9.0 | NS |
| Training (h/week) | 23.2 (3.4) | 18.0–27.0 | 25.6 (2.1) | 23.0–27.0 | 22.1 (3.9) | 18.0–25.0 | NS |

*$p<0.05$, **$p<0.001$, ***$p<0.0001$. NS, not significant.
†Relaxed; ††flexed and tensed.

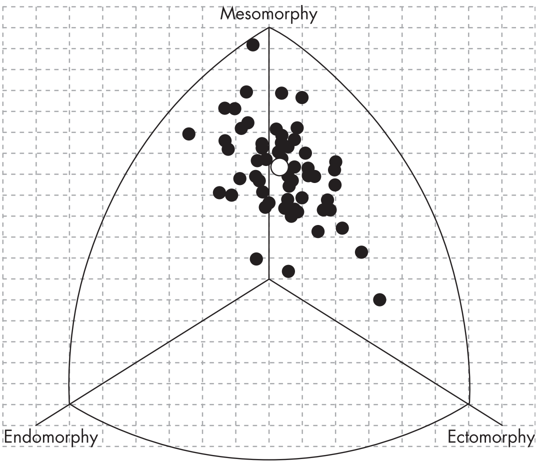


**Figure 1** Somatotype distribution of elite male junior tennis players (n = 57). ○: mean somatotype = 2.4–5.2–2.9.

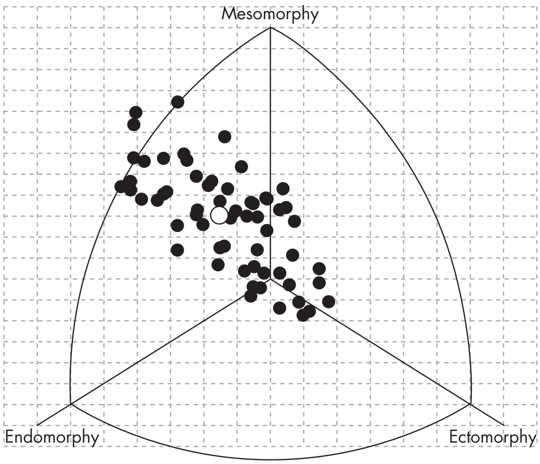


**Figure 2** Somatotype distribution of elite female junior tennis players (n = 66). ○: mean somatotype = 3.8–4.6–2.4.

The study was approved by the Review Committee for Research Involving Human Subjects of the University of Granada, and oral as well as written information was given. Before measurement, written informed consent was obtained from each participant and coach.

### Data collection

Measurements were performed following the standardised techniques adopted by the International Society for the Advancement of Kinanthropometry (ISAK).[47] All measurements were taken by the same investigator, an anthropometrist accredited by the ISAK. The technical error of measurement (TEM) was lower than 5% for skinfolds and lower than 1% for the other measurements. The instruments were calibrated prior to use and all measurements were taken on the subject's right side. Anthropometric variables included body mass, height, breadth, eight skinfolds (biceps, triceps, subscapular, suprailiac, supraspinal, abdominal, thigh and medial calf), four girths (upper arm relaxed, upper arm flexed and tensed, thigh and maximum calf), and two breadths (humeral and femoral). Height was measured on a stadiometer (GPM, Seritex, Inc., Carlstadt, New Jersey) to the nearest 0.1 cm, and the weight was recorded on a portable scale (model 707, Seca Corporation, Columbia, Maryland) to the nearest 0.1 kg. Skinfolds were taken using a calliper (Holtain Ltd, Crymych, UK) to the nearest 0.2 mm, and the girths were performed with a flexible metallic tape measure (Holtain Ltd). Skinfolds were taken three times and the average was employed in further calculations. The sum of three skinfolds (triceps, subscapular, supraspinal), six skinfolds (sum of three and suprailiac, abdominal and thigh), and eight skinfolds (sum of six and biceps and medial calf) were also calculated. BMI was calculated as weight/height$^2$ where weight was expressed in kilograms (kg) and height in metres (m). Body density was estimated using the method of Durnin and Womersley.[48] Density was transformed to percentage of body fat (%BF) by the Siri's equation.[49] Percentage of muscle mass (% MM) was determined using the method of Poortmans *et al*.[50] Somatotype was determinate according to the equations of Carter and Heath.[51]

### Statistical analysis

Standard descriptive statistics (mean, SD and range) were used to present the characteristics of the subjects for all variables. A non-parametric Mann–Whitney U test was used to compare the anthropometric data between the first 12 and the lower ranked players groups of both genders. The 5% level of probability was chosen to represent statistical significance. A profile chart with norms, using percentiles (p values of 5, 10, 25, 50, 75, 90, 95) was constructed. The statistical analysis using a statistical package was carried out (V.14.0; SPSS, Inc, Chicago, Illinois, USA).

## RESULTS

Tables 1 and 2 gives the mean, SD, and ranges for the age, anthropometric characteristics, body composition, somatotype, total years playing tennis and hours of training per week for the elite male and female junior tennis players. In addition, the results of the statistical analysis for the differences between the first 12 and the lower ranked players of both genders are presented. There were no significant differences in height and weight between the first 12 and the lower ranked boys, while the first 12 girls were significantly taller than the lower ranked girls ($p = 0.009$). No significant differences were observed in breadth, body mass index (BMI), skinfold thickness, girth, body composition, or somatotype between the first 12 players and the lower ranked boys, while significant differences were found for humeral and femoral breadths between the first 12 and the lower ranked girls ($p = 0.000$; $p = 0.004$, respectively).

## DISCUSSION

A few studies have examined physical characteristics related to playing tennis.[41–45] Our study attempts to describe the anthropometric characteristics, body composition and somatotype in a homogeneous sample (according to performance) of elite junior tennis players.

Elliot *et al*[42] tested a sample of male and female tennis players (age range 10–12 years) who regularly attained a semi-final position in the Western Australian Lawn Tennis Association sanctioned tournaments biannually over a 5 year period. He compared them with another sample who regularly or occasionally attended a quarter final position in the same tournaments and with non-competitive performers. In the present study, elite male and female junior tennis players were taller and heavier than those in the study by Elliot *et al*[42] (mean (SD) 176.8 (6.4) cm vs 169.6 (8.3) cm; 69.9 (6.8) kg vs 54.0

**Table 2** Descriptive anthropometric characteristics for female junior tennis players (mean (SD and range), and differences among the first 12 and the lower ranked players

| | All female junior tennis players (n = 57) | | First 12 players (n = 12) | | Lower ranked players (n = 45) | | |
|---|---|---|---|---|---|---|---|
| | Mean (SD) | Range | Mean (SD) | Range | Mean (SD) | Range | p Value |
| Age (years) | 15.9 (0.6) | 14.2–16.7 | 16.1 (0.5) | 14.8–16.6 | 15.9 (0.6) | 14.2–16.7 | NS |
| Height (cm) | 165.4 (6.3) | 149.7–180.0 | 170.0 (6.9) | 156.6–180.0 | 164.3 (5.8) | 149.7–177.3 | 0.009* |
| Weight (kg) | 59.9 (6.2) | 45.1–77.6 | 62.0 (4.4) | 55.6–68.7 | 59.4 (6.5) | 45.1–77.6 | NS |
| BMI (kg/m$^2$) | 21.9 (1.7) | 18.7–25.4 | 21.5 (1.9) | 19.0–24.6 | 22.0 (1.7) | 18.7–25.4 | NS |
| Breadth (cm) | 167.9 (6.9) | 153.6–186.1 | 170.9 (7.5) | 156.5–183.2 | 167.3 (6.6) | 153.6–186.1 | NS |
| Triceps skinfold (mm) | 16.3 (4.0) | 9.3–26.1 | 15.8 (4.1) | 11.1–25.7 | 16.4 (4.0) | 9.3–26.1 | NS |
| Biceps skinfold (mm) | 7.4 (2.6) | 3.3–17.1 | 7.8 (2.7) | 4.9–13.1 | 7.3 (2.6) | 3.3–17.1 | NS |
| Subscapular skinfold (mm) | 9.3 (2.4) | 5.9–17.3 | 9.6 (2.6) | 6.5–15.5 | 9.2 (2.4) | 5.9–17.3 | NS |
| Suprailiac skinfold (mm) | 19.1 (6.0) | 8.6–33.9 | 19.5 (7.0) | 9.9–31.5 | 19.1 (5.9) | 8.6–33.9 | NS |
| Supraspinal skinfold (mm) | 10.8 (3.7) | 5.6–22.5 | 11.2 (4.2) | 6.5–20.5 | 10.7 (3.6) | 5.6–22.5 | NS |
| Abdominal skinfold (mm) | 17.7 (5.9) | 6.9–30.3 | 19.0 (6.4) | 9.8–28.3 | 17.4 (5.8) | 6.9–30.3 | NS |
| Thigh skinfold (mm) | 20.4 (4.5) | 10.9–31.7 | 18.9 (3.7) | 13.1–26.7 | 20.8 (4.6) | 10.9–31.7 | NS |
| Calf skinfold (mm) | 14.3 (3.9) | 7.9–24.0 | 14.3 (3.1) | 11.1–20.7 | 14.3 (4.1) | 14.3–4.1 | NS |
| Upper arm girth (cm) † | 27.0 (1.8) | 22.9–31.5 | 27.2 (1.5) | 25.1–30.4 | 26.9 (1.8) | 22.9–31.5 | NS |
| Upper arm girth (cm)†† | 27.9 (1.7) | 24.4–31.9 | 28.1 (1.6) | 26.0–31.1 | 27.9 (1.7) | 24.4–31.9 | NS |
| Thigh girth (cm) | 49.7 (2.9) | 43.1–57.4 | 49.3 (2.5) | 45.3–53.9 | 49.8 (3.0) | 43.1–57.4 | NS |
| Calf girth (maximum) (cm) | 35.7 (2.1) | 31.6–40.0 | 36.5 (2.2) | 33.4–39.1 | 35.6 (2.0) | 31.6–40.0 | NS |
| Humeral breadth (cm) | 6.3 (0.3) | 5.3–6.9 | 6.6 (0.2) | 6.3–6.9 | 6.2 (0.3) | 5.3–6.9 | 0.000** |
| Femoral breadth (cm) | 9.8 (0.6) | 8.8–11.4 | 10.1 (0.5) | 9.3–10.8 | 9.7 (0.6) | 8.8–11.4 | 0.004* |
| Sum of 3 skinfolds (mm) | 44.7 (10.9) | 25.9–67.6 | 44.9 (12.0) | 29.4–65.0 | 44.7 (10.7) | 25.9–67.6 | NS |
| Sum of 6 skinfolds (mm) | 102.0 (24.2) | 58.7–155.5 | 102.2 (27.3) | 64.9–147.8 | 102.0 (23.8) | 58.7–155.5 | NS |
| Sum of 8 skinfolds (mm) | 123.7 (28.8) | 73.1–190.0 | 124.3 (31.5) | 83.5–180.9 | 123.6 (28.5) | 73.1–190.0 | NS |
| % body fat[48] | 28.5 (3.7) | 21.1–34.7 | 28.6 (3.9) | 23.2–34.7 | 28.5 (3.6) | 21.1–34.7 | NS |
| % muscle mass[50] | 45.2 (1.5) | 41.6–49.3 | 44.9 (1.5) | 41.6–46.6 | 45.3 (1.5) | 42.9–49.3 | NS |
| Endomorphy | 3.8 (0.9) | 2.4–5.7 | 3.7 (1.0) | 2.6–5.5 | 3.8 (0.9) | 2.4–5.7 | NS |
| Mesomorphy | 4.6 (1.0) | 2.6–6.8 | 4.6 (1.2) | 3.1–6.5 | 4.6 (0.9) | 2.6–6.8 | NS |
| Ectomorphy | 2.4 (1.0) | 0.7–4.6 | 2.9 (1.2) | 0.8–4.6 | 2.3 (0.9) | 0.7–4.2 | NS |
| Total years playing tennis | 7.2 (0.9) | 6.0–8.0 | 8.1 (0.7) | 7.0–8.0 | 6.9 (1.2) | 6.0–8.0 | NS |
| Training (h/week) | 21.4 (2.9) | 16.0–25.0 | 23.2 (2.3) | 22.0–25.0 | 20.4 (2.6) | 16.0–26.0 | NS |

*$p<0.05$, **$p<0.001$, ***$p<0.0001$. NS, not significant.
†Relaxed; ††flexed and tensed.

**Table 3** Anthropometric profile chart for the total male junior tennis players (n = 57)

| | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 25 | 50 | 75 | 90 | 95 |
| Height (cm) | 166.3 | 166.8 | 173.0 | 177.3 | 179.9 | 184.5 | 190.2 |
| Weight (kg) | 56.1 | 61.6 | 66.3 | 69.2 | 73.7 | 79.6 | 82.5 |
| Breadth (cm) | 172.2 | 174.1 | 177.4 | 182.3 | 186.6 | 190.8 | 193.0 |
| Triceps skinfold (mm) | 5.7 | 6.0 | 7.1 | 9.2 | 11.5 | 14.0 | 14.2 |
| Biceps skinfold (mm) | 3.0 | 3.1 | 3.2 | 4.1 | 4.9 | 5.7 | 7.0 |
| Subscapular skinfold (mm) | 5.8 | 6.5 | 7.1 | 8.1 | 9.2 | 10.9 | 11.1 |
| Suprailiac skinfold (mm) | 6.6 | 7.5 | 9.4 | 12.2 | 15.9 | 20.2 | 21.8 |
| Supraspinal skinfold (mm) | 4.7 | 5.2 | 5.8 | 7.1 | 8.4 | 11.1 | 14.7 |
| Abdominal skinfold (mm) | 5.8 | 6.0 | 8.4 | 10.5 | 13.1 | 16.4 | 22.4 |
| Thigh skinfold (mm) | 6.9 | 7.3 | 8.5 | 11.0 | 12.2 | 15.0 | 16.5 |
| Calf skinfold (mm) | 5.4 | 5.7 | 6.6 | 7.8 | 9.7 | 11.0 | 11.9 |
| Upper arm relaxed girth (cm) | 25.5 | 26.1 | 27.6 | 29.1 | 29.6 | 30.6 | 31.5 |
| Upper arm flexed and tensed girth (cm) | 27.2 | 27.9 | 29.7 | 30.8 | 31.8 | 32.8 | 33.6 |
| Thigh girth (cm) | 47.2 | 48.2 | 49.6 | 51.4 | 52.8 | 54.1 | 55.9 |
| Maximum calf girth (cm) | 34.2 | 34.8 | 36.3 | 37.0 | 38.4 | 39.8 | 40.6 |
| Humeral breadth (cm) | 6.6 | 6.7 | 7.0 | 7.2 | 7.4 | 7.8 | 7.9 |
| Femoral breadth (cm) | 9.7 | 9.8 | 10.0 | 10.2 | 10.7 | 11.1 | 11.3 |
| Body fat (%) | 9.6 | 10.8 | 13.5 | 15.4 | 18.6 | 21.5 | 22.1 |
| Muscle mass (%) | 43.9 | 44.6 | 45.2 | 46.6 | 48.0 | 48.9 | 50.8 |

(8.8) kg for male and 165.4 (6.3) cm vs 164.5 (7.5) cm; 59.9 (6.2) kg vs 54.2 (6.8) kg for female; respectively). In 1982, Powers and Walker[44] compiled anthropometric data of 10 women top 15 at a Louisiana Tennis Association. In agreement with the results of Power and Walker,[44] the elite junior tennis players in the present study were smaller and heavier than those (165.4 (6.3) cm vs 168.7 (2.35); 59.9 (6.2) kg vs 57.99 (2.59), respectively).

In relation to skinfolds, our results indicated that biceps and triceps skinfolds values found in our female tennis players are higher than those data reported by Powers and Walker[44] (mean (SD) 7.4 (2.6) mm vs 6.55 (1.38) mm and 16.3 (4.0) vs 13.2 (2.34), respectively). Also, the upper arm girth of our female tennis players was greater than those found by Power and Walker.[44]

In our study, elite male and female junior tennis players tended to show a greater mesomorphic component and a lower ectomorphic component than those in the study by Elliot *et al*[42] (5.2 (0.8) vs 3.90 (0.99) and 2.9 (0.76) vs 4.46 (1.07) for male; 4.6 (1.0) vs 3.2 (0.97) and 2.4 (1.0) vs 3.4 (1.17) for female; respectively). Similar results were found in respect to the somatotype components observed in the study of Elliot *et al*,[43] who analysed a total of 866 leading junior tennis players (516 males and 350 females), aged 10–17 years.

Leone and Larivière[46] studied 35 male regional level tennis players, aged 12–17 years (14.5 (1.5) years), but they did not discriminate by age group. Our male subjects were taller (176.8 (6.3) cm vs 165.6 (11.5) cm) and heavier (69.9 (6.8) cm vs 54.8 (11.0) cm). Also, our males showed greater upper arm (28.7 (1.7) cm vs 26.5 (3.0) cm) and calf (37.3 (1.8) cm vs 34.4 (2.6) cm) girth than those studied by Leone and Larivière.[46]

Leone *et al*[41] identified the anthropometric and biomotor variables of 15 regional level female tennis players aged 13.9 (1.3) years. Our female subjects were taller (165.4 (6.3) cm vs 161.0 96.0) cm) and heavier (59.9 (6.2) kg vs 50.6 (8.3) kg). Also, our females showed greater upper arm (27.0 (1.8) cm vs

**Table 4** Anthropometric profile chart for the total female junior tennis players (n = 66)

| | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|
| | 5 | 10 | 25 | 50 | 75 | 90 | 95 |
| Height (cm) | 153.4 | 157.0 | 161.6 | 165.4 | 168.9 | 174.6 | 178.0 |
| Weight (kg) | 48.6 | 51.8 | 55.8 | 60.0 | 64.3 | 66.7 | 68.4 |
| Breadth (cm) | 155.3 | 158.3 | 163.3 | 168.2 | 172.4 | 176.6 | 178.8 |
| Triceps skinfold (mm) | 10.4 | 11.1 | 13.5 | 15.5 | 19.7 | 21.5 | 24.9 |
| Biceps skinfold (mm) | 4.1 | 4.5 | 5.4 | 7.2 | 8.9 | 11.2 | 12.9 |
| Subscapular skinfold (mm) | 6.2 | 6.6 | 7.5 | 8.8 | 10.7 | 12.9 | 14.0 |
| Suprailiac skinfold (mm) | 10.7 | 11.3 | 13.9 | 18.9 | 23.4 | 26.7 | 30.6 |
| Supraspinal skinfold (mm) | 6.1 | 6.6 | 8.1 | 10.1 | 12.4 | 16.2 | 19.4 |
| Abdominal skinfold (mm) | 8.4 | 9.7 | 13.3 | 17.2 | 22.8 | 26.5 | 28.3 |
| Thigh skinfold (mm) | 12.8 | 13.8 | 17.6 | 20.6 | 23.0 | 25.8 | 28.1 |
| Calf skinfold (mm) | 9.2 | 9.8 | 11.1 | 13.5 | 17.3 | 20.1 | 22.5 |
| Upper arm relaxed girth (cm) | 23.5 | 24.8 | 25.8 | 27.0 | 28.0 | 29.0 | 30.3 |
| Upper arm flexed and tensed girth (cm) | 24.9 | 25.7 | 26.7 | 28.0 | 29.0 | 30.1 | 31.2 |
| Thigh girth (cm) | 44.2 | 45.5 | 47.6 | 50.0 | 51.6 | 53.7 | 54.2 |
| Maximum calf girth (cm) | 32.0 | 33.1 | 34.4 | 35.8 | 37.2 | 38.6 | 39.1 |
| Humeral breadth (cm) | 5.8 | 6.0 | 6.1 | 6.3 | 6.5 | 6.7 | 6.9 |
| Femoral breadth (cm) | 8.8 | 9.0 | 9.3 | 9.7 | 10.1 | 10.7 | 10.8 |
| Body fat (%) | 22.2 | 23.2 | 25.0 | 28.9 | 31.5 | 33.1 | 34.4 |
| Muscle mass (%) | 42.9 | 43.6 | 44.0 | 45.3 | 46.2 | 46.7 | 48.7 |

**What is already known on this topic**

- The interest in anthropometric characteristics, body composition and somatotype from different competitive sports has been increasing in recent years.
- It is well documented that for many sports there are specific physical characteristics that indicate suitability to compete in that sport at the highest level, the anthropometric profile being an important selective factor for success in sport.
- Quantification of the physiques of top athletes is a reference point in relating body structure and sports performance, and at present there is little data on the physical characteristics of junior and senior tennis players at the highest level.

**What this study adds**

- Our study consists of a greater sample size (123 elite junior tennis players of the best teams: 57 males and 66 females) than other similar studies.
- The sample source is important as the subjects were the best junior players in the world at the time of study.
- The best players were compared with lower ranks to ascertain if any key point could be found with regard to anthropometric variables.
- The study was carried out during the most important competitions in the world for junior category (the Davis Cup and Fed Cup), so all the players should be in top physical shape.
- The somatotype for this category has never been elucidated previously.

25.5 (2.8) cm) and calf (35.7 (2.1) cm vs 34.0 (2.8) cm) girth than those studied by Leone *et al*.[41]

The different characteristics of the best female junior tennis players of our study—taller, heavier, and with wider humeral and femoral breadths—compared with the lower ranked players, suggest this could nowadays influence playing style in this category for this gender. This style is more aggressive, as increased height is an advantage when serving or when trying to reach the balls in emergency situations. By contrast, the profile in male junior tennis players is more homogeneous than in the female players.

Sanchis-Moysi *et al*[45] studied body composition of professional tennis players by using DEXA (dual *x* ray absoptiometry) measurement, which is not comparable with the anthropometric method generally used.

With respect to the anthropometric data observed in studies of others racquet sports, the elite male junior tennis players of our study were taller and heavier than the Asian elite squash players[52] aged 20.7 (2.5) years (176.8 (6.4) cm vs 172.6 (4.3) cm and 69.9 (6.8) kg vs 67.7 (6.9) kg, respectively) and than male badminton players[53] of national level aged 24.3 (4.1) years (176.8 (6.4) cm vs 175.4 (5.4) cm and 69.9 (6.8) kg vs 64.8 (6.9) kg, respectively). Finally, when comparing the tennis players of the present study with the top class senior squash players evaluated by Jaski and Bale,[54] our athletes were smaller and heavier than those, and showed smaller girths, greater skinfold thicknesses, and similar somatotype components.

The main limitation of this kind of study is that the results have to be taken into account as a point of reference, but should not be taken as an obligatory model for better performance. In this way, the results presented can be used as a standard reference, but should be interpreted with caution according to individual characteristics and necessities.

A longitudinal follow-up study of these characteristics and variables is recommended. Even though the DEXA method would be more accurate than anthropometrical measurements, using DEXA would not be feasible for this size of sample under competition circumstances because of the high costs and the limited availability of the subjects. We do think the large sample size (123 elite junior tennis players of the best teams) is an asset of this study compared to the other studies found in the literature. In addition, the sample source was important as the subjects were the best junior players in the world at the time of testing. Furthermore, at the time of the study, the players were competing in the most important junior competitions in the world (the junior Davis Cup and Fed Cup), and were therefore in optimal shape.

## CONCLUSIONS

There were no significant differences in any of the variables studied when comparing the first 12 and the lower ranked elite male junior tennis players. However, significant differences were observed in height and humeral and femoral breadth when comparing the first 12 and the lower ranked female players, whereby the first 12 players were significantly taller than the lower ranked players, and had wider humeral and femoral breadth. These differences could influence the playing pattern in junior women, allowing a more attacking playing style.

This study provides reference values of anthropometric characteristics, body composition and somatotype of elite male and female junior tennis players. This information provides a reference frame for coaches to control the training process in order to help improve athletes' performance, and to improve talent detection and identification in tennis.

## ACKNOWLEDGEMENTS

The authors would like to thank all coaches and tennis players competing in the 2005 and 2006 Davis Junior Cup and Fed Junior Cup for their participation and cooperation. The authors also wish to thank all members of the Organising Committee of the 2005 and 2006 Davis Junior Cup and Fed Junior Cup, and to the International Tennis Federation for their permission to set up this study and for their full support and collaboration during the investigation.

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Competing interests: None declared.

## REFERENCES

1 **Bourgois J**, Claessens AL, Vrijens J, *et al.* Anthropometric characteristics of elite male junior rowers. *Br J Sports Med* 2000;**34**:213–17.
2 **Bourgois J**, Claessens AL, Janssens M, *et al.* Anthropometric characteristics of elite female junior rowers. *J Sports Sci* 2001;**19**:195–202.
3 **Claessens AL**, Lefevre J, Beunen G, *et al.* The contribution of anthropometric characteristics to performance scores in elite female gymnasts. *J Sports Med Phys Fitness* 1999;**39**:355–60.
4 **Slater GJ**, Rice AJ, Mujika I, *et al.* Physique traits of lightweight rowers and their relationship to competitive success. *Br J Sports Med* 2005;**39**:736–41.
5 **Reilly T**, Bangsbo J, Franks A. Anthropometric and physiological predispositions for elite soccer. *J Sports Sci* 2000;**18**:669–683.
6 **Ackland TR**, Ong KB, Kerr DA, *et al.* Morphological characteristics of Olympic sprint canoe and kayak padlers. *J Sci Med Sport* 2003;**6**:285–94.

7 **Legaz A**, Gonzalez JJ, Serrano E. Differences in skinfold thicknesses and fat distribution among top-class runners. *J Sports Med Phys Fitness* 2005;**45**:512–7.
8 **Gabbett TJ**. Physiological and anthropometric characteristics of amateur rugby league players. *Br J Sports Med* 2000;**34**:303–7.
9 **Fernandez J**, Mendez-Villanueva A, Pluim BM. Intensity of tennis match play. *Br J Sports Med* 2006;**40**:387–91.
10 **Smekal G**, Von Duvillard SP, Rihacek C, *et al.* A physiological profile of tennis match play. *Med Sci Sports Exerc* 2001;**33**:999–1005.
11 **König D**, Hounker M, Schmid A, *et al.* Cardiovascular, metabolic, and hormonal parameters in professional tennis players. *Med Sci Sports Exerc* 2000;**33**:654–8.
12 **Christmass MA**, Richmond SE, Cable NT, *et al.* Exercise intensity and metabolic response in singles tennis. *J Sport Sci* 1998;**16**:739–47.
13 **Bergeron MF**, Maresh CM, Kraemer WJ, *et al.* Tennis: a physiological profile during match play. *Int J Sports Med* 1991;**12**:447–79.
14 **Groppel JL**, Roetert EP. Applied physiology of tennis. *Sports Med* 1992;**14**:260–68.
15 **Morgan L**, Jordan D, Baeyens D, *et al.* Heart rate responses during singles and doubles tennis competition. *Physician Sportsmed* 1987;**15**:67–74.
16 **Elliot B**, Dawson B, Pyke F. The energetics of single tennis. *J Hum Mov Stud* 1985;**11**:11–20.
17 **Seliger V**, Ejem M, Pauer M, *et al.* Energy metabolism in tennis. *Int Z Angew Physiol* 1973;**31**:333–40.
18 **Akutagawa S**, Jojima T. Trunk rotation torques through the hip joints during the one- and two-handed backhand tennis strokes. *J Sports Sci* 2005;**23**:781–93.
19 **Elliot B**, Fleisig G, Nicholls R, *et al.* Technique effects on upper limb loading in the tennis serve. *J Sci Med Sport* 2003;**6**:76–87.
20 **Chow J**, Shim J-h, Lim Y-t. Lower trunk muscle activity during the tennis serve. *J Sci Med Sport* 2003;**6**:512–18.
21 **Fleisig G**, Nicholls R, Elliott B, *et al.* Kinematics used by world class tennis players to produce high-velocity serves. *Sports Biomech* 2002;**2**:51–71.
22 **Reid M**, Elliott B. The one- and two-handed backhands in tennis. *Sports Biomech* 2002;**1**:47–68.
23 **Bahamonde R**. Changes in angular momentum during the tennis serve. *J Sports Sci* 2002;**18**:579–92.
24 **Elliott B**, Takahashi K, Noffal G. The influence of grip position on upper limb contributions to racket head velocity in a tennis forehand. *J Appl Biomech* 1997;**13**:182–96.
25 **Elliott BC**, Marshall RN, Noffal GJ. Contributions of upper limb segment rotations during the power serve in tennis. *J Appl Biomech* 1995;**11**:433–42.
26 **Sprigings E**, Marshall R, Elliott B, *et al.* A three-dimensional kinematic method for determining the effectiveness of arm segment rotations in producing racket head speed. *J Biomech* 1994;**27**:245–54.
27 **Knudson D**. Intra-subject variability of upper extremity angular kinematics in the tennis forehand drive. *Int J Sport Biomech* 1990;**6**:415–21.
28 **Elliott BC**, Overheu P, Marsh P. The service line and net volleys in tennis: a cinematographic analysis. *J Sci Med Sport* 1988;**20**:10–18.
29 **Groppel JL**. The biomechanics of tennis: an overview. *Int J Sport Biomech* 1986;**2**:141–55.
30 **Roetert EP**, Brown SW, Piorkowski PA, *et al.* Fitness comparisons among three different levels of elite tennis players. *J Strength Cond Res* 1996;**10**:139–43.
31 **Chandler TJ**, Kibler WB, Uhl TL, *et al.* Flexibility comparisons of junior elite tennis players to other athletes. *Am J Sports Med* 1990;**18**:134–6.
32 **Kibler WB**, Chandler TJ. Grip strength and endurance in elite tennis players. *Med Sci Sports Exerc* 1989;**21**:S65.
33 **Kibler WB**, McQueen C, Uhl T. Fitness evaluations and fitness findings in competitive junior tennis players. *Clin Sports Med* 1988;**7**:403–16.
34 **Pluim BM**, Staal JB, Windler GE, *et al.* Tennis injuries: occurrence, aetiology, and prevention. *Br J Sports Med* 2006;**40**:415–423.
35 **Montalvan B**, Parier J, Brasseur JL, *et al.* Extensor carpi ulnaris injuries in tennis players: a study of 28 cases. *Br J Sports Med* 2006;**40**:424–9.
36 **Van der Hoeven H**, Kibler WB. Shoulder injuries in tennis players. *Br J Sports Med* 2006;**40**:435–40.
37 **Maquirriain J**, Ghisi JP. The incidence and distribution of stress fractures in elite tennis players. *Br J Sports Med* 2006;**40**:454–9.
38 **Tsur A**, Gillson S. Brachial biceps tendon injuries in young female high-level tennis players. *Croat Med J* 2000;**41**:184–5.
39 **Bylak J**, Hutchinson MR. Common sports injuries in young tennis players. *Sport Med* 1998;**26**:119–32.
40 **Faraj A**, Rahman H, Norton R. Acute calcific tendonitis of abductor pollicis longus in a tennis player. *Sports Exerc Inj* 1998;**4**:138–9.
41 **Leone M**, Lariviere G, Comtois AS. Discriminant analysis of anthropometric and biomotor variables among elite adolescent female athletes in four sports. *J Sports Sci* 2002;**20**:443–9.
42 **Elliot BC**, Ackland TR, Blanksby BA, *et al.* A prospective study of physiological and kinanthropometric indicators of junior tennis performance. *Australian J Sci Med Sport* 1990;**22**:87–92.
43 **Elliot BC**, Ackland TR, Blanksby BA, *et al.* Profiling junior tennis players part 1: morphological, physiological and psychological normative data. *Australian J Sci Med Sport* 1989;**21**:14–21.
44 **Powers SK**, Walker R. Physiological and anatomical characteristics of outstanding female junior tennis players. *Res Quart Exerc Sport* 1982;**53**:172–5.
45 **Sanchis-Moysi J**, Dorado-Garcia C, Calbet JAL. Regional body composition in professional tennis players. In: Lees A, Maynard I, Hughes M, *et al*, eds. *Science and racket sports II.* London: E & FN Spon, 1998.
46 **Leone M**, Larivière G. Caractéristiques anthroométriques et biomotrices d'adolescents athlètes élites de disciplines sportives différentes. *Sci Sports* 1998;**13**:26–33.
47 **Ross WD**, Marfell-Jones MJ. Kinanthropometry. In: Mac Dougall JD, Wenger HA, Green HJ, eds. *Physiological testing of the high performance athlete*, Champaign, Illinois, USA.Human Kinetics, 1991.
48 **Durnin JV**, Womersley J. Body fat assessed from total body density and its estimation from skinfold thicknesses measurements on 481 men and women aged 16–72 years. *Br J Nutr* 1974;**32**:77–97.
49 **Siri WE**. The gross composition of the body. In: Lawrence JH, Tobias CA, eds. *Advances in biological and medical physics.* New York, USA: Academic Press, Inc, 1956.
50 **Poortmans JR**, Boisseau N, Moraine JJ, *et al.* Estimation of total-body skeletal muscle mass in children and adolescents. *Med Sci Sports Exerc* 2005;**37**:316–22.
51 **Carter JEL**, Heath BH. *Somatotyping: development and applications.* Cambridge, UK: Cambridge University Press, 1990.
52 **Chin M-K**, Steininger K, So RCH, *et al.* Physiological profiles and sport specific fitness of Asian elite squash players. *Br J Sports Med* 1995;**29**:158–64.
53 **Majumdar P**, Khanna GL, Malik V, *et al.* Physiological analysis to quantify training load in badminton. *Br J Sports Med* 1997;**31**:342–5.
54 **Jaski A**, Bale P. The physique and body composition of top class squash players. *J Sports Med* 1987;**27**:114–118.

III

# WORLD AND OLYMPIC MOUNTAIN BIKE CHAMPIONS' ANTHROPOMETRY, BODY COMPOSITION AND SOMATOTYPE

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**J Sports Sci**

*Revised version submitted*

**Journal of Sports Sciences**


# World and Olympic mountain bike champions' anthropometry, body composition and somatotype


| | |
|---|---|
| Journal: | *Journal of Sports Sciences* |
| Manuscript ID: | RJSP-2015-0512.R1 |
| Manuscript Type: | Original Manuscript |
| Keywords: | Anthropometry, body composition, somatotype, Olympic mountain bike |
| | |

**Title:** World and Olympic mountain bike champions' anthropometry, body composition and somatotype

**Abstract**

The aim of the study was to describe the anthropometric profile of male Olympic cross country (XCO) mountain bikers. Fifty one XCO bikers participated in this study, divided into 1) an elite group who competed in top level international competitions, and 2) a non-elite group who competed at a national level. The elite group was further classified according to whether they had been world or Olympic champion mountain bikers ~~WOC~~ or not ~~NWOC~~. The anthropometric profiles included the measurements of stature ~~height~~, body mass ~~weight~~, arm span, skinfolds, girths, and breadths. Body mass index (BMI), body composition and somatotype were also calculated. Elite riders were significantly younger, had significantly lower BMI, lower percentage of fat, total thigh area and larger thigh muscle area than the sub-elite riders, and presented significantly lower values for the endomorphic component and higher values for the ectomorphic component. The mean somatotype of the elite riders could be defined as ecto-mesomorphic (1.7-4.6-3.1). Comparisons between of world or Olympic champion mountain bikers ~~WOC riders~~ and not world nor Olympic champion riders ~~NWOC~~, showed that the world or Olympic champion mountain ~~WOC~~ bikers had a significantly higher value for training distance per year, body mass ~~weight~~, arm span, upper arm girth relaxed and upper arm girth flexed and tensed, calf girth, total upper arm area, and upper arm muscle area than the not world nor Olympic champion ~~NWOC~~ riders group.

**Keywords:** Anthropometry, body composition, somatotype, Olympic mountain bike.

## Introduction

Olympic cross-country mountain bike (XCO) is an individual sport which was included as an Olympic sport since the 2000 Summer Games in Sydney. Previously, cross-country mountain bike debuted as an Olympic demonstration sport at the Atlanta Summer Games in 1996. XCO is an endurance event consisting of a single day mass-start race which involves completing a pre-determined number of laps on an off-road circuit. The winning time is typically around 1:30 h to 1:45 h for both men and women. Each lap ranges from 4 km to 6 km in length and the course normally includes a variety of terrains such as forest tracks, fields, road sections, and earth or gravel paths, including significant segments of climbing and descending (International Cycling Union, 2015). XCO performance requires the interaction of supra-maximal and sub-maximal efforts combined with high levels of technical skill (Macdermid & Edwards, 2010).

During the past two decades, several studies have been conducted in order to determine the physiological (Baron, 2001; Costa & De-Oliveira, 2008; Gregory, Johns, & Walls, 2007; Impellizzeri & Marcora, 2007; Impellizzeri, Marcora, Rampinini, Mognoni, & Sassi (2005a); Impellizzeri, Rampinini, Sassi, Mognoni, & Marcora (2005b); Lee, Martin, Anson, Grundy, & Hahn (2002); Macdermid & Stannard, 2012; Prins, Terblanche, & Myburgh, 2007; Wilber, Zawadzki, Kearney, Shannon, & Disalvo, 1997), biomechanical (Faiss, Praz, Meichtry, Gobelet, & Deriaz, 2007; Herrick, Flohr, Wenos, & Saunders, 2011), psychological (Lion, Gauchard, Deviterne, & Perrin, 2009), and nutritional (Cramp, Broad, Martin, & Meyer, 2004; Som-Castillo, Sánchez-Muñoz, Ramírez-Lechuga, & Zabala-Díaz, 2010; Zajac et al., 2014) parameters that contribute to cross-country mountain biking performance, as well as to describe the most common types of injury (Carmont, 2008; Chow & Kronisch, 2000; Lareau & McGinnis, 2011).

Although the relationship between morphological characteristics and performance in many sports is well known, such as rugby (Gabbett, Kelly, Ralph, & Driscoll, 2009), Olympic slalom canoe and kayak paddle (Ridge, Broad, Kerr, & Ackland, 2007), road motorcycling (Sánchez-Muñoz et al., 2011), tennis (Sánchez-Muñoz, Sanz, & Zabala, 2007) or rowing (Slater et al., 2005) (Gabbett, Kelly, Ralph, & Driscoll, 2009; Ridge, Broad, Kerr, & Ackland, 2007; Sánchez-Muñoz et al., 2011; Sánchez-Muñoz, Sanz, & Zabala, 2007; Slater et al., 2005), to our knowledge no studies have investigated the anthropometric profile of XCO bikers and their relationship with competition level. The purpose of our investigation therefore was to describe the anthropometric profile of male XCO riders, and to compare the anthropometric characteristics, body composition and somatotype at different levels of elite and sub-elite groups, and between world or Olympic champion riders (WOC) and the rest of elite riders that were not world nor Olympic champions (NWOC). We hypothesised that, given the technical requirements of the world class tracks, those cyclists that compete at the highest level would have higher levels of skeletal muscle mass in the upper arm in comparison to the same level of cyclists studied previously and to those that compete at a sub-elite level.

## Methods

*Participants*

Fifty one XCO mountain bikers (30.1 ± 3.9 years) volunteered to participate in the study. They were divided into 1) an elite group (n=22) who competed in top level international competitions including the World Champions and the Olympic Champions, and constituted 20 of the 28 leading bikers in the 2011 UCI World Cup, and 2) a non-elite group (n=29) who competed at a national level. The elite group was further classified according to whether they had been world or Olympic champion mountain bikers in the last ten years WOC (n=5) or not NWOC (n=17). Elite riders were evaluated during the 2011 UCI XCO Mountain Bike World Cup (Val di Sole, Italy), two weeks before the 2011 UCI Mountain Bike World Championships (Champery, Switzerland). Non-elite bikers were evaluated before the 2011 Andalucía Bike Race (Jaén & Cordoba, Spain). The study was approved by the Ethics Committee of the University of Granada and written consent was obtained from each participant prior to data collection.

*Anthropometric measurements*

Measurements were performed following the guidelines outlined by the International Society for the Advancement of Kinanthropometry (ISAK) (Marfell-Jones et al., 2006). All measurements were taken by the same experienced evaluator (ISAK-certificated level II anthropometric research). The technical error of measurement (TEM) was less than 5% for skinfolds and less than 1% for the other measurements. Anthropometric variables included body mass weight, stature height, 8 skinfolds (biceps, triceps, subscapular, suprailiac, supraspinale, abdominal, thigh and medial calf), 4 girths (upper arm relaxed, upper arm flexed and tensed, medial thigh and maximum calf), and 2 breadths (humeral and femoral). Stature Height was measured to the nearest 0.1 cm using a stadiometer (GPM, Seritex, Inc., Carlstadt, New Jersey), and body mass weight was measured to the nearest 0.1 kg using a portable scale (model 707, Seca Corporation, Columbia, Maryland). Skinfold thickness were taken using a skinfold caliper (Holtain Ltd., Crymych, UK) to the nearest 0.2 mm, and the girths were performed using a flexible anthropometric steel tape (Holtain Ltd., Crymych, UK) to the nearest 0.1 cm. Skinfolds were taken 3 times and the median mean was used in the analyses. The sum of 3 skinfolds (triceps, subscapular, and supraspinale), 6 skinfolds (sum of 3, suprailiac, abdominal, thigh, and calf thigh), 8 skinfolds (sum of 6, biceps, and suprailiac maximum calf), upper limb (triceps, biceps, subscapular, suprailiac, supraspinale, and abdominal), and lower limb (thigh and maximum calf), were also calculated. Body mass index (BMI) was calculated as body mass/stature$^2$ weight/height$^2$ where body mass weight was expressed in kilograms (kg) and stature height in meters (m). Five different equations (Durnin & Womersley, 1974; Katch & McArdle, 1973; Sloan, 1967; Wilmore & Behnke, 1969; Withers, Craig, Bourdon, & Norton, 1987) were used to estimate body density. Body fat percentage (% BF) was determined by the Siri's equation (1961). Skeletal muscle mass Muscle mass was determined in kg using the methods of Lee et al. (2000). Arm's and thigh's total, muscle and fat areas were calculated (Frisancho, 1990; Heymsfield, McManus, Smith, Stevens, & Nixon, 1982). Somatotype characteristics were determined according to the Carter and Heath method (1990).

*Statistical analyses*

Variables are described as mean, standard deviation and range. The standardising of the variables was carried out using the Shapiro-Wilk with Lillieforts correction and homoscedasticity was analysed using the Levene test. After verifying that the variables were normal, the data were analysed using non-paired t-tests T-tests (elite vs. non-elite and world or Olympic champion mountain bikers WOC vs. not world nor Olympic champion riders NWOC). All statistical analyses were performed using the Statistical Package for Social Sciences (IBM SPSS Statistics for Windows, Version 21.0. Armonk, NY: IBM Corp). Statistical significance was established at 0.05, and Cohen's d was also calculated.

**Results**

The demographic characteristics of the sample are represented in Table 1. Elite riders were significantly younger in age (28.2 ± 3.1 vs. 32.4 ± 3.6 years), had significantly lower BMI (21.8 ± 1.0 vs. 22.8 ± 1.1 kg/m$^2$), lower percentage of fat calculated with different equations (Katch & McArdle, 1973; Wilmore & Behnke, 1969; Withers, Craig, Bourdon, & Norton, 1987), total thigh area (207.5 ± 15.9 vs. 225.5 ± 18.5 cm$^2$), and smaller ~~larger~~ thigh muscle area (193.2 ± 16.1 vs. 207.6 ± 20.1 cm$^2$) than the sub-elite riders. In the same way, elite riders were engaged in significantly more training hours per week (16.1 ± 1.2 vs 14.0 ± 2.7) and training distance per year (18409.1 ± 1053.8 vs. 13970.6 ± 3174.5 km) than the sub-elite riders. Somatotype differences were observed between both, elite and sub-elite riders. Elite riders had significantly lower values for the endomorphic component (1.7 ± 0.3 vs. 2.1 ± 0.7) and higher values for the ectomorphic component (3.1 ± 0.6 vs. 2.5 ± 0.5) than the sub-elite riders. The somatotype of the elite riders (1.7–4.6–3.1) demonstrated that these riders were predominantly mesomorphic, being characterised as ecto-mesomorphic according to Carter and Heath (1990).

*****Table 1 near here*****

Table 2 compares the anthropometric characteristics of world or Olympic champion ~~WOC~~ riders and not world nor Olympic champion mountain bikers ~~NWOC~~. World Championship riders showed a significantly higher value for training distance per year (19400.0 ± 1140.2 vs. 18117.7 ± 857.5 km), body mass ~~weight~~ (70.2 ± 2.8 vs. 66.1 ± 3.2 kg), arm span (183.1 ± 4.8 vs. 177.4 ± 4.9 cm), upper arm girth relaxed (28.6 ± 0.4 vs. 27.5 ± 1.1 cm) and upper arm girth flexed and tensed (31.1 ± 0.7 vs. 29.7 ± 1.1 cm), calf girth (36.5 ± 1.1 vs. 35.2 ± 1.2 cm), total upper arm area (65.0 ± 2.0 vs. 60.2 ± 4.6

$cm^2$), and upper arm muscle area (59.2 ± 2.0 vs. 55.0 ± 4.1 $cm^2$). Figure 1 shows average somatotypes of male Olympic cross-country mountain bikers.

*****Table 2 near here*****

*****Figure 1 near here*****



**Discussion**

The relationship between the morphological characteristics and performance in certain sports specialties is well known, such as rugby (Gabbett, Kelly, Ralph, & Driscoll, 2009), Olympic slalom canoe and kayak paddle (Ridge, Broad, Kerr, & Ackland, 2007), road motorcycling (Sánchez-Muñoz et al., 2011), tennis (Sánchez-Muñoz, Sanz, & Zabala, 2007) or rowing (Slater et al., 2005) ~~(Gabbett et al., 2009; Ridge et al., 2007; Sánchez-Muñoz et al., 2007; Sánchez-Muñoz et al., 2011; Slater et al., 2005)~~. By ~~Buy~~ the way, to our knowledge this is the first study to determine physical profile of male XCO mountain bikers and to establish differences by competition level, showing that anthropometric characteristics, body composition and somatotype differ among XCO mountain bikers of different competitive levels.

The mean age of the elite XCO bikers was significantly lower than the sub-elite category (- 4.2 years), and also showed a significantly greater number of training hours per week and yearly training volume (+ 2.1 hours/week and + 4439 km/year, respectively). Also, although not statistically different, elite riders were lighter (− 2.4 kg; p=0.055) and taller (+ 0.8 cm), and had significantly lower values for the BMI (− 1.0 $kg/m^2$), abdominal skinfold (− 2.8 mm), upper arm flexed and tensed girth (− 1.1

cm), thigh girth (− 2.2 cm), and maximum calf (− 1.9 cm), than the sub-elite group. Elite bikers showed significantly lower % BF (between 1.1 and 1.2 %) using three different equations (Katch & McArdle, 1973; Wilmore & Behnke, 1969; Withers et al., 1987) and thigh muscle area (- 14.4 $cm^2$), and also significant differences were observed for somatotype compared to the sub-elite mountain bikers (lower in the elite group for the endomorphic component of the somatotype, and higher for the ectomorphic). There were no significant differences between groups for the rest of studied variables. The mean somatotype for the elite mountain bikers (1.7–4.6–3.1) demonstrates that these athletes were predominantly mesomorphic, being characterised as ecto-mesomorphic according to Carter and Heath (1990). So, XCO elite riders can be defined in general as medium stature ~~height~~ (in the range from the basketball players to the gymnasts), light body mass ~~ligth weigth~~ (in the range from the weightlifters or throwers to the marathoners), low % BF (in the range from marathoners to weightlifters or throwers) and low skinfolds sum values, with high relative total upper arm and upper arm muscle area.

Comparing the results of the present study with previous reports (Table 3), the elite XCO riders were taller (175.5 vs 172.7 cm) and lighter (67.1 vs 71.5 kg) than the professional competitive off-road cyclists evaluated by Rostami, Ansari, Noormohammadpour, Ali Mansournia, and Kordi (2014), and presented a lower BMI value (21.8 vs 24.0 $kg/m^2$). Same findings were observed regarding elite Brazilian mountain bikers investigated by Costa and De-Oliveira (2008) where our riders also were taller (175.5 vs 174.0 cm) and lighter (67.1 vs 69.1 kg). Carpes, Mota, & Faria (2007) reported for elite mountain bikers an higher mean stature ~~height~~ and body mass ~~weight~~ values (185.0 vs 175.5 cm and 72.1 vs 67.1 kg, respectively) than the elite XCO riders of the present study, and same findings were informed by Gregory et al. (2007) to elite level bikers with respect our riders (180.2 vs 175.5 cm and 71.6 vs 67.1 kg, respectively). Elite XCO riders were shorter (175.5 vs 179.9 cm) and lighter (67.1 vs 69.4 kg) than the elite bikers of the German national cycling team (Stapelfeldt, Schwirtz, Schumacher, & Hillebrecht, 2004), were shorter (175.5 vs 178.0 cm) and heavier (67.1 vs 65.3 kg) than the Australian nationally and internationally competitive cross-country mountain bikers (Lee et al., 2002), and were lighter (67.1 vs 71.5 kg) and presented similar stature height value (175.5 vs 176.0 cm) than the cyclists of the USA cross-country team (Wilber et al., 1997). Warner, Shaw, and Dalsky (2002) reported for elite level mountain bikers a lower mean stature height value (180.4 vs 175.5 cm) and an higher mean body mass weight value (78.7 vs 67.1 kg) than the elite XCO riders of the present study, while Sewall and Fernhall (1995) informed for expert and professional off-road cyclists a similar mean stature height value (176.7 vs 175.5 cm) and a higher mean body mass weight value (70.5 vs 67.1 kg) than our riders. Finally, elite XCO riders of the present study were shorter (175.5 vs 185.1 cm) and lighter (67.1 vs 68.0 kg) than the elite downhill bikers evaluated by Sperlich et al. (2012). On the other hand, the sub-elite XCO riders of the present study were shorter (174.7 vs 177.9 cm) and presented a similar mean body mass men weight value (69.5 vs 68.7 kg) than the regional and national level XCO bikers evaluated by Inoue, Sá Filho, Mello, and Santos (2012). Regarding nationally competitive cross country mountain bike cyclists investigated by Mcdermid and Stannard (2012) our riders were shorter (176.0 vs 174.7 cm) and heavier (66.9 vs 69.5 kg). Sub-elite XCO riders were shorter (174.7 vs 179.0 cm) and lighter (69.5 vs 74.8 kg), and presented similar mean BMI value (22.8 vs 23.2 $kg/m^2$) than the sub-elite cross-country bikers participants of the 2008 Swiss Bike Masters race (Knechtle, Knechtle, Rosemann, & Senn, 2009). They were heavier (69.5 vs 67.0 kg) and showed similar mean stature height value (174.7 vs 175.2 cm) than sub-elite mountain bikers investigated by Costa, Carminatti, Nakamura, and De-Oliveira (2008), and were shorter (174.7 vs 177.0 cm) and heavier (69.5 vs 65.0 kg) than under-23 regional, national and international cross-country cyclists (Impellizzeri et al., 2005b). Cramp, Broad, Martin, and Meyer (2004) reported for trained mountain bikers an higher mean stature ~~height~~ and similar body mass ~~weight~~ values (179.0 vs 174.7 cm and 69.0 vs 69.5 kg, respectively) than the sub-elite XCO riders of the present study, and different findings were informed by McRae, Hise, and Allen (2000) to sub-elite mountain bike cyclists with respect our riders in case of mean body mass ~~weight~~ values (179.5 vs 174.7 cm and 76.9 vs 69.5 kg, respectively). Impellizzeri, Sassi, Rodriguez-Alonso, Mognoni, and Marcora (2002) reported for sub-elite mountain bikers a similar mean stature ~~height~~ value (174.6 vs 174.7 cm) and a lower mean body mass ~~weight~~ value (64.3 vs 69.5 kg) than the sub-elite XCO riders of the present study, while Nielens and Lejeune (2001) informed for competitive racers same finding to mean stature ~~height~~ value (175.0 vs 174.7 cm), but their riders also presented similar mean body mass ~~weight~~ value (70.2 vs 69.5 kg) than our riders. Finally, sub-elite XCO riders of the present study were shorter (174.7 vs 180.4 cm) and lighter (69.5 vs 77.9 kg) than the sub-elite ultra-marathon bikers (Chlíbková et al., 2014), and also were shorter (174.7 vs 179.0 cm) and lighter (69.5 vs 77.6 kg) than the sub-elite downhill bikers evaluated by Hurst and Atkins (2006). It was not possible to compare %BF because the used equations were different, nor the sum of skinfolds because they were different or not reported.

*****Table 3 near here*****

Comparing the results obtained between the world or Olympic champion mountain bikers ~~WOC~~ and not world nor Olympic champion ~~NWOC~~ riders, the mean training volume of 19400±1140.2 km/year of the world or Olympic champion mountain ~~WOC~~ bikers was significantly greater than the not world nor Olympic champion ~~NWOC~~ riders (+ 1282.3 km/year). Also they were significantly taller (+ 3.8 cm) and heavier (+ 4.1 kg), showing also ~~significantly~~ higher values for the arm span (+ 5.7 cm), upper arm relaxed (+ 1.1 cm), upper arm flexed and tensed girth (+ 1.4 cm), and maximum calf (+ 1.3 cm), than the not world or Olympic champion ~~NWOC~~ mountain bikers. In the same sense, world or Olympic mountain ~~WOC~~ bikers showed significantly higher total upper arm area and upper arm muscle area (+ 4.8 $cm^2$ and + 3.6 $cm^2$, respectively). Non-significant differences between groups were observed for the rest of studied variables. In XCO mountain bike races, there are constant velocity changes with a great importance of accelerating the bike after curves or obstacles that slow velocity, or even in the massive start in which getting the best position from ~~since~~ the beginning is a crucial tactical advantage. Therefore, being a light body mass ~~weight~~ athlete is an advantage to make more effective and/or efficient the required numerous accelerations. Also, since 2007, the rules and the characteristics of the tracks have been changed (from 2h to 1h 30’, and including more difficult specific technical zones -e.g. “rock garden” zones-), so that riders need to be also strong enough to perform the required skills in a shorter race duration.

Because body mass could explain 10 to 20 % of the performance during climbing (Swain, 1994), it could be argued that years ago a lower body mass in XCO riders could lead to a better performance (Lee et al., 2002). Years ago as international XCO competitions emphasized climbing, it was logical that small and light riders could have a performance advantage because of the great importance of uphill segments among the course (Lee et al., 2002), and this is why riders in 1997-2000 period showed approximately 60 kg of body mass, while the average body mass for the top five placed male mountain bikers competing at the Sydney 2000 Olympic Games was 63.6±7.9 kg. Nevertheless, from 2001 to 2004 world champions showed an average body mass of 72 kg (Impellizzeri & Marcora, 2007), while the average body mass of the 2005-2008 world champions was of 69.4 kg, being de 70.2 kg the one of the 2009-2012 world champions (our previous unpublished measurements). Since 2007 season, especially since 2008 Olympic Games, XCO mountain bike has evolved into a shorter, more explosive and technique (with dubbies, rocks sections, jumps, inclined curves…) event, and this evolution seems to affect the gain in riders' upper arm muscle mass to better perform the required skills. In fact, nowadays technical requirements in XCO races have been increased more and more since 2010 to 2012 seasons, may be mediated by the goal of ~~seek by~~ the UCI of a more spectacular event for the audience. In any case, the relationship between power generated by the rider and body mass (watts/kg) is still very important for the uphills and accelerations at the same time the upper arm strength is needed to execute repeatedly the required skills.

A comparison with other cycling disciplines revealed that the stature ~~height~~ of the elite male XCO riders of the present study (175.5±4.6) is lower than the elite BMX riders (177.3-180.0 cm) (Bertucci & Hourde, 2011; Hodgkins, Slyter, Adams, Berning, & Warner, 2001; Louis et al., 2013; Novak & Dascombe, 2014; Slyter et al., 2001; Zabala et al., 2011), elite track cyclists riders (179.3-186.3 cm) (Craig et al., 1993; Dorel et al., 2005; Foley, Bird, & White, 1989; Schumacher & Mueller, 2002), and most investigated professional road cyclists (176.0-186.0 cm) (Abergel et al., 2004; Aguiló et al., 2003; Antón et al., 2007; Campion et al., 2010; Campos et al., 2012; Chicharro, Hoyos, & Lucía, 2000; Chow & Kronisch, 2000; Fernández-García, Terrados, Pérez-

Landaluce, & Rodríguez-Alonso, 2000; Foley et al., 1989; Hagberg, Mullin, Bahrke, & Limburg, 1979; Hug, Bendahan, Le Fur, Cozzone, & Grélot, 2004; Lucía, Hoyos, & Chicharro, 2001; Lucía et al., 2000; Manetta, et al., 2002; Menaspà, Sassi, & Impellizzeri, 2010; Menaspà et al., 2012; Novak & Dascombe, 2014; Padilla, Mujika, Cuesta, & Goiriena, 1999; Sallet, Mathieu, Fenech, & Baverel, 2006; Vogt et al., 2005; Warner, Shaw, & Dalsky, 2002; White, Quinn, Al-Dawalibi, & Mulhall, 1982b). The elite XCO riders of our investigation (67.1±3.5 kg) were lighter ~~leaner~~ than the elite BMX riders (74.2-81.3 kg) (Bertucci & Hourde, 2011; Hodgkins et al., 2001; Louis et al., 2013; Novak & Dascombe, 2014; Slyter et al., 2001; Zabala et al., 2011), elite track cyclists (71.1-83.0 kg) (Craig et al., 1993; Dorel et al., 2005; Foley et al., 1989; Schumacher & Mueller, 2002), and professional road cyclists in all specialties (67.6-74.4 kg) (Abergel et al., 2004; Aguiló et al., 2003; Antón et al., 2007; Campion et al., 2010; Campos et al., 2012; Chicharro et al., 2000; Chow & Kronisch, 2000; Fernández-García et al., 2000; Foley et al., 1989; Hagberg et al., 1979; Hug et al., 2004; Lucía et al., 2001; Lucía et al., 2000; Manetta, et al., 2002; Menaspà et al., 2010; Menaspà et al., 2012; Novak & Dascombe, 2014; Padilla et al., 1999; Sallet et al., 2006; Vogt et al., 2005; Warner et al., 2002; White et al., 1982b), except in the case of climber road cyclists that were leaner than the elite XCO riders of this study (59.7-67.0 kg) (Lucía, Joyos, & Chicharro, 2000; Menaspà et al., 2010; Menaspà et al., 2012; Padilla et al., 1999; Sallet et al., 2006). Mean BMI value of our elite XCO bikers (21.8±1.0 kg/m$^2$) was lower than those international level BMX riders studied by Louis et al. (2013) (24.2±1.6 kg/m$^2$) and similar to the values reported in professional road cyclists (20.0-22.4 kg/m$^2$) (Aguiló et al., 2003; Campion et al., 2010; Chicharro et al., 2000; Corsetti et al., 2012; Hug et al., 2004; Lucía et al., 2001; Lucía et al., 2000; Menaspà et al., 2012; Vogt et al., 2005). Percentage of body fat of elite XCO mountain bikers determined by Durnin and Womersley equation's (1974) (9.5±2.0 %) was lower than the British Olympic track cyclists reported by White et al. (1982a) (10.8±0.5 %) and higher than the professional road cyclists studied by Sallet, Mathieu, Fenech, and Baverel (2006) (8.5±1.6 %). Finally, mean somatotype of elite XCO riders of the present study was less endomorphic and mesomorphic but slightly more ectomorphic than the sprint and pursuit track cyclists reported by Foley, Bird, and White (1989), showing similar somatotype to British Olympic road cyclists analyzed by White, Quinn, Al-Dawalibi, and Mulhall (1982b) and similar to professional road cyclists investigated by Foley et al. (1989).

Swain (1994) reported an average % BF of approximately 6.4% in high-level off-road cyclists and between 8.5% and 14.3% in elite mountain bikers, suggesting an association between relative body composition and competitive level. From our study, XCO riders also showed a higher % BF which can mean that it is not as important as for road cycling climbers, so the association between body mass per se and performance is not as strong as it was suggested in the past, while body composition seems to be more important. In fact, in the 90s XCO was a more amateur sport than years later so the higher % BF could be related to this fact. Later the % BF was similar to the road cycling climbers, and nowadays the difference is mainly perceived in a slightly higher % BF but especially in the increase of the upper arm muscle mass due to a shorter event that requires a higher strength from the arms in technical segments.

It is important to point out that, like in the present study and as suggested by Legaz Arrese, González Badillo, and Serrano Ostáriz (2005), all the studies should report the values of the skinfolds, to make possible the comparison between different samples and studies. This is why this study appears to be the first of their kind including all the anthropometrical variables, body composition and somatotype from elite XCO riders of different performance level.

The main strengths of this study are that a) it is the first time that anthropometrical, somatotype, and body composition variables are measured in XCO mountain biking; b) the quality of the subjects studied (they were the best riders in the world at the time of study); c) the best riders were compared with lower ranked to ascertain if any difference could be found with regard to anthropometric variables; d) the study was carried out during one of the most important competitions in the world for elite riders, so all the cyclists should be in top physical shape. The main limitation of this of study is that the results have to be taken into account as a point of reference, but should not be taken as an obligatory model for the best performance. In this sense, the results presented can be used as a standard reference, but should be interpreted with caution according to individual characteristics and necessities. For further research, a longitudinal follow-up study of these characteristics and variables is recommended. Even though the DEXA method would be more accurate than anthropometrical measurements, using DEXA would not be feasible for this kind of sample under competition circumstances because of the high costs and the limited availability of the subjects. From a practical point of view, this study provides reference values of anthropometric characteristics, body composition and somatotype of elite male XCO mountain bikers, and this information provides a reference frame for coaches to control the training process in order to help improve athletes' performance, and to improve talent detection and identification in mountain biking.

## Conclusions

The present study gives valuable data of reference data on anthropometry, body composition and somatotype of elite XCO mountain bikers at different competitive levels. Elite and world or Olympic champion WOC riders showed physical differences from sub-elite and not world nor Olympic mountain NWOC bikers, respectively. The use of anthropometry to study the physical characteristics and body composition of XCO riders provides practical information to enhance performance in competitive mountain bike. Also, anthropometric data could be used by coaches to identify young talents and to evaluate the morphological profile of their bikers.

## References

Abergel, E., Chatellier, G., Hagege, A.A., Oblak, A., Linhart, A., Ducardonnet, A., & Menard, J. (2004). Serial left ventricular adaptations in world-class professional cyclists. *Journal of the American College of Cardiology, 44*, 144-149.

Aguiló, A., Tauler, P., Guix, M.P., Villa, G., Córdova, A., Tur, J.A., & Pons, A. (2003). Effect of exercise intensity and training on antioxidants and cholesterol profile in cylists. *The Journal of Nutritional Biochemistry, 14*, 319-325.

Antón, M.M., Izquierdo, M., Ibánez, J., Asiain, X., Mendiguchía, J., & Gorostiaga, E.M. (2007). Flat and uphill climb time trial performance prediction in elite amateur cyclists. *International Journal of Sports Medicine, 28*, 306-313.

Ball, S.D., Altena, T.S., & Stan, P.D. (2004a). Comparison of anthropometry to DXA: a new prediction equation for men. *European Journal of Clinical Nutrition, 58*, 1525-1531.

Ball, S.D., Stan, P., & Desimone, R. (2004b). Accuracy of anthropometry compared to dual energy X-ray absorptiometry. A new generalizable equation for women. *Research Quarterly for Exercise and Sport, 75*, 248-258.

Baron, R. (2001) Aerobic and anaerobic power characteristics of off-road cyclists. *Medicine and Science in Sports and Exercise, 33*, 1387-1393.

Bertucci, W.M., & Hourde, C. (2011). Laboratory testing and field performance in BMX riders. *Journal of Sports Science & Medicine, 10*, 417-419.

Campion, F., Nevill, A.M., Karlsson, M.K., Lounana, J., Shabani, M., Fardellone, P., & Medelli, J. Bone status in professional cyclists. (2010). *International Journal of Sports Medicine, 31*, 511-515.

Campos, E.Z., Bastos, F.N., Papoti, M., Freitas Junior, I.F., Gobatto, C.A., & Balikian Junior, P. (2012). The effects of physical fitness and body composition on oxygen consumption and heart rate recovery after high-intensity exercise. *International Journal of Sports Medicine, 33*, 621-626.

Carmont, M.R. (2008). Mountain biking injuries: a review. *British Medical Bulletin, 85*, 101-112.

Carpes, F.P., Mota, C.B., & Faria, I.E. (2007). Heart rate response during a mountain-bike event: a case report. *Journal of Exercise Physiology Online, 10*, 12-20.

Carter, J.E.L., & Heath, B.H. (1990). *Somatotyping: development and applications*. Cambridge, UK: Cambridge University Press.

Chicharro, J.L., Hoyos, J., & Lucía, A. (2000). Effects of endurance training on the isocapnic buffering and hypocapnic hyperventilation phases in profesional cyclists. *British Journal of Sports Medicine, 34*, 450-455.

Chlíbková, D., Knechtle, B., Rosemann, T., Zákovská, A., Tomášková, I., Shortall, M., & Tomášková, I. (2014). Changes in foot volume, body composition, and hydration status in male and female 24-hour ultra-mountain bikers. *Journal of the International Society of Sports Nutrition, 11*, 12.

Chow, T.K., & Kronisch, R.L. (2000). Mechanisms of injury in competitive off-road bicycling. *Wilderness & Environmental Medicine. 2002, 13*, 27-30.

Corsetti, R., Lombardi, G., Lanteri, P., Colombini, A., Graziani, R., & Banfi, G. (2012). Haematological and iron metabolism parameters in professional cyclists during the Giro d'Italia 3-weeks stage race. *Clinical Chemistry and Laboratory Medicine, 50*, 949-956.

Costa, V.P., & De-Oliveira, F.R. (2008). Physiological variables to predict performance in cross-country mountain bike races. *Journal of Exercise Physiology Online, 11*, 14-24.

Costa, V.P., Carminatti, L.J., Nakamura, F.Y., & De-Oliveira, FR. (2008). Morph-physiological similarities between road cyclists and mountain bikers. *Italian Journal of Sports Sciences, 1*, 11-16.

Craig, N.P., Norton, K.I., Bourdon, P.C., Woolford, S.M., Stanef, T., Squires, B., Olds, T.S., Conyers, R.A., & Walsh, C.B. (1993). Aerobic and anaerobic indices contributing to track endurance cycling performance. *European Journal of Applied Physiology and Occupational Physiology, 67*, 150-158.

Cramp, T., Broad, E., Martin, D., & Meyer, B.J. (2004). Effects of Prexercise Carbohydrate ingestion on mountain bike performance. *Medicine and Science in Sports and Exercise, 36*, 1602-1609.

Dorel, S., Hautier, C.A., Rambaud, O., Rouffet, D., Van Praagh, E, Lacour, J.R., & Bourdin, M. (2005). Torque and power-velocity relationships in cycling: relevance to track sprint performance in world-class cyclists. *International Journal of Sports Medicine, 26*, 739-746.

Durnin J.V., & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thicknesses measurements on 481 men and women aged 16-72 years. *British Journal of Nutrition, 32*, 77-97.

Faiss, R., Praz, M., Meichtry, A., Gobelet, C., & Deriaz, O. (2007). The effect of mountain bike suspensions on vibrations and off-road uphill performance. *The Journal of Sports Medicine and Physical Fitness, 47*, 151-158.

Fernández-García, B., Terrados, N., Pérez-Landaluce, J., & Rodríguez-Alonso, M. (2000). Intensity of exercise during road race pro-cycling competition. *Medicine and Science in Sports and Exercise, 32*, 1002-1006.

Foley, J.P., Bird, S.R, & White, J.A. (1989). Anthropometric comparison of cyclists from different events. *British Journal of Sports Medecine, 23*, 30-33.

Frisancho, A.R. (1990). *Anthropometric standards for the assessment of growth and nutritional status*. Ann Arbor, MI: University of Michigan Press.

Gabbett, T., Kelly, J., Ralph, S., & Driscoll, D. (2009). Physiological and anthropometric characteristics of junior elite and sub-elite rugby league players, with special reference to starters and non-starters. *Journal of Science and Medicine in Sport, 12*, 215-222.

González-Haro, C., Galilea, P.A., González-de-Suso, J.M., Drobnic, F., & Escanero, J.F. (2007). Maximal lipidic power in high competitive level triathletes and cyclists. *British Journal of Sports Medicine, 41*, 23-28.

Gregory, J., Johns, D.P., & Walls, J.T. (2007). Relative vs. absolute physiological measures as predictors of mountain bike cross-country race performance. *Journal of Strength and Conditioning Research, 21*, 17-22.

Hagberg, J.M., Mullin, J.P., Bahrke, M., & Limburg, J. (1979). Physiological profiles and selected psychological characteristics of national class American cyclists. *The Journal of Sports Medicine, 19*, 341-346.

Herrick, J.E., Flohr, J.A., Wenos, D.L., & Saunders, M.J. (2011). Comparison of physiological responses and performance between mountain bicycles with differing suspension systems. *International Journal of Sports Physiology and Performance, 6*, 546-558.

Hodgkins, T.D., Slyter, M.S., Adams, K.J., Berning, J.M., & Warner, S. (2001). A comparison of anaerobic power and ranking among professional BMX racers. *Med Sci Sports Exerc, 33 Supplement 1*, S246

Hug, F., Bendahan, D., Le Fur, Y., Cozzone, P.J., & Grélot, L. (2004). Heterogeneity of muscle recruitment pattern during pedaling in profesional road cyclists: a magnetic resonance imaging and electromyography study. *European Journal of Applied Physiology, 92*, 334-342.

Hurst, H.T., & Atkins, S. (2006). Power output of field-based downhill mountain biking. *Journal of Sports Sciences, 24*, 1047-1053.

Impellizzeri, F.M, & Marcora SM. (2007). The physiology of mountain biking. *Sports Medicine, 37*, 59-71.

Impellizzeri, F.M., Ebert, T., Sassi, A., Menaspà, P., Rampinini, E., Martin, D.T. (2008). Level ground and uphill cycling ability in elite female mountain bikers and road cyclists. *European Journal of Applied Physiology, 102*, 335-341.

Impellizzeri, F.M., Marcora, S.M., Rampinini, E., Mognoni, P., & Sassi, A. (2005a). Correlations between physiological variables and performance in high level cross country off road cyclists. *British Journal of Sports Medicine, 39*, 747-751.

Impellizzeri, F.M., Rampinini, E., Sassi, A., Mognoni, P., & Marcora, S. (2005b). Physiological correlates to off-road cycling performance. *Journal of Sports Sciences, 23*, 41-47.

Impellizzeri, F.M., Sassi, A., Rodriguez-Alonso, M., Mognoni, P., & Marcora, S. (2002). Exercise intensity during off-road cycling competitions. *Medicine and Science in Sports and Exercise, 34*, 1808-1813.

Inoue, A., Sá Filho, A.S., Mello, F.C.M., & Santos, T.M. (2012). Relationship between anaerobic cycling tests and mountain bike cross-country performance. *Journal of Strength and Conditioning Research, 26*, 1589-1593.

International Cycling Union. *Part IV: Mountain Bike. UCI regulations*. Retrieved from http://www.uci.ch/mm/Document/News/Rulesandregulation/16/72/76/MTBReglementsENG_English.pdf.

Jackson, A.S., & Pollock, M.L. (1978). Generalized equations for predicting body density of men. *British Journal of Nutrition, 40*, 497-504.

Jackson, A.S., Pollock, M.L., & Ward, A. (1980). Generalized equations for predicting body density of women. *Medicine and Science in Sports and Exercise, 12*, 175-182.

Katch, F.I., & McArdle, W.D. (1973). Prediction of body density from simple anthropometric measurements in college-age men and women. *Human Biology, 45*, 445-455.

Knechtle, B., Knechtle, P., Rosemann, T., & Senn, O. (2009). No dehydration in mountain bike ultra-marathoners. *Clinical Journal of Sport Medicine, 19*, 415-420.

Lareau, S.A., & McGinnis, H.D. (2011). Injuries in mountain bike racing: frequency of injuries in endurance versus cross country mountain bike races. *Wilderness & Environmental Medice, 22*, 222-227.

Lee, H., Martin, D.T., Anson, J.M., Grundy, D., & Hahn, A.G. (2002). Physiological characteristics of successful mountain bikers and professional road cyclists. *Journal of Sports Sciences, 20*, 1001-1008.

Lee, R.C., Wang, Z., Heo, M., Ross, R., Janssen, I., & Heymsfield, S.B. (2000). Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. *The American Journal of Clinical Nutrition, 72*, 796-803.

Legaz Arrese, A., González Badillo, J.J., & Serrano Ostáriz, E. (2005). Differences in skinfold thicknesses and fat distribution among top-class runners. *The Journal of Sports Medicine and Physical Fitness, 45*, 512-517.

Lion, A., Gauchard, G.C., Deviterne, D., & Perrin, P.P. (2009). Differentiated influence of off-road and on-road cycling practice on balance control and the related-neurosensory organization. *Journal of Electromyography and Kinesiology, 19*, 623-630.

Lohman, T.G. (1981). Skinfolds and body density and their relation to body fatness: a review. *Human Biology, 53*, 181-225.

Louis, J., Billaut, F., Bernad, T., Vettoretti, F., Hausswirth, C., & Brisswalter, J. (2013). Physiological demands of a simulated BMX competition. *International Journal of Sports Medicine, 34*, 491-496.

Lucía, A., Hoyos, J., & Chicharro, J.L. (2001). Preferred pedalling cadence in professional cycling. *Medicine and Science in Sports and Exercise, 33*, 1361-1366.

Lucía, A., Joyos, H., & Chicharro, J.L. (2000). Physiological response to professional road cycling: climbers vs. time trialists. *International Journal of Sports Medicine, 21*, 505-512.

Macdermid, P.W., & Edwards, A.M. (2010). Influence of crank length on cycle ergomety performance of well-trained female cross-country mountain bike athletes. *European Journal of Applied Physiology, 108*, 177-182.

Macdermid, P.W., & Stannard, S. (2012). Mechanical work and physiological responses to simulated cross country mountain bike racing. *Journal of Sports Sciences, 30*, 1491-1501.

MacRae, H. S.-H., Hise, K.J., & Allen, P.J. (2000). Effects of front and dual suspension mountain bike systems on uphill cycling performance. *Medicine and Science in Sports and Exercise, 32*, 1276-1280.

Manetta, J., Brun, J.F., Maimoun, L., Galy, O., Coste, O., Maso, F., Taibaut, J.L., Benezis, C., Lac, G., & Mercier, J. (2002). Carbohydrate dependence during hard-intensity exercise in trained cyclists in the competitive season: importance of training status. *International Journal of Sports Medicine, 23*, 516-523.

Marfell-Jones, M., Olds, T., Stewart, A., & Carter, L. (2006). *International standards for anthropometric assessment*. Potchefstroom, South Africa: ISAK.

Menaspà, P., Rampinini, E., Bosio, A., Carlomagno, D., Tiggio, M., & Sassi, A. (2012). Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. *Scandinavian Journal of Medicine & Science in Sports, 22*, 392-398.

Menaspà, P., Sassi, A., & Impellizzeri, F.M. (2010). Aerobic fitness variables do not predict the professional career of young cyclists. *Medicine and Science in Sports and Exercise, 42*, 805-812.

Nielens, H., & Lejeune, T.M. (2001). Energy cost of riding bicycles with shock absorption systems on a flat surface. *International Journal of Sports Medicine, 22*, 400-404.

Novak, A.R, & Dascombe, B.J. (2014). Physiological and performance characteristics of road, mountain bike and BMX cyclists. *Journal of Science and Cycling, 3*, 9-16.

Padilla, S., Mujika, I., Cuesta, G., & Goiriena, J.J. (1999). Level ground and uphill cycling ability in professional road cycling. *Medicine and Science in Sports and Exercise, 31*, 878-885.

Prins, L., Terblanche, E., & Myburgh, K.H. (2007). Field and laboratory correlates of performance in competitive cross-country mountain bikers. *Journal of Sports Sciences, 25*, 927-935.

Ridge, B.R., Broad, E., Kerr, D.A., & Ackland, T.R. (2007). Morphological characteristics of Olympic slalom canoe and kayak paddlers. *European Journal of Sport Science, 7*, 107-113.

Rose, S., & Peters-Futre, E.M. (2010). Ad libitum adjustments to fluid intake during cool environmental conditions maintain hydration status during a 3-day mountain bike race. *British Journal of Sports Medicine, 44*, 430-436.

Rostami, M., Ansari, M., Noormohammadpour, P., Ali Mansournia, M., & Kordi, R. (2014). Ultrasound assessment of trunk muscles and back flexibility, strength and endurance in off-road cyclists with and without low back pain. *Journal of Back Musculoskeletal Rehabilitation*. [Epub ahead of print]

Sallet, P., Mathieu, R., Fenech, G., & Baverel, G. (2006). Physiological differences of elite and professional road cyclists related to competition level and rider specialization. *The Journal of Sports Medicine and Physical Fitness, 46*, 361-365.

Sánchez-Muñoz, C., Rodríguez, M.A., Casimiro-Andújar, A.J., Ortega, F.B., Mateo-March, M., & Zabala, M. (2011). Physical profile of elite young motorcyclists. *International Journal of Sports Medicine, 32*, 788-793.

Sánchez-Muñoz, C., Sanz, D., & Zabala, M. (2007).Anthropometric characteristics, body composition and somatotype of elite junior tennis players. *British Journal of Sports Medicine, 41*, 793-799.

Schenk, K., Gatterer, H., Ferrari, M., Ferrari, P., Cascio, V.L., & Burtscher, M. (2010). Bike Transalp 2008: liquid intake and its effect on the body's fluid homeostasis in the course of a multistage, cross-country, MTB marathon race in the central Alps. *Clinical Journal of Sport Medicine, 20*, 47-52.

Schumacher, Y.O., & Mueller, P. (2002). The 4000-m team pursuit cycling world record: theoretical and practical aspects. *Medicine and Science in Sports and Exercise, 34*, 1029-1036.

Sewall, K.A., & Fernhall, B. (1995). Physiological characteristics and their relationship to performance in off-road cycling. *Sports Med, Training and Rehab, 6*, 89-95.

Siri, W.E. (1961). *Body composition from fluid space and density*. In: Brozek, J., & Hanschel, A. Techniques for measuring body composition. Washington, DC: National Academy of Science, 223-224.

Slater, G.J., Rice, A.J., Mukika, I., Hahn, A.G., Sharpe, K., & Jenkins, D.G. (2005). Physique traits of lightweight rowers and their relationship to competitive success. *British Journal of Sports Medicine, 39*, 736-741.

Sloan, A.W. (1967). Estimation of body fat in young men. *J Applied Physiol, 23*, 311-315.

Slyter, M.S., Pinkham, K.K., Adams, K.J., Durham, M.P., Moss, C.K., & Wenger, T.E. (2001). Comparison of lower body power output between expert and professional bicycle motor cross. *Medicine and Science in Sports and Exercise, 33 Supplement 1*, S157.

Som-Castillo, A., Sánchez-Muñoz, C., Ramírez-Lechuga, J., & Zabala-Díaz, M. (2010). Analysis of the feeding habits in cyclists of the Spanish National Mountain Bike Team. *Nutrición Hospitalaria, 25*, 85-90.

Sperlich, B., Achtzehn, S., Buhr, M., Zinner, C., Zelle, S., & Holmberg, H.C. (2012). Salivary cortisol, heart rate, and blood lactate responses during elite downhill mountain bike racing. *International Journal of Sports Physiology and Performance, 7*, 47-52.

Stapelfeldt, B., Schwirtz, A., Schumacher, Y.O., & Hillebrecht, M. (2004). Workload demands in mountain bike racing. *International Journal of Sports Medicine, 25*, 294-300.

Swain, D.P. (1994). The influence of body mass in endurance bicycling. *Medicine and Science in Sports and Exercise, 26*, 58-63.

Vogt, S., Heinrich, L., Schumacher, Y.O., Großhauser, M., Blum, A., König, D., Berg, A., & Schmid, A. (2005). Energy intake and energy expenditure of elite cyclists during preseason training. *International Journal of Sports Medicine, 26*, 701-706.

Warner, S.E., Shaw, J.M., & Dalsky, G.P. (2002). Bone mineral density of competitive male mountain and road cyclists. *Bone, 30*, 281-286.

White, J.A., Quinn, G., Al-Dawalibi, M., & Mulhall, J. (1982a). Seasonal changes in cyclists' performance. Part II. The British Olympic track squad. *British Journal of Sports Medicine, 16*, 13-21.

White, J.A., Quinn, G., Al-Dawalibi, M., & Mulhall, J. (1982b). Seasonal changes in cyclists' performance. Part I. The British Olympic road race squad. *British Journal of Sports Medicine, 16*, 4-12.

Wilber, R.L., Zawadzki, K.M., Kearney, J.T., Shannon, M.P., & Disalvo, D. (1997). Physiological profiles of elite off-road and road cyclists. *Med Sci Sports Exerc, 29*, 1090-1094.

Wilmore, J.H., & Behnke, A.R. (1969). An anthropometric estimation of body density and lean body weight in young men. *Journal of Applied Physiology, 27*, 25-31.

Withers, R.T., Craig, N.P., Bourdon, P.C., & Norton, K.I. (1987). Relative body fat and anthropometric prediction of body density of male athletes. *European Journal of Applied Physiololy and Occupational Physiology,* 56, 191-200.

Withers, R.T., Smith, D.A., Chatteron, B.E., Scultz, C.G., & Gaffney, R.D. (1992). Comparison of four methods of estimating the body composition of male endurance athletes. *Eur J Clin Nutr, 46*, 773-784.

Yamaner, F., Atmaca, H., Bayraktaroglu, T., Aydin, M., & Aydemir, S. (2011). Gonadal function in male mountain bikers. *Journal of Strength and Conditional Research, 25*, 2311-2315.

Zabala, M., Peinado, A.B., Calderón, F.J., Sampedro, J., Castillo, M.J., & Benito, PJ. (2011). Bicarbonate ingestion has no ergogenic effect on consecutive all out sprint tests in BMX elite cyclists. *European Journal of Applied Physiology, 111*, 3127-3134.

Zajac, A., Poprzecki, S., Maszczyk, A., Czuba, M., Michalczyk, M., & Zydek, G. (2014). The effects of a ketogenic diet on exercise metabolism and physical performance in off-road cyclists. *Nutrients, 6*: 2493-2508.

**List of graphics legends**

Table 1. Anthropometric characteristics, body composition and somatotypes of the total sample, and elite and sub-elite bikers (mean ± SD, range, and *p* value).

Table 2. Differences in anthropometric characteristics, body composition and somatotypes among elite riders: world or Olympic champion mountain bikers vs. the rest elite bikers (mean ± SD, range, and *p* value).

Table 3. Summary table of studies examining age, stature ~~height~~, body mass ~~weight~~, BMI, body fat percentage, sum of skinfolds and skeletal muscle mass of mountain bikers of different events (mean ± standard deviation).

Figure 1. Average somatotypes of male Olympic cross-country mountain bikers in the present study: elite ○ (n = 22), sub-elite △ (n = 29), world and Olympic champions ☆ (n = 5) and non-world nor Olympic champions □ (n = 17).

Table 1.

| Dimension | Total sample (n=51) Mean ± SD | Total sample (n=51) Range | Elite (n=22) Mean ± SD | Elite (n=22) Range | Sub-elite (n=29) Mean ± SD | Sub-elite (n=29) Range | *p value* | *Cohen's d* |
|---|---|---|---|---|---|---|---|---|
| Age (yr) | 30.1 ± 3.9 | 22.9-37.2 | 28.2 ± 3.1 | 22.9-35.4 | 32.4 ± 3.6 | 24.7-37.2 | 0.000*** | 1.26 |
| Total years biking (yr) | 13.2 ± 3.6 | 7.0-20.0 | 15.1 ± 2.7 | 10.0-20.0 | 10.7 ± 3.1 | 7.0-16.0 | 0.183 | 1.53 |
| Training (hours/week) | 15.2 ± 2.2 | 9.0-20.0 | 16.1 ± 1.2 | 15.0-20.0 | 14.0 ± 2.7 | 9.0-18.0 | 0.008** | 0.98 |
| Training distance per year (km) | 16474.4 ± 3135.0 | 9000.0-21000.0 | 18409.1 ± 1053.8 | 17000.0-21000.0 | 13970.6 ± 3174.5 | 9000.0-19000.0 | 0.000*** | 1.81 |
| Stature ~~Height~~ (cm) | 175.1 ± 3.9 | 169.0-187.0 | 175.5 ± 4.6 | 169.5-187.0 | 174.7 ± 2.9 | 169.0-179.4 | 0.509 | 0.22 |
| Body mass ~~Weight~~ (kg) | 68.1 ± 4.0 | 58.7-76.0 | 67.1 ± 3.5 | 58.7-75.0 | 69.5 ± 4.4 | 62.5-76.0 | 0.055 | 0.61 |
| BMI (kg/m$^2$) | 22.2 ± 1.2 | 20.3-24.9 | 21.8 ± 1.0 | 20.3-23.6 | 22.8 ± 1.1 | 20.7-24.9 | 0.006** | 0.96 |
| Arm span (cm) | 179.1 ± 4.5 | 169.0-191.0 | 178.7 ± 5.3 | 169.0-191.0 | 179.5 ± 3.1 | 173.0-185.6 | 0.583 | 0.19 |
| Triceps skinfold (mm) | 5.4 ± 1.5 | 3.6-10.4 | 5.0 ± 0.9 | 3.6-6.6 | 6.0 ± 1.8 | 3.6-10.4 | 0.052 | 0.69 |
| Biceps skinfold (mm) | 2.7 ± 0.7 | 2.0-5.6 | 2.8 ± 0.7 | 2.0-5.6 | 2.7 ± 0.6 | 2.0-4.2 | 0.790 | 0.16 |
| Subscapular skinfold (mm) | 6.6 ± 1.5 | 3.0-10.8 | 6.3 ± 1.3 | 3.0-9.2 | 6.9 ± 1.7 | 5.2-10.8 | 0.212 | 0.41 |
| Suprailiac skinfold (mm) | 8.4 ± 2.9 | 4.6-18.2 | 7.6 ± 1.7 | 5.6-11.6 | 9.5 ± 3.8 | 4.6-18.2 | 0.076 | 0.63 |
| Supraspinale skinfold (mm) | 4.9 ± 1.4 | 3.2-9.8 | 4.7 ± 0.7 | 3.6-6.0 | 5.2 ± 1.9 | 3.2-9.8 | 0.289 | 0.34 |
| Abdominal skinfold (mm) | 7.5 ± 2.8 | 4.2-16.8 | 6.3 ± 1.4 | 4.2-9.6 | 9.1 ± 3.5 | 5.2-16.8 | 0.005** | 1.02 |
| Thigh skinfold (mm) | 6.2 ± 2.2 | 3.8-13.6 | 5.7 ± 1.3 | 3.8-8.6 | 6.9 ± 2.9 | 3.8-13.6 | 0.119 | 0.52 |
| Calf skinfold (mm) | 4.3 ± 1.1 | 2.6-8.6 | 4.0 ± 0.6 | 2.8-5.2 | 4.6 ± 1.5 | 2.6-8.6 | 0.089 | 0.51 |
| Upper arm girth (cm)[a] | 28.1 ± 1.3 | 25.7-30.8 | 27.7 ± 1.1 | 25.7-29.1 | 28.5 ± 1.4 | 26.3-30.8 | 0.058 | 0.64 |
| Upper arm girth (cm)[b] | 30.5 ± 1.4 | 27.0-33.3 | 30.0 ± 1.2 | 27.0-31.7 | 31.1 ± 1.4 | 29.1-33.3 | 0.013* | 0.85 |
| Thigh girth (cm) | 52.0 ± 2.3 | 45.7-57.5 | 51.0 ± 2.0 | 45.7-54.5 | 53.2 ± 2.2 | 48.7-57.5 | 0.002** | 1.06 |
| Calf girth (maximum) (cm) | 36.3 ± 2.4 | 32.2-47.7 | 35.5 ± 1.3 | 32.2-37.8 | 37.4 ± 3.1 | 33.4-47.7 | 0.015* | 0.78 |
| Humerus breadth (cm) | 6.9 ± 0.3 | 6.4-7.6 | 7.0 ± 0.3 | 6.4-7.6 | 6.9 ± 0.2 | 6.4-7.3 | 0.309 | 0.40 |
| Stylion breath (cm) | 5.7 ± 0.3 | 5.3-6.3 | 5.8 ± 0.2 | 5.5-6.3 | 5.7 ± 0.3 | 5.3-6.3 | 0.121 | 0.39 |
| Femur breadth (cm) | 9.8 ± 0.4 | 9.2-10.6 | 9.8 ± 0.4 | 9.2-10.6 | 9.8 ± 0.4 | 9.3-10.4 | 0.679 | 0.00 |
| Sum of 3 skinfolds (mm) | 17.0 ± 3.6 | 12.2-25.6 | 16.0 ± 2.1 | 12.2-20.0 | 18.2 ± 4.6 | 13.4-25.6 | 0.091 | 0.60 |
| Sum of 6 skinfolds (mm) | 34.9 ± 8.0 ~~39.1 ± 9.8~~ | 23.4-55.2 ~~26.6-65.6~~ | 32.0 ± 4.5 ~~35.6 ± 5.5~~ | 23.4-48.2 ~~26.6-48.6~~ | 38.8 ± 9.9 ~~43.6 ± 12.2~~ | 28.2-55.2 ~~30.0-65.8~~ | 0.015 ~~0.020*~~ | 0.86 |
| Sum of 7 skinfolds (mm) | 41.2 ± 9.8 | 28.2-67.2 | 37.7 ± 5.6 | 28.2-50.4 | 45.8 ± 12.1 | 32.4-67.2 | 0.018* | 0.84 |
| Sum of 8 skinfolds (mm) | 46.1 ± 10.9 | 31.8-74.6 | 42.4 ± 6.3 | 31.8-56.4 | 51.0 ± 13.6 | 36.2-74.6 | 0.025* | 0.79 |
| Sum upper limb skinfolds (mm) | 35.6 ± 8.9 | 24.8-62.6 | 32.7 ± 5.0 | 24.8-43.2 | 39.4 ± 11.4 | 27.6-62.6 | 0.034* | 0.74 |
| Sum lower limb skinfolds (mm) | 10.5 ± 3.1 | 6.4-21.0 | 9.7 ± 1.7 | 7.0-13.2 | 11.6 ± 4.2 | 6.4-21.0 | 0.092 | 0.58 |
| % body fat | | | | | | | | |
| Durnin and Womersley (1974) | 10.2 ± 2.9 | 5.8-17.6 | 9.5 ± 2.0 | 6.2-12.9 | 11.2 ± 3.7 | 5.8-17.6 | 0.099 | 0.59 |
| Katch and McArdle (1973) | 6.9 ± 1.3 | 5.0-10.5 | 6.4 ± 0.7 | 5.0-8.1 | 7.6 ± 1.6 | 5.8-10.5 | 0.010** | 0.95 |
| Sloan (1967) | 5.2 ± 1.5 | 3.0-9.1 | 4.8 ± 1.1 | 3.0-7.1 | 5.8 ± 1.9 | 3.4-9.1 | 0.057 | 0.63 |
| Wilmore and Behnke (1969) | 9.9 ± 1.2 | 8.3-13.5 | 9.4 ± 0.7 | 8.3-11.1 | 10.6 ± 1.5 | 8.8-13.5 | 0.003** | 1.00 |
| Withers et al. (1987) | 6.8 ± 1.4 | 4.7-10.3 | 6.3 ± 0.8 | 4.7-8.2 | 7.4 ± 1.7 | 5.5-10.3 | 0.020* | 0.81 |
| Skeletal muscle ~~Muscle~~ mass (kg), Lee et al. (2000) | 47.3 ± 2.4 | 42.8-55.9 | 47.2 ± 1.8 | 42.8-50.3 | 47.4 ± 3.1 | 42.9-55.9 | 0.737 | 0.08 |
| Total upper arm area (cm$^2$) | 62.8 ± 5.7 | 52.6-75.5 | 61.3 ± 4.6 | 52.6-67.4 | 64.8 ± 6.5 | 55.0-75.5 | 0.066 | 0.62 |
| Upper arm muscle area (cm$^2$) | 55.4 ± 5.0 | 46.8-66.3 | 54.5 ± 4.0 | 46.8-62.0 | 56.6 ± 6.0 | 47.9-66.3 | 0.213 | 0.41 |
| Upper arm fat area (cm$^2$) | 7.4 ± 2.1 | 4.7-13.8 | 6.8 ± 1.3 | 4.7-9.1 | 8.3 ± 2.6 | 5.3-13.8 | 0.022* | 0.71 |
| Total thigh area (cm$^2$) | 215.3 ± 19.1 | 166.2-263.1 | 207.5 ± 15.9 | 166.2-236.4 | 225.5 ± 18.5 | 188.7-263.1 | 0.002** | 1.05 |
| Thigh muscle area (cm$^2$) | 199.5 ± 19.1 | 148.9-245.0 | 193.2 ± 16.1 | 148.9-222.9 | 207.6 ± 20.1 | 157.1-245.0 | 0.018* | 0.81 |
| Thig fat area (cm$^2$) | 15.9 ± 5.4 | 9.9-33.0 | 14.3 ± 3.0 | 9.9-21.5 | 17.9 ± 7.1 | 10.0-33.0 | 0.058 | 0.64 |
| Somatotype | | | | | | | | |
| Endomorphy | 1.9 ± 0.6 | 1.1-3.5 | 1.7 ± 0.3 | 1.2-2.4 | 2.1 ± 0.7 | 1.1-3.5 | 0.049* | 0.72 |
| Mesomorphy | 4.8 ± 0.8 | 3.3-6.9 | 4.6 ± 0.7 | 3.6-6.0 | 5.1 ± 0.8 | 3.3-6.9 | 0.055 | 0.67 |
| Ectomorphy | 2.8 ± 0.6 | 1.6-3.9 | 3.1 ± 0.6 | 1.8-3.9 | 2.5 ± 0.5 | 1.6-3.6 | 0.010** | 1.12 |

SD, standard deviation.
* $p<0.05$, ** $p<0.01$, *** $p<0.001$.
[a]Relaxed; [b]Flexed and tensed.

Table 2.

| | World and Olympic Champions (n=5) | | Non-world nor Olympic Champions (n=17) | | *p value* | *Cohen's d* |
|---|---|---|---|---|---|---|
| Dimension | Mean ± SD | Range | Mean ± SD | Range | | |
| Age (yr) | 30.3 ± 4.2 | 25.3-35.4 | 27.6 ± 2.5 | 22.9-31.3 | 0.094 | 0.97 |
| Total years biking (yr) | 16.8 ± 3.3 | 12.0-20.0 | 14.7 ± 2.4 | 10.0-18.0 | 0.240 | 0.84 |
| Training (hours/week) | 16.4 ± 2.1 | 15.0-20.0 | 16.0 ± 0.9 | 15.0-18.0 | 0.536 | 0.34 |
| Training distance per year (km) | 19400.0 ± 1140.2 | 18000.0-21000.0 | 18117.7 ± 857.5 | 17000.0-20000.0 | 0.013* | 1.46 |
| Stature ~~Height~~ (cm) | 178.4 ± 6.4 | 172.0-187.0 | 174.6 ± 3.8 | 169.5-183.0 | 0.112 | 0.90 |
| Body mass ~~Weight~~ (kg) | 70.2 ± 2.8 | 67.8-75.0 | 66.1 ± 3.2 | 58.7-69.9 | 0.019* | 1.38 |
| BMI (kg/m$^2$) | 22.1 ± 1.0 | 21.3-23.3 | 21.7 ± 1.0 | 20.3-23.6 | 0.460 | 0.42 |
| Arm span (cm) | 183.1 ± 4.8 | 178.5-191.0 | 177.4 ± 4.9 | 169.0-183.8 | 0.033* | 1.22 |
| Triceps skinfold (mm) | 5.6 ± 0.7 | 5.0-6.6 | 4.8 ± 0.9 | 3.6-6.4 | 0.080 | 0.97 |
| Biceps skinfold (mm) | 2.7 ± 0.5 | 2.0-3.4 | 2.8 ± 0.8 | 2.0-5.6 | 0.885 | 0.14 |
| Subscapular skinfold (mm) | 6.2 ± 0.9 | 4.8-7.2 | 6.4 ± 1.4 | 3.0-9.2 | 0.746 | 0.46 |
| Suprailiac skinfold (mm) | 7.9 ± 2.2 | 6.0-11.6 | 7.5 ± 1.6 | 5.6-10.6 | 0.672 | 0.24 |
| Supraspinale skinfold (mm) | 4.3 ± 0.6 | 3.8-5.4 | 4.8 ± 0.7 | 3.6-6.0 | 0.199 | 0.77 |
| Abdominal skinfold (mm) | 6.1 ± 1.3 | 5.0-7.8 | 6.3 ± 1.4 | 4.2-9.6 | 0.717 | 0.15 |
| Thigh skinfold (mm) | 5.4 ± 0.9 | 4.4-6.6 | 5.8 ± 1.4 | 3.8-8.6 | 0.560 | 0.32 |
| Calf skinfold (mm) | 3.7 ± 0.9 | 2.8-5.2 | 4.0 ± 0.5 | 3.2-4.8 | 0.303 | 0.52 |
| Upper arm girth (cm)[a] | 28.6 ± 0.4 | 27.9-29.1 | 27.5 ± 1.1 | 25.7-29.1 | 0.037* | 1.15 |
| Upper arm girth (cm)[b] | 31.1 ± 0.7 | 30.3-31.7 | 29.7 ± 1.1 | 27.0-31.6 | 0.017* | 1.42 |
| Thigh girth (cm) | 51.6 ± 0.9 | 50.4-52.7 | 50.9 ± 2.2 | 45.7-54.5 | 0.487 | 0.36 |
| Calf girth (maximum) (cm) | 36.5 ± 1.1 | 34.7-37.8 | 35.2 ± 1.2 | 32.2-37.2 | 0.046* | 1.15 |
| Humerus breadth (cm) | 7.1 ± 0.4 | 6.6-7.6 | 6.9 ± 0.3 | 6.4-7.4 | 0.261 | 0.65 |
| Stylion breath (cm) | 5.9 ± 0.2 | 5.7-6.2 | 5.8 ± 0.2 | 5.5-6.3 | 0.150 | 0.52 |
| Femur breadth (cm) | 10.0 ± 0.6 | 9.2-10.6 | 9.8 ± 0.4 | 9.3-10.5 | 0.506 | 0.47 |
| Sum of 3 skinfolds (mm) | 16.0 ± 1.4 | 14.0-18.0 | 16.0 ± 2.3 | 12.2-20.0 | 0.988 | 0 |
| Sum of 6 skinfolds (mm) | 31.2 ± 4.0 ~~35.4 ± 5.2~~ | 26.4-37.0 ~~29.6-43.4~~ | 32.2 ± 4.7 ~~35.7 ± 5.7~~ | 23.4-42.8 ~~26.6-48.6~~ | 0.690 ~~0.930~~ | 0.23 |
| Sum of 7 skinfolds (mm) | 37.6 ± 5.7 | 30.4-46.2 | 37.7 ± 5.8 | 28.2-50.4 | 0.964 | 0.02 |
| Sum of 8 skinfolds (mm) | 41.9 ± 6.3 | 34.4-51.6 | 42.5 ± 6.4 | 31.8-56.4 | 0.850 | 0.10 |
| Sum upper limb skinfolds (mm) | 32.8 ± 4.6 | 27.2-39.8 | 32.7 ± 5.2 | 24.8-43.2 | 0.976 | 0.02 |
| Sum lower limb skinfolds (mm) | 9.1 ± 1.7 | 7.2-11.8 | 9.8 ± 1.7 | 7.0-13.2 | 0.418 | 0.43 |
| % body fat | | | | | | |
| Durnin and Womersley (1974) | 9.9 ± 2.0 | 7.0-12.7 | 9.3 ± 2.0 | 6.2-12.9 | 0.603 | 0.31 |
| Katch and McArdle (1973) | 6.6 ± 0.5 | 5.9-7.1 | 6.4 ± 0.8 | 5.0-8.1 | 0.605 | 0.28 |
| Sloan (1967) | 4.5 ± 1.0 | 3.2-5.5 | 4.9 ± 1.1 | 3.0-7.1 | 0.547 | 0.39 |
| Wilmore and Behnke (1969) | 9.2 ± 0.6 | 8.7-9.9 | 9.4 ± 0.7 | 8.3-11.1 | 0.631 | 0.31 |
| Whiters et al. (1987) | 6.1 ± 0.7 | 5.2-7.1 | 6.3 ± 0.9 | 4.7-8.2 | 0.694 | 0.24 |
| Skeletal muscle ~~Muscle~~ mass (kg), Lee et al. (2000) | 47.4 ± 1.7 | 44.9-48.8 | 47.1 ± 1.9 | 42.8-50.3 | 0.791 | 0.17 |
| Total upper arm area (cm$^2$) | 65.0 ± 2.0 | 61.9-67.4 | 60.2 ± 4.6 | 52.6-67.4 | 0.036* | 1.20 |
| Upper arm muscle area (cm$^2$) | 57.3 ± 2.2 | 54.9-60.0 | 53.7 ± 4.0 | 46.8-62.0 | 0.021* | 1.02 |
| Upper arm fat area (cm$^2$) | 7.7 ± 0.9 | 7.0-9.1 | 6.5 ± 1.3 | 4.7-8.8 | 0.070 | 1.02 |
| Total thigh area (cm$^2$) | 211.8 ± 7.1 | 202.1-221.0 | 206.2 ± 17.6 | 166.2-236.4 | 0.504 | 0.37 |
| Thigh muscle area (cm$^2$) | 198.0 ± 5.3 | 191.2-206.0 | 191.8 ± 18.0 | 148.9-222.9 | 0.223 | 0.40 |
| Thig fat area (cm$^2$) | 13.7 ± 2.4 | 10.9-16.8 | 14.4 ± 3.2 | 9.9-21.5 | 0.666 | 0.24 |
| Somatotype | | | | | | |
| Endomorphy | 1.8 ± 0.3 | 1.3-2.2 | 1.7 ± 0.4 | 1.2-2.4 | 0.754 | 0.27 |
| Mesomorphy | 4.8 ± 0.4 | 4.3-5.3 | 4.6 ± 0.7 | 3.6-6.0 | 0.459 | 0.32 |
| Ectomorphy | 3.1 ± 0.8 | 2.1-3.9 | 3.0 ± 0.6 | 1.8-3.9 | 0.910 | 0.16 |

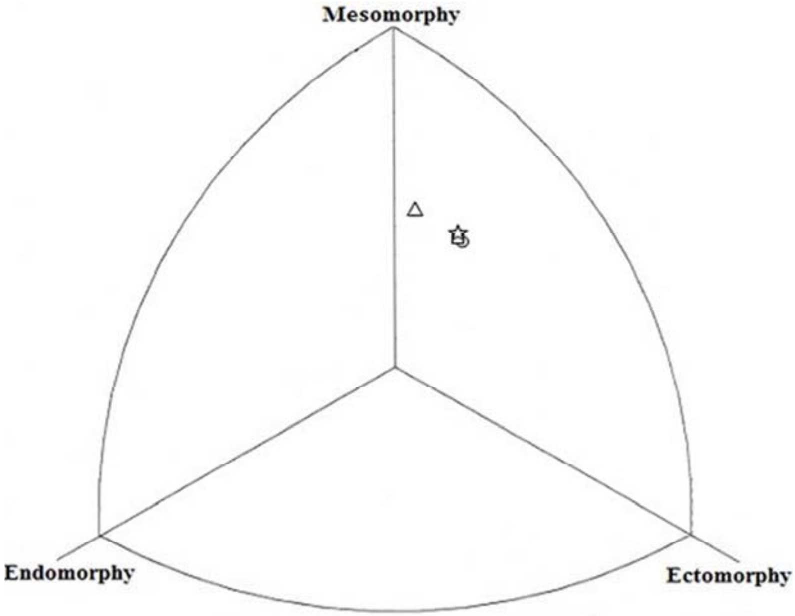
SD, standard deviation.
* p<0.05, ** p<0.01, *** p<0.001.
[a] Relaxed; [b] Flexed and tensed.

Table 3.

| Study | n | Gender | Age (yr) | Stature ~~Height~~ (cm) | Body mass ~~Weight~~ (kg) | BMI (kg·m$^{-2}$) | Body fat (%) | Sum of skinfolds (mm) | Skeletal muscle mass (kg) Lee et al. (2000) | Level | Event |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Chlíbková et al. (2014) | 37 | Male | 36.6 ± 8.4 | 180.4 ± 0.1 | 77.9 ± 9.6 | -[#] | 13.2 ± 5.7[a] | -[#] | 38.4 ± 4.9 | Sub-elite | Ultra-Marathon |
| | 12 | Female | 36.8 ± 8.9 | 167.8 ± 29.3 | 60.6 ± 4.9 | -[#] | 15.4 ± 6.5[b] | -[#] | 26.7 ± 3.3 | Sub-elite | Ultra-Marathon |
| Rostami, Ansari, Noormohammadpour, Ali Mansournia, and Kordi (2014) | 14 | Male | 27.2 ± 4.7 | 172.7 ± 5.5 | 71.5 ± 12.0 | 24.0 ± 4.1 | 20.1 ± 7.4 | -[#] | -[#] | Elite | Cross-country |
| Inoue, Sá Filho, Mello, and Santos (2012) | 10 | Male | 28.7 ± 5.1 | 177.9 ± 7.4 | 68.7 ± 7.6 | -[#] | 5.7 ± 2.8[c] | -[#] | -[#] | Sub-elite | Cross-country |
| Macdermid and Stannard (2012) | 7 | Male | 23.0 ± 9.0 | 176.0 ± 4.0 | 66.9 ± 7.7 | -[#] | -[#] | -[#] | -[#] | Sub-elite | Cross-country |
| Sperlich et al. (2012) | 17 | Male | 22.0 ± 5.0 | 185.1 ± 5.3 | 68.0 ± 3.9 | -[#] | -[#] | -[#] | -[#] | Elite | Downhill |
| Yamaner, Atmaca, Bayraktaroglu, Aydin, and Aydemir (2011) | 22 | Male | 25.5 ± 6.1 | -[#] | -[#] | 22.3 ± 2.0 | -[#] | -[#] | -[#] | Elite | Cross-country |
| Macdermid and Edwards (2010) | 7 | Female | 26.0 ± 3.8 | 168.5 ± 5.4 | 59.3 ± 4.0 | 20.9 ± 1.6 | -[#] | -[#] | -[#] | Well trained | Cross-country |
| Rose and Peters-Futre (2010) | 18 | Male | 40.0 ± 1.4 | 182.0 ± 2.0 | 81.8 ± 2.2 | 24.7 ± 0.6 | 18.1 ± 0.8[d] | -[#] | -[#] | Amateur | Cross-country |
| Schenk et al. (2010) | 25 | Male | 38.0 ± 10.0 | 179.0 ± 7.0 | 75.0 ± 9.5 | 23.5 ± 2.0 | 15.7 ± 3.8[l] | -[#] | -[#] | Amateur | Cross-country |
| Knechtle, Knechtle, Rosemann, and Senn (2009) | 37 | Male | 38.8 ± 9.0 | 179.0 ± 6.0 | 74.8 ± 7.7 | 23.2 ± 1.9 | 12.1 ± 2.7[a] | -[#] | 40.8 ± 3.0 | Sub-elite | Cross-country |
| Costa and De-Oliveira (2008) | 6 | Male | 26.5 ± 3.6 | 174.0 ± 1.2 | 69.1 ± 2.1 | -[#] | 5.9 ± 0.9[c] | 21.1 ± 1.9[o] | -[#] | Elite | Cross-country |
| Costa, Carminatti, Nakamura, and De-Oliveira (2008) | 10 | Male | 27.1 ± 7.4 | 175.2 ± 4.2 | 67.0 ± 6.0 | -[#] | 8.9 ± 2.0[e] | 24.3 ± 4.9[p] | -[#] | Sub-elite | Cross-country |
| Impellizzeri et al. (2008) | 12 | Female | 27.3 ± 4.4 | 166.0 ± 6.2 | 53.7 ± 3.3 | -[#] | -[#] | -[#] | -[#] | Elite | Cross-country |
| Carpes, Mota, and Faria (2007) | 1 | Male | 21.0 | 185.0 | 72.1 | -[#] | 6.6[c] | -[#] | -[#] | Elite | Cross-country |
| González-Haro, Galilea, González-de-Suso, Drobnic, and Escanero (2007) | 4 | Male | 23.0 ± 4.7 | 178.1 ± 5.2 | 71.3 ± 7.3 | 22.5 ± 1.9 | -[#] | -[#] | -[#] | High level | Cross-country |
| Gregory, Johns, and Walls (2007) | 11 | Male | 25.1 ± 4.9 | 180.2 ± 3.5 | 71.6 ± 6.3 | -[#] | 9.2 ± 2.8[f] | 51.0 ± 14.8[s] | -[#] | Elite | Cross-country |
| Hurst and Atkins (2006) | 17 | Male | 27.1 ± 5.1 | 179.0 ± 1.0 | 77.6 ± 6.9 | -[#] | -[#] | -[#] | -[#] | Sub-elite | Downhill |
| Impellizzeri, Marcora, Rampinini, Mognoni, and Sassi (2005a) | 15 | Male | 25.5 ± 3.8 | 175.9 ± 6.4 | 66.2 ± 5.4 | -[#] | -[#] | -[#] | -[#] | High level | Cross-country |
| Impellizzeri, Rampinini, Sassi, Mognoni, and Marcora (2005b) | 13 | Male | 20.0 ± 1.0 | 177.0 ± 8.0 | 65.0 ± 6.0 | -[#] | 5.3 ± 1.6[c] | -[#] | -[#] | Sub-elite | Cross-country |
| Cramp, Broad, Martin, and Meyer (2004) | 8 | Male | 22.0 ± 6.3 | 179.0 ± 6.4 | 69.0 ± 7.6 | -[#] | -[#] | 47 ± 6.8[s] | -[#] | Sub-elite | Cross-country |
| Stapelfeldt, Schwirtz, Schumacher, and Hillebrecht, (2004) | 9 | Male | 21.2 ± 1.8 | 179.9 ± 5.9 | 69.4 ± 4.7 | -[#] | -[#] | -[#] | -[#] | Elite | Cross-country |
| | 2 | Female | 28.5 ± 2.1 | 170.5 ± 2.1 | 63.0 ± 1.4 | -[#] | -[#] | -[#] | -[#] | Elite | Cross-country |
| Impellizzeri, Sassi, Rodriguez-Alonso, Mognoni, and Marcora (2002) | 5 | Male | 21.0 ± 4.0 | 174.6 ± 3.4 | 64.3 ± 4.8 | -[#] | 4.7 ± 1.4[c] | -[#] | -[#] | Sub-elite | Cross-country |
| Lee, Martin, Anson, Grundy, and Hahn (2002) | 7 | Male | 24.4 ± 3.4 | 178.0 ± 7.0 | 65.3 ± 6.5 | -[#] | 6.1 ± 1.0[g] | 33.9 ± 5.7[s] | -[#] | Elite | Cross-country |
| Warner, Shaw, and Dalsky (2002) | 14 | Male | 31.4 ± 5.5 | 180.4 ± 5.7 | 78.7 ± 9.3 | -[#] | 15.6 ± 4.0[m] | -[#] | -[#] | Elite | Cross-country |
| Nielens and Lejeune (2001) | 12 | Male | 32.7 ± 7.5 | 175.0 ± 6.0 | 70.2 ± 5.5 | -[#] | -[#] | -[#] | -[#] | Sub-elite | Cross-country |
| MacRae, Hise, and Allen (2000) | 6 | Male | 35.6 ± 3.7 | 179.5 ± 6.7 | 76.9 ± 3.6 | -[#] | 8.5 ± 0.9[c] | -[#] | -[#] | Sub-elite | Cross-country |
| Wilber, Zawadzki, Kearney, Shannon, and Disalvo (1997) | 10 | Male | 29.0 ± 4.0 | 176.0 ± 7.0 | 71.5 ± 7.8 | -[#] | 5.8 ± 1.1[c] | -[#] | -[#] | Elite | Cross-country |
| | 10 | Female | 31.0 ± 2.0 | 162.0 ± 5.0 | 57.5 ± 4.7 | -[#] | 13.2 ± 2.0[h] | -[#] | -[#] | Elite | Cross-country |
| Sewall and Fernhall (1995) | 10 | Male | 28.4 ± 3.8 | 176.7 ± 4.9 | 70.5 ± 8.0 | -[#] | 8.9 ± 2.8[c] | -[#] | -[#] | Elite | Cross-country |
| | 8 | Male | 25.4 ± 4.7 | 178.7 ± 4.7 | 71.2 ± 7.1 | -[#] | 12.3 ± 3.5[c] | -[#] | -[#] | Elite | Cross-country |
| | 28 | Male | 27.0 ± 4.4 | 177.6 ± 4.8 | 70.8 ± 7.4 | -[#] | 10.5 ± 3.5[c] | -[#] | -[#] | Elite and sub-elite | Cross-country |
| *Present study* | 22 | Male | 28.2 ± 3.1 | 175.5 ± 4.6 | 67.1 ± 3.5 | 21.8 ± 1.0 | 9.5 ± 2.0[d] | 16.0 ± 2.1[q] | 47.2 ± 1.8 | Elite | Cross-country |
| | | | | | | | 6.4 ± 0.7[i] | 32.0 ± 4.5 ~~35.6 ± 5.5~~[r] | | | |
| | | | | | | | 4.8 ± 1.1[j] | 42.4 ± 6.3[t] | | | |
| | | | | | | | 9.4 ± 0.7[k] | | | | |
| | | | | | | | 6.3 ± 0.8[g] | | | | |
| | 29 | Male | 32.4 ± 3.6 | 174.7 ± 2.9 | 69.5 ± 4.4 | 22.8 ± 1.1 | 11.2 ± 3.7[d] | 18.2 ± 4.6[q] | 47.4 ± 3.1 | Sub-elite | Cross-country |
| | | | | | | | 7.6 ± 1.6[i] | 38.8 ± 9.9 ~~43.6 ± 12.2~~[r] | | | |
| | | | | | | | 5.8 ± 1.9[j] | 51.0 ± 13.6[t] | | | |
| | | | | | | | 10.6 ± 1.5[k] | | | | |
| | | | | | | | 7.4 ± 1.7[g] | | | | |

[a]Ball, Altena, and Stan equation (2004a); [b]Ball, Stan, and Desimone equation (2004b); [c]Jackson and Pollock equation (1978); [d]Durnin and Womersley equation (1974); [e]Lohman equation (1981); [f]Withers, Smith, Chatteron, Scultz, and Gaffney equation (1992); [g]Withers, Craig, Bourdon, and Norton equation (1987); [h]Jackson, Pollock, and Ward equation (1980); [i]Katch and McArdle equation (1973); [j]Sloan equation (1967); [k]Wilmore and Behnke equation (1969); [l]Bioimpedance method (BIA); [m]Dual Energy X-ray Absorptiometry (DXA); [n]Underwater Weighing method (UWW); [o]Sum of 3 skinfolds: pectoral, abdominal, thigh; [p]Sum of 3 skinfolds: triceps, subscapular, abdominal; [q]Sum of 3 skinfolds: triceps, subscapular, supraspinale; [r]Sum of 6 skinfolds: triceps, subscapular, ~~suprailiac,~~ supraspinale, abdominal, thigh, calf; [s]Sum of 7 skinfolds: triceps, biceps, subscapular, supraspinale, abdominal, thigh, calf; [t]Sum of 8 skinfolds: biceps, triceps, subscapular, suprailiac, supraspinale, abdominal, calf.

-[#] Data not availaible.




132x103mm (96 x 96 DPI)

# ANALYSIS OF THE FEEDING HABITS IN CYCLISTS OF THE SPANISH NATIONAL MOUNTAIN BIKE TEAM

IV

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**Nutr Hosp 2010; 25:85-90**

Nutrición Hospitalaria

Nutr Hosp. 2010;25(1):85-90
ISSN 0212-1611 • CODEN NUHOEQ
S.V.R. 318

# Original

# Estudio de los hábitos alimentarios de los ciclistas de la selección española de mountain bike

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**Resumen**

***Objetivo:*** **Conocer los hábitos alimentarios de los integrantes de la selección nacional de ciclismo en la disciplina de mountain bike (MTB) para mejorar su rendimiento.**

***Método:*** **Cuarenta ciclistas fueron distribuidos en dos grupos atendiendo al nivel de dedicación mostrado y categoría (25 Cadetes/juniors (C/J) —16,68 ± 0,99 años— y 15 sub23/élites (S23/E) —25,33 ± 4,25 años—. Todos los sujetos completaron un cuestionario específico acerca de sus hábitos alimentarios. Se realizó una estadística descriptiva y de contraste (Mann-Whitney) entre los grupos establecidos.**

***Resultados:*** **El 76% de los sujetos pertenecientes al grupo de C/J muestran un incorrecto hábito alimenticio, siendo este porcentaje del 36% en el grupo de S23/E (p = 0,003). El 76% de los C/J y el 60% de los S23/E realizan 3 ingestas al día (p = 0,348), mientras que el 20% de los C/J y el 26,7% de los S23/E afirman realizar 5 tomas al día. El 64% de los C/J y el 26% de los S23/E manifiestan "picar" entre horas (p = 0,024). Por último, el 56% de los C/J y el 20% de los S23/E manifiestan ingerir alimentos precocinados (p = 0,028).**

***Conclusiones:*** **Los hábitos alimentarios de los ciclistas C/J de la selección española de MTB no eran los adecuados, considerándose mejores los de los S23/E, aunque con importantes aspectos básicos a mejorar.**

(*Nutr Hosp.* 2010;25:85-90)

**DOI:10.3305/nh.2010.25.1.4216**

Palabras clave: *Nutrición. Ciclismo. Mountain bike.*

**ANALYSIS OF THE FEEDING HABITS IN CYCLISTS OF THE SPANISH NATIONAL MOUNTAIN BIKE TEAM**

**Abstract**

***Objective:*** **The aim of the study was to determine the feeding habits of the cyclists of the Spanish mountain bike (MTB) national team.**

***Method:*** **Forty cyclists were distributed in two categories according to time spent in training and competing category (25 Cadet/junior (C/J) —16.68 ± 0.99 years—, and 15 Under-23/elite (U23/E) —25.33 ± 4.25 years—. All the subjects completed a specific questionnaire about their feeding habits. Descriptive and contrast (Mann-Whitney) statistic was carried out in the 2 studied groups.**

***Results:*** **Seventy Six per cent of the subjects of the C/J group showed incorrect feeding habit, and significantly less (36%) than the U23/E showed also incorrect patterns (p = 0.003). Seventy six per cent of the C/J and 60% of the U23/E do 3 intakes/day (p = 0.348), while 20% of C/J and 26.7% of the U23/E do 5 intakes/day. Sixty four per cent of the C/J and 26% of the U23/E eat between meals (p = 0.024). Also, 56% of C/J group and 20% of the U23/E group eat "fast food" (p = 0.028).**

***Conclusions:*** **Feeding habits of the C/J cyclists of the Spanish national team are considered inadequate, being significantly better for the U23/E group, although also in this older group there are basic aspects to improve.**

(*Nutr Hosp.* 2010;25:85-90)

**DOI:10.3305/nh.2010.25.1.4216**

Key words: *Nutrition. Cycling. Mountain bike.*

## Introducción

Es sabido que la alimentación tiene un papel determinante en el deporte de alto rendimiento[1]. Una correcta ingesta de macronutrientes y micronutrientes conlleva una adecuada recuperación de los depósitos celulares, preparando al organismo para esfuerzos posteriores[2]. Es importante conocer el estado nutricional del deportista para evitar un posible déficit de determinadas sustancias en el organismo que puedan conllevar a una disminución de las reservas celulares a corto plazo y a su vez perjuicios metabólicos en el tiempo[3].

Es necesario tener en cuenta las Ingestas Dietéticas Recomendadas (IDR) para diagnosticar y evaluar el estado nutricional de una persona[4]. El *American College of Sports Medicine* (ACSM)[5] ha establecido

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Recibido: 21-I-2009.
Aceptado: 9-II-2009.

una serie de directrices para adecuar las ingestas nutricionales a deportistas de alto rendimiento, mostrando ciertas limitaciones para las ingestas de agua y para recomendaciones en deportes en los que se produce gran desgaste físico[6]. Por ello, las propuestas nutricionales para deportistas de alto rendimiento se realizan utilizando los resultados de investigaciones llevadas a cabo en circunstancias similares a las de entrenamiento y competición de estos deportistas[7]. Se considera una dieta correcta aquella que proporciona la suficiente energía y el adecuado aporte de nutrientes para el deportista en base a su edad, género, especialidad e intensidad del esfuerzo[8], siendo la ingesta energética y la proporción de ciertos macronutrientes las bases que permiten mejorar la recuperación y reparar los tejidos musculares[9]. Las necesidades nutricionales y la ingesta calórica del deportista dependerá del periodo de la temporada en el que se encuentre[10], no siendo las mismas por ejemplo en un periodo de competición que en un período de carga o en un periodo de transición[7].

Existen numerosos estudios que han tratado acerca de diferentes intervenciones nutricionales o el efecto de la ingesta de determinadas sustancias en la población de ciclistas con el fin de mejorar el rendimiento de los mismos y observar el efecto en el rendimiento. Kern y cols.[11] observaron las ventajas de ingerir determinados frutos secos como las pasas frente a determinados alimentos en forma de gel, además de comprobar el efecto de ciertos macronutrientes en el organismo y observar la velocidad de recuperación de la energía gastada durante la competición. Rowlands y cols.[12] estudiaron el efecto de la ingesta de proteínas y su acción recuperadora. Hawemann y cols.[13] por su parte comprobaron el efecto producido por la ingesta de carbohidratos y Rowlands & Hopkins[14] analizaron el efecto de la ingesta de nutrientes de alto contenido en grasas, de alto contenido en carbohidratos y de alto contenido en proteínas sobre la recuperación. Otros estudios analizaron la ingesta de varios días, como es el caso del trabajo realizado por Hawley y cols.[15], quienes administraron una dieta rica en carbohidratos durante tres días, ó el de Sánchez-Benito & Sánchez-Soriano[16], quienes analizaron la alimentación de un grupo de ciclistas durante siete días. Por su parte, Lambert y cols.[17] propusieron una intervención nutricional previa a la competición consistente en una dieta rica en grasas durante diez días y seguida de otra rica en carbohidratos el día antes de la prueba.

Diferentes estudios realizados con deportistas de élite[18,19] y con jóvenes[20-22] ponen de manifiesto que es necesario formar en conceptos específicos por la continua evolución de los avances nutricionales, realizando dicha formación de una manera adecuada y que involucrara a padres y entrenadores en el proceso[23]. De esta manera los deportistas adquirirían los hábitos nutricionales adecuados que por un lado les permitan rendir al máximo nivel en sus competiciones y por otro lado favorecer que se recupere, lo antes posible y de la forma más adecuada, la energía gastada durante la competición.

**Tabla I**
*Características antropométricas de los ciclistas diferenciados por grupos*

| | *C/J* | *S23/E* |
|---|---|---|
| Peso (kg) | 62,94 ± 7,0 | 60,24 ± 7,0 |
| Talla (cm) | 172,48 ± 7,0 | 168,05 ± 7,0 |
| IMC (kg/m²) | 21,10 ± 1,3 | 21,28 ± 1,5 |
| % Graso | 11,49 ± 1,4 | 11,49 ± 1,4 |
| % Muscular | 49,89 ± 1,5 | 54,31 ± 1,4 |

Media ± DS. C/J = Cadete/Junior; S23/E = Sub-23/Élite.

Una vez analizada la bibliografía afín, el objetivo del presente estudio es conocer los hábitos alimentarios de los ciclistas de la selección nacional de *mountain bike* (MTB), diferenciando entre las categorías C/J y S23/E en base a cuatro importantes bloques de contenidos a tratar (tipo de alimentación en cuanto al grado de adecuación de la misma, "picar" entre horas, ingesta de alimentos precocinados y reposiciones alimentarias).

## Material y método

### *Sujetos*

En el estudio participaron un total de 40 ciclistas (26 hombres y 14 mujeres) de edades comprendidas entre los 15 y 34 años, y pertenecientes a la selección española de ciclismo en la especialidad de MTB. La muestra se dividió en dos grupos atendiendo al nivel de dedicación mostrado y a la categoría (25 C/J —16,68 ± 0,9 años— y 15 S23/E —25,33 ± 4,2 años—). En la tabla I se muestran las principales características de la muestra.

### *Diseño y material*

Se empleó un diseño transversal descriptivo y de contraste entre grupos para conocer los hábitos nutricionales de los ciclistas. Se utilizó un cuestionario específico para conocer los hábitos alimentarios, profundizando sobre 4 contenidos: a) tipo de alimentación en cuanto al grado de adecuación de la misma, b) "picar" entre horas, c) ingesta de alimentos precocinados y d) reposiciones alimentarias. El cuestionario recoge en sus preguntas un periodo de tiempo de varias semanas, obteniéndose de esta forma una visión más completa de la ingesta que otros métodos[3].

La puntuación del cuestionario se categorizó dependiendo de las cuestiones planteadas. Las referidas al contenido tipo de alimentación en cuanto al grado de adecuación de la misma, se categorizó en correcta, mejorable y muy mejorable; mientras que el contenido referido al número de reposiciones alimentarias que se realizan al cabo del día osciló entre 3 y 5 reposiciones, siendo esta última el valor más acertado. Para los dos

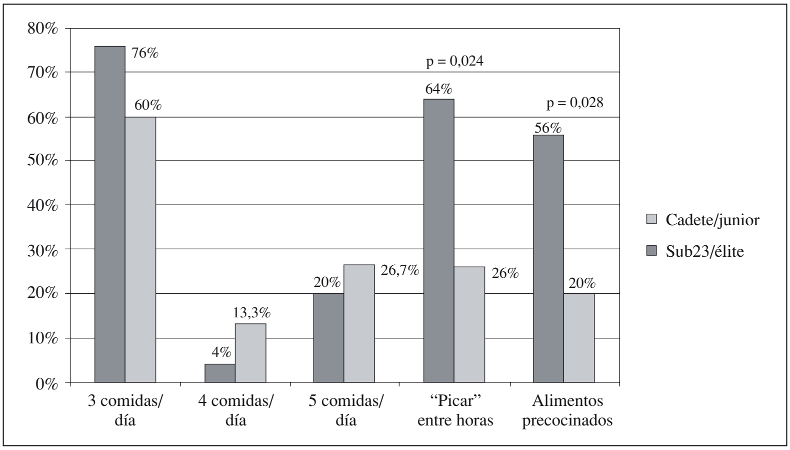


*Fig. 1.—Principales parámetros a considerar en la alimentación del ciclista.*

contenidos siguientes ("picar" entre horas y alimentos precocinados) las preguntas se categorizaron de forma dicotómica en función de si lo realizaban de forma correcta o por el contrario lo llevaban a cabo incorrectamente. De las diferentes cuestiones planteadas al respecto de estos 4 contenidos se obtuvo un valor resultante sobre el hábito alimenticio de los deportistas evaluados.

*Procedimiento*

Los cuestionarios se pasaron en las diversas concentraciones realizadas durante los años 2006, 2007 y 2008 a los ciclistas de que formaron parte de la selección nacional de MTB. Se mantuvo un mismo protocolo de actuación consistente en: una breve explicación del cuestionario, distribución de los mismos, cumplimentación por parte de los sujetos sin preguntas al respecto y recogida de los mismos. El cuestionario se pasó el primer día de la concentración y de forma independiente.

Se realizó una estadística descriptiva y el test de contraste para muestran independientes de Mann-Whitney, estableciendo la diferencia estadística al nivel $p \leq 0,05$. Para el análisis de los resultados se utilizó el paquete estadístico SPSS 15.0.

## Resultados

En la figura 1 se muestran los resultados globales obtenidos en 3 de los contenidos trabajados sobre la alimentación de los ciclistas analizados. El 56% de los C/J y el 20% de los S23/E consumen alimentos precocinados, observándose diferencias estadísticamente significativas ($p = 0,028$). Para el contenido "picar" entre horas, los valores ascienden hasta el 64% en los C/J y al 26% en los S23/E, existiendo diferencias significativas entre ambos grupos ($p = 0,024$). En cuanto al número de ingestas realizadas al día, el 76% de los C/J y el 60% de los S23/E realizan 3 tomas al día; el 4% de los C/J y el 13,3% de los S23/E realizan 4 ingestas al día; y el 20% de los C/J y el 26,7% de los S23/E realizan 5 ingestas diarias. No existen diferencias significativas entre ambos grupos en ninguno de los tres casos mencionados anteriormente, aunque sí se observan diferencias prácticas en cuanto a una tendencia a un mayor número de ingestas diarias en el grupo de S23/E.

En la tabla II se expone el tipo de alimentación de los ciclistas en cuanto al grado de adecuación de la misma. Para obtener los resultados globales que conforman este concepto, se realizaron una serie de preguntas en el cuestionario referidas a la ingesta de nutrientes y la cantidad de los mismos. El 4% de los C/J y el 0% de los S23/E tienen un tipo de alimentación muy mejorable; el 68% de los C/J y el 33,3% de los S23/E muestran una alimentación mejorable; mientras que el 28% de los C/J y el 66,7% de los S23/E realizan una alimentación correcta. Se observan diferencias muy significativas ($p = 0,009$) entre ambos grupos estudiados.

Por último, de la ponderación de los 4 contenidos anteriores, se obtuvo una nueva variable referida a la adecuación de los hábitos nutricionales de los ciclistas de MTB. En este caso, se observa cómo el 76% de los C/J y el 36% de los S23/E muestran un incorrecto hábito alimenticio, hallándose diferencias muy significativas entre ambos grupos a este respecto ($p = 0,003$).

**Tabla II**
*Grado de adecuación de la alimentación para cada grupo*

| | *Correcta* | *Mejorable* | *Muy mejorable* |
|---|---|---|---|
| Cadete/junior | 28% | 68% | 4% |
| Sub23/élite | 66,7% | 33,3% | 0% |

## Discusión

Los resultados obtenidos en nuestro estudio ponen de manifiesto que existe una disparidad entre ambos grupos analizados (C/J vs S23/E), observando unos hábitos alimenticios más adecuados para la mejora del rendimiento en el grupo S23/E, posiblemente debido al trabajo previo realizado consistente en concentraciones de formación específica y al carácter con el que este grupo afronta la especialidad ciclista (profesionalismo), encontrando una mayor dedicación deportiva y un mayor cuidado de las variables relacionadas con el rendimiento[24,25], aunque los resultados mostrados para ambos grupos podrían mejorarse, pudiendo obtener una mejora en el rendimiento de los deportistas.

En el estudio realizado por Saris y cols.[26] a cinco ciclistas masculinos durante un tour de Francia, se observó que la ingesta calórica fue la adecuada, manteniéndose unos niveles medios de consumo calórico durante los 22 días de competición de 5.900 kcal/día. En el estudio de Gabel & Aldous[27] sucede un caso similar, observándose un promedio adecuado en la ingesta energética de 7.195 kcal/día en dos ciclistas durante una competición de 10 días. En otro estudio realizado a mujeres ciclistas de la modalidad de carretera durante una competición de siete días, se puso de manifiesto que la cantidad de kcal/día consumidas en proporción al gasto energético fue la adecuada y correcta, obteniéndose una distribución de macronutrientes en base a las necesidades nutricionales correcta y un aporte de micronutrientes con ciertas carencias que eran suplidas mediante aportes ergogénicos[28]. En los estudios anteriores, se muestra una correcta alimentación por parte de los ciclistas, posiblemente a causa de que su análisis tuviera lugar durante las propias competiciones, donde se pone un mayor énfasis tanto en los descansos y la alimentación[29] como en la hidratación[30] con el fin de que los deportistas recuperen lo antes posible. García-Rovés y cols.[31] analizaron las ingestas nutricionales de ciclistas profesionales de carretera durante el periodo más exigente de la temporada, que comprendía competiciones y entrenamientos. Se concluyó que los ciclistas tenían una alimentación similar y correcta. Resultados del presente estudio con ciclistas de MTB de categoría sub23 y élites muestran un incorrecto hábito alimenticio en el 36% de los casos, siendo este valor más negativo que los sugeridos por los estudios anteriormente mencionados[26-28,31].

Por otro lado y en mayor consonancia con nuestro estudio, Da Silva, Gonçalves & De Abreu[32] tras comprobar que la alimentación del equipo brasileño de fútbol para discapacitados durante la celebración de un campeonato del mundo era muy mejorable, concluyeron que era necesario desarrollar programas de intervención individualizados. Por otro lado y teniendo en cuenta los consumos energéticos promedios de 1781 kcal/día obtenidos por Keith, O'Keeffe, Alt & Young[33] en ciclistas en iniciación, se puede afirmar que teniendo en cuenta las IDR para la población estudiada, la ingesta calórica es insuficiente, debiendo rondar las 2.300 kcal/día[34].

En el trabajo realizado por Sánchez-Benito & Sánchez-Soriano[16], donde se analizó la ingesta nutricional de 34 ciclistas de un equipo de categoría sub-23 y élite, se pone de manifiesto que los ciclistas tienen un consumo alto de lípidos y de prótidos (16,36% y 38,71% respectivamente) y un consumo del 44% de carbohidratos, siendo estos porcentajes diferentes a los recomendados para esta población. Esta observación es similar a la obtenida en nuestro estudio, donde se muestra como los S23/E presentan un elevado índice de hábito nutricional incorrecto, el cual se duplica en el caso de los C/J.

El número de ingestas al día que realizan los ciclistas de nuestro estudio se aleja de las IDR, puesto que tan solo el 20% de los C/J y el 26.7% de los S23/E realizan las 5 recomendadas; mientras que por el contrario, el 76% de los C/J y el 60% de los S23/E realizan 3 ingestas al día. Rodríguez & García[35] mostraron cómo los jugadores de baloncestos estudiados realizan 3 ingestas al día. En el anterior estudio mencionado con mujeres ciclistas de Grandjean y cols.[28], las ingestas fueron de 4,3 ± 0,9 con un rango promedio de 3 a 7 al día y con un mayor aporte calórico en el desayuno y en la cena. En el estudio de García-Rovés y cols.[31] se expone que la dieta que siguen los ciclistas profesionales durante el periodo competitivo y el entrenamiento es de 4 ingestas al día (desayuno, aperitivos sobre la bicicleta, almuerzo a media tarde antes de 1 hora de acabar la competición o entrenamiento y cena). Este tipo de alimentación continuado durante los periodos competitivos en pruebas por etapas incluso de 3 semanas, pueden conllevar cambios en los hábitos de los ciclistas profesionales. Este posible cambio no tiene porqué darse en la disciplina de MTB debido a que las competiciones se realizan en la mayoría de los casos en días aislados.

La ingesta de alimentos precocinados en nuestro estudio es del 56% para los C/J y del 20% para los S23/E. En el estudio de García-Rovés y cols.[31] los ciclistas no consumen alimentos de tipo precocinados, al igual que se observa en el estudio de Saris y cols.[26] con ciclistas durante las tres semanas del tour de Francia. Ambos estudios se realizaron en pruebas por etapas, con lo que es muy probable que los hábitos alimentarios de esos mismos ciclistas evaluados en periodos no competitivos fueran diferentes y más semejantes a nuestros resultados. Por contra, en los estudios de Keith y cols.[33] y Grandjean y cols.[28] con mujeres ciclistas que no competían de forma profesional, se observó en sus dietas un consumo de alimentos precocinados semejante a nuestros resultados.

Por último y al respecto del contenido "picar" entre horas, no entendido como reposición sincrónica, del presente estudio, el 64% de los C/J consume alimentos fuera de los horarios establecidos, por tan solo el 26% de los S23/E. En los estudios de Saris y cols.[26], Keith y cols.[33], Gabel & Aldous[27] y García-Rovés y cols.[31], los ciclistas no "picaban" entre horas, probablemente a causa de que los análisis realizados en esos estudios se realizaron durante competiciones de varios días y no en sus contextos de entrenamiento individual fuera de la dinámica de equipo.

## Conclusiones

Los patrones alimenticios de los ciclistas de la selección nacional de MTB son muy mejorables, especialmente en los más jóvenes. Se observa una diferencia significativa en la alimentación entre las dos categorías estudiadas para los contenidos "picar entre horas", "ingestas de alimentos precocinados", "grado de adecuación de alimentación" y "corrección de los hábitos alimentarios", siempre en perjuicio de los C/J.

Por todo lo anteriormente comentado, el rendimiento de los ciclistas, sobre todo en las categorías de iniciación, puede verse afectado, disminuyendo los logros a causa de una mala alimentación. De ahí que se requiera un mayor trabajo de formación nutricional especialmente con los más jóvenes y un mayor seguimiento, control e incentivación con una adecuada alimentación de los deportistas a lo largo de la temporada y especialmente en los periodos no competitivos. Se debe implicar tanto a los ciclistas como a las familias para el cuidado de la alimentación.

Una posible vía de continuación de este trabajo podría ir enfocada al desarrollo de programas de intervención específicos e individualizados basados en la adquisición de hábitos nutricionales y su efecto en la composición corporal y el rendimiento a medio y largo plazo de los ciclistas.

## Referencias


1. Meyer F, O'Connor H, Shirreffs SM. Nutrition for the young athlete. *Journal of Sports Sciences* 2007; 25 (1): 73-82.
2. Rowlands DS, Rössler K, Thorp RM, Graham DF, Timmons BW, Stannard SR, Tarnopolsky MA. Effects of dietary protein content during recovery from high-intensity cycling on subsequent performance and markers of stress, inflammation, and muscle damage in well-trained men. *Appl Physiol Nutr Metab* 2008; 33 (1): 39-51.
3. Mataix J, Aranceta J. Valoración del estado nutricional. II conceptos y determinación de la ingesta de nutrientes. En: J. Mataix. *Nutrición y Alimentación Humana*. 2002; (2). Madrid: Ergón.
4. Institute of Medicine. *Dietary Referencie intakes Applications in Dietary Assessment*. 2000; Washington, DC: National Academy.
5. American College of Sports Medicine, Amerocan Dietetic Association, Dietitians of Canada. Nutrition and athletic performance. *Med Sci Sports Exerc* 2000; 32: 2130-2145.
6. De Sousa EF, Da Costa TH, Nogueira AD, Vivaldi LJ. Assessment of nutrient and wáter intake among adolescents from sports federations in the federal district, Brazil. *British Journal of Nutrition* 2007: 1-9.
7. Houtkooper L, Abbot JM, Nimmo M. Nutrition for throwers, jumpers, and combined events athletes. *Journal of Sports Sciencies* 2007; 25 (1): 39-47.
8. Willians C, Breuer J, Walter M. The effect of high carbohydrate diet on running performance during a 30 km tread mill time trial. *Eur J Appl Physiol* 1992; 65: 18-24.
9. Kerksick C, Harvey T, Stout J, Campbell B, Wilborn C, Kreider R, Kalman D, Ziegenfuss T, López H, Landis J, Ivy JL, Antonio J. International Society of Sports Nutrition position stand nutrient timing. *Journal of the International Society of Sports Nutrition*. 2008: 5-17.
10. Stellingwerff T, Boit M, Res P. Nutritional strategies to optimize training and racing in middle-distance athletes. *Journal of Sports Sciences* 2007; 25: 17-28.
11. Kern M, Heslin CJ, Rezende RS. Metabolic and performance effects of raisins versus sports gel as pre-exercise feedings in cyclists. *J Strength Cond Res* 2007; 21 (4): 1204-1207.
12. Rowlands DS, Thorp RM, Rössler K, Graham DF, Rockell MJ. Effect of protein-rich feeding on recovery after intense exercise. *Int Sport Nutr Exerc Metab* 2007; 17 (6): 521-543.
13. Hawemann L, West SJ, Goedecke JH, Macdonald IA, St Clair Gibson A, Noakes TD, Lambert EV. Fat adaptation followed by carbohydrate loading compromises high-intensity sprint performance. *J Appl Physiol* 2006; 100 (1): 194-202.
14. Rowlands DS, Hopkins WG. Effect of high-fat, high-carbohydrate, and hig-protein meals on metabolism and performance during endurance cycling. *Int J Sport Nutr Exerc Metab* 2002; 12 (3): 318-335.
15. Hawley JA, Palmer GS, Noakes TD. Effects of 3 day of carbohydrate supplementation on muscle glycogen content and utilization during a 1-h cycling performance. *Eur J Appl Physiol Occup Physiol* 1997; 75 (5): 407-412.
16. Sánchez-benito JL, Sánchez-Soriano E. The excesive intake of macronutrients: does it influence the sports performances of young cyclists? *Nutr Hosp* 2007; 22 (4): 461-470.
17. Lambert EV, Goedecke JH, Zyle C, Murphy K, Hawley JA, Dennis SC, Noakes TD. High-fat diet versus habitual diet prior to carbohydrate loading: effects of exercise metabolism and cycling performance. *Int J Sport Nutr Exerc Metab* 2001; 11 (2): 209-225.
18. Burke LM. A food pyramid for Swiss athletes. *Int J Sport Nutr Exerc Metab* 2008; 18 (4): 430-437.
19. Iglesias-Gutiérrez E, García-Rovés PM, García A, Patterson AM. Food preferences do not influence adolescents high-level athletes dietary intake, *Appetite* 2008; 50 (2-3): 536-543.
20. Zapata LB, Bryant CA, McDermott RJ, Hefelfinger JA. Dietary and physical activity behaviors of middle school youth: the youth physical activity and nutrition survey. *J Sch Health* 2008; 78 (1): 9-18.
21. Lin W, Yang HC, Hang CM, Pan WH. Nutrition knowledge, attitude, and behavior of Taiwanese elementary school children. *Asia Pac J Clin Nutr* 2007; 16 (2): 534-546.
22. Bayona-Marzo I, Navas-Cámara FJ, Fernández de Santiago FJ, Mingo-Gómez T, De la Fuente-Sanz MªM, Cacho del Amo A. Hábitos dietéticos en estudiantes de fisioterapia. *Nutr Hosp* 2007; 22 (5): 573-577.
23. Fournal-Urban A, Keska A, Dobosz J, Nowacka-Dobosz S. Nutritional habits of young chess players. *Endokrynol Diabetol Chor Przemiany Materii Wieku Rozw* 2008; 14 (3): 187-191.
24. Franks AM, Williams AM, Reilly T, Nevill A. Talent identification in elite youth soccer players: physical and physiological characteristics. *J Sports Sci* 1999; 17: 812.
25. Gil S, Ruiz F, Irazusta A, Gil J, Irazusta J. Selection of young soccer players in terms of anthropometric and physiological factors. *J Sports Med Phys Fit* 2007; 47: 25-32.
26. Saris WHM, Van Erp-Baart MA, Brouns F, Westerterp KR, Ten Hoor F. Study on food intake and energy expenditure during extreme sustained exercise: the Tour de France. *Int J Sport Med* 1989; 10: 526-531.
27. Gabel KA, Aldous A. Dietary and haematological assessment of elite cyclists during ten day 2,050 mile ride. *J Am Diet Assoc* 1990; 90 (9): A107 (Supl.).
28. Grandjean AC, Lolkus LJ, Lind RA, Schaefer AE. Ingesta Alimenticia en Ciclistas Mujeres Durante Días Sucesivos de Competencia. *Revistas de Actualización en Ciencias del Deporte* 1994; 2 (6): 65-71.

29. Noakes TD. Physiologycal models to understand exercise fatigue and the adaptations that predict or enhance athletic performance. *Scand J Med Sci Sports* 2000; 10: 123-145.
30. Von Duvillard SP, Arciero PJ, Tietjen-Smith T, Alford K. Sports IDRnks, exercise training and competition. *Curr Sports Med Rep* 2008; 7 (4): 202-208.
31. García-Rovés PM, Terrados N, Fernández S, Patterson AM. Comparison of dietary intake and eating behavior of professional road cyclists during training and competition. *Int J Sport Nutr Exerc Metab* 2000; 10 (1): 82-98.
32. Da Silva AI, Gonçalves B, De Abreu E. Nutritional profile of the Brazilian Amputee Soccer Team during the precompetition period for the world championship. *Nutrition* 2006; 22: 989-995.
33. Keith RE, O'Keeffe KA, Alt LA, Young KL. Dietary status of trained female cyclists. *J Am Diet Assoc* 1989; 89 (11): 1620-1623.
34. Moreiras O, Carbajal A, Cabrera L, Cuadrado C. *Tabla de composición de alimentos* (12ª edición).2008. Madrid: Pirámide.
35. Rodríguez M, García I. Nutrición y dieta en el deporte. Aspectos básicos a tener presente en jugadores profesionales de baloncesto. *Revista digital efdeporte* 2008; 118. http://www.efdeportes.com/efd118/nutricion-y-dieta-en-el-deporte.htm. (28/11/08).

# NUTRITIONAL INTAKE AND ANTHROPOMETRIC CHANGES OF PROFESSIONAL ROAD CYCLISTS DURING A 4-DAY COMPETITION

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**Scand J Med Sci Sports 2015; [Epub ahead of print]**

Scand J Med Sci Sports 2015: ••: ••–••
doi: 10.1111/sms.12513



SCANDINAVIAN JOURNAL OF
MEDICINE & SCIENCE
IN SPORTS

# Nutritional intake and anthropometric changes of professional road cyclists during a 4-day competition

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Accepted for publication 26 May 2015

**Appropriate nutrition through adequate dietary intake of total calories, macronutrients, and micronutrients is an essential component of optimizing the performance of all elite athletes. The aim of this study was to describe the food intake, body composition, and biochemical profile of professional cyclists during the Tour of Andalusia, a four-stage race covering a total distance of 647.6 km. Nutritional data were collected by trained investigators who weighed all of the food and fluid ingested by the cyclists. The nutritional intake of the cyclists was as follows: CHO, 12.8 ± 1.7 g/kg of body weight (BW; 62.3%); fat, 2.1 ± 0.2 g/kg BW (23.2%); proteins, 3.0 ± 0.3 g/kg BW (14.5%); total kcal was 5644.3 ± 593.1. Intake of all micronutrients, except for folate and potassium [which were 93.7% and 91.3% of Recommended Dietary Allowances (RDA)] exceeded the RDA/I. Percentage of body fat and fat weight significantly decreased ($P < 0.05$) while weight of muscle mass remained unchanged after the Tour. Concentrations of urea, aspartate aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, and high-density lipoproteins significantly increased ($P < 0.05$) after the Tour. To our knowledge, this is the first study to describe both nutritional intake and the body and biochemical composition of a sample of professional road cyclists during a top-class cycling race.**

Competitive road cyclists may participate in a variety of stage races with professional cyclists spending around 100 days per year racing. Nutritional intake during these events is an important consideration. Appropriate nutrition through adequate dietary intake of total calories, macronutrients, and micronutrients is an essential component of optimizing the performance of all elite athletes (Lun et al., 2009). The sport nutrition literature provides only a limited amount of information on the dietary intake of highly trained endurance cyclists (Burke, 2001). However, there is evidence that carbohydrate (CHO) feeding provides an important fuel for the racing performance of cyclists (Burke et al., 2001), helping to maintain blood glucose levels during exercise and replenishing muscle glycogen through synthesis, ultimately leading to improved performance (Currell & Jeukendrup, 2008). Adequate amounts of protein are also important to build and regenerate tissues, and fat intake must be adequate to supply essential fatty acids and liposoluble vitamins (Rodriguez et al., 2009). Routine exercise may also increase the turnover and loss of these micronutrients from the body. As a result, greater intakes of micronutrients may be required to cover increased needs for building, repair, and maintenance of lean body mass in athletes (Driskell, 2006).

During long-lasting endurance exercise, energy derives mainly from subcutaneous adipose tissue (Reynolds et al., 1999), although existing evidence is equivocal. Another study has shown that more fat is oxidized during running than during an equivalent amount of cycling (Knechtle et al., 2004). Results relating to body mass are similarly inconclusive with evidence of both increases (Dressendorfer & Wade, 1991) and decreases (Knechtle et al., 2005).

The human physiological system is placed under extreme stress during endurance sports competitions such a bicycle racing. A long duration of exercise might produce substantial changes in biochemical parameters (Waśkiewicz et al., 2012), which could be associated with potential risk of hyponatremia, skeletal muscle breakdown, hepatic damage, and the gastrointestinal complaints associated with ultra-endurance sports.

The aim of this study was to describe the food intake, body composition, and biochemical profile of professional cyclists during a four-stage race and to evaluate the adequacy of nutrient intake in relation to the current recommendations for endurance athletes. Bodily and biochemical changes during this period were also analyzed.

## Methods

### Participants

Six professional road cyclists (24.8 ± 1.2 years) volunteered for the study. All participants belonged to the Andalusia-Cajasur team, a professional UCI continental team. All members of the team who participated in this race also participated in the present study. No specific criteria were set for training volume or years spent in practice. All participants were highly trained and performed regular exercise training, mostly cycling, on a daily basis. Cyclists trained on average for 20–25 h per week accumulating 21 000–25 000 km in a typical year. The aim of this training was to prepare for and compete in a top-class road cycling race (Andalusia Tour, Andalusia, Spain, 2009) covering a total distance of 647.6 km over 4 days, distributed as follows: day one, 123.4 km, highest altitude 600 m; day two, 176.2 km, highest altitude 1800 m; day three, 174.5 km, highest altitude 1250 m; and day four, 173.5 km, highest altitude 800 m. Minimum and maximum temperatures during the Tour of Andalusia were 6 °C and 20 °C, respectively. The Tour of Andalusia requires endurance and resistance in combination with sprint bouts. Load intensity usually reached both submaximal and maximal strength and power. The average power output during the Tour of Andalusia was 246 ± 21.59 watts with a peak of 1061 ± 32.51 watts. The average heart rate was 134.25 ± 5.19 beats per minute (bpm) with a maximum of 176.5 ± 3.21 bpm.

All the participants took part voluntarily in accordance with the Declaration of Helsinki regarding ethical research. The bioethical committee of the University of Granada for human research approved the study.

### Anthropometric data

Guidelines of the International Society for the Advancement of Kinanthropometry (Marfell-Jones et al., 2006) were followed. All anthropometric measurements were taken by the same investigator (ISAK-certified level II anthropometrics researcher). Technical error was less than 5% for skinfold measures and less than 1% for the other measurements. The following instruments were used: Stadiometer (GPM, Serites, Inc., Carlstandt, New Jersey, USA; ± 1 mm accuracy); scale (model 707, Seca Corporation, Columbia, Maryland, USA; ± 50 g accuracy); Holtain skinfold compass (Holtain Ltd, Crymych, UK; ± 1 mm accuracy); Holtain caliper (Holtain Ltd; ± 1 mm accuracy); Holtain flexible metallic metric belt (Holtain Ltd; ± 1 mm accuracy). The following measurements were taken: height, weight, skinfolds (triceps, biceps, subscapular, suprailiac, supraspinal, abdominal, thigh, and calf), perimeters (waist, hip, relaxed biceps, flexed and contracted biceps, thigh, and calf), and diameters (bicondylar humerus, bistiloid, and bicondylar femur). Skinfolds were taken three times and the mean of the three measurements was used in the analyses. Body mass index (BMI) was calculated from height and weight. We compared the results gathered from the sum of the three skinfolds (triceps, subscapular, and supraspinal), six (triceps, subscapular, suprailiac, supraspinal, abdominal, and thigh), and eight skinfolds (triceps, biceps, subscapular, suprailiac, supraspinal, abdominal, thigh, and calf). Five different equations (Sloan, 1967; Wilmore & Behnke, 1969; Katch & McArdle, 1973; Durnin & Womersley, 1974; Withers et al., 1987) were used to estimate body density, and body fat percentage was determined by the Siri (1961) equation. Muscle mass in kg was determined using the method of Lee et al. (2000). Somatotype characteristics were determined according to the Carter and Heath (1990) method.

### Blood biochemistry

Blood samples were collected from the antecubital vein at 6:00 h the day before the race (rest group), and also at the end of the Tour of Andalusia (24 h after the last stage). Plasma was separated by centrifugation of the blood samples at 1500 rpm for 20 min at 18–25 °C. The following parameters were measured: glucose, urea, creatinine, uric acid, sodium, chloride, aspartate aminotransferase (AST), alanine aminotransferase (ALT), creatine kinase, total cholesterol, high-density lipoprotein (HDL) cholesterol, low-density lipoprotein cholesterol and triglycerides.

### Dietary assessment

Nutritional data were collected by trained investigators who weighed all of the food and fluid ingested by the cyclists. Nutritional data were analyzed for nutrient composition using nutritional software (DietSource 3.0, Healthcare Nutrition S. A., Esplugues de Llobregat, Spain). Information about the nutritional content of foods not available in the computer program was obtained from the manufacturer. All the food was weighed on a digital scale (Soehnle 8020, Murrhardt, Germany) with a precision of 1 g increments up to 1 kg and 2 g increments between 1 and 2 kg. Sport products such as energy bars and gels ingested by the cyclists during the race were described from the label of the products. Food consumed during races was weighed and packaged into bags beforehand. The investigators weighed each bag immediately after each stage to determine the amount of food consumed during the race.

### Statistical analysis

The statistics programme SPSS version 20.0 (SPSS, Inc., Chicago, Illinois, USA) was used to analyze the data. The qualitative variables are presented as average and percentage, while the quantitative variables are presented with the average and the typical deviation. The standardizing of the variables was carried out using the Shapiro–Wilk test using Lillieforts correction and the homoscedasticity through the Levene test. After verifying that the variables were normal, the data were analyzed using the *t*-test (before and after the competition). The level of significance was established at 0.05.

## Results

The demographic characteristics of the sample are represented in Table 1. The mean energy and macronutrient intakes consumed during breakfast, during the race, after the race, and dinner over the 4-day period, are summarized in Table 2. The nutritional intake of the cyclists was as follows: CHO, 12.8 ± 1.7 g/kg of body weight (BW; 62.3%); fat, 2.1 ± 0.2 g/kg BW (23.2%); proteins, 3.0 ± 0.3 g/kg BW (14.5%); total kcal was 5644.3 ± 593.1. Table 3 describes cyclist micronutrient intake compared with applicable Recommended Dietary Intakes (RDI) values. Intake of all micronutrients, except for folate and potassium [which were 93.7% and 91.3% of Recommended Dietary Allowances (RDA)] exceed the RDA/AI.

Table 4 compared the anthropometric characteristics of the cyclists before and after the Tour of Andalusia.

Table 1. Demographic characteristics of participants

| | |
|---|---|
| Age (years) | 25.5 ± 1.5 |
| Weight (kg) | 67.7 ± 3.6 |
| Height (cm) | 176.2 ± 5.6 |
| BMI (kg/m$^2$) | 21.8 ± 1.0 |

BMI, body mass index.

Table 2. Energy and macronutrient intake during the Tour

| | 1 | 2 | 3 | 4 | 5 | 6 | Total |
|---|---|---|---|---|---|---|---|
| Breakfast | | | | | | | |
| CHO (g) % | 198.9 (55) | 158.2 (46) | 171.9 (50) | 181.2 (51) | 148.4 (41) | 177.5 (57) | 172.7 ± 17.8 (50.0 ± 5.9) |
| Fat (g) % | 48.1 (30) | 61.3 (41) | 55.9 (36) | 58.2 (37) | 67.9 (42) | 39.0 (28) | 55.1 ± 10.2 (35.7 ± 5.7) |
| Protein (g) % | 54.6 (15) | 44.3 (13) | 46.9 (14) | 43.8 (12) | 59.7 (17) | 47.0 (15) | 49.4 ± 6.4 (14.3 ± 1.8) |
| Energy (kcal) | 1447 | 1362 | 1378 | 1424 | 1444 | 1249 | 1384 ± 74.7 |
| During the race | | | | | | | |
| CHO (g) % | 268.2 (76) | 369.7 (79) | 294.2 (73) | 143.1 (69) | 379.3 (81) | 210.8 (74) | 277.6 ± 91.4 (75.2 ± 4.3) |
| Fat (g) % | 29.9 (19) | 34.3 (17) | 40.3 (23) | 24.7 (26) | 30.5 (15) | 27.4 (22) | 31.2 ± 5.5 (20.5 ± 4.1) |
| Protein (g) % | 17.2 (5) | 20.4 (4) | 17.3 (4) | 10.1 (5) | 18.8 (4) | 11.9 (4) | 16.0 ± 4.0 (4.3 ± 0.5) |
| Energy (kcal) | 1411 | 1869 | 1609 | 835 | 1867 | 1137 | 1454.7 ± 412.9 |
| After race | | | | | | | |
| CHO (g) % | 70.7 (47) | 64.1 (46) | 64.1 (49) | 60.4 (42) | 114.9 (58) | 70.9 (56) | 74.2 ± 20.4 (49.5 ± 6.2) |
| Fat (g) % | 16.3 (24) | 12.1 (20) | 12.6 (22) | 16.6 (26) | 14.2 (16) | 13.7 (24) | 14.3 ± 1.9 (22.1 ± 3.6) |
| Protein (g) % | 43.3 (29) | 46 (34) | 38.3 (29) | 46.6 (32) | 50.4 (26) | 25.1 (20) | 41.6 ± 9.0 (28.4 ± 4.9) |
| Energy (kcal) | 603 | 537 | 523 | 577 | 789 | 507 | 589.3 ± 104.0 |
| Dinner | | | | | | | |
| CHO (g) % | 342.5 (64) | 326.1 (61) | 384.4 (67) | 304.5 (62) | 357.5 (63) | 346.6 (66) | 343.6 ± 27.2 (64.0 ± 2.3) |
| Fat (g) % | 45.5 (19) | 50.5 (21) | 40.3 (16) | 39.6 (19) | 50.7 (20) | 38.4 (17) | 44.2 ± 5.5 (18.5 ± 1.9) |
| Protein (g) % | 92.5 (17) | 93.7 (18) | 97.8 (17) | 93.9 (19) | 98.0 (17) | 89.8 (17) | 94.3 ± 3.2 (17.5 ± 0.8) |
| Energy (kcal) | 2215 | 2180 | 2408 | 2019 | 2325 | 2149 | 2216.0 ± 136.6 |
| Total | | | | | | | |
| CHO (g) g/kg BW % | 880.3 13.8 (63) | 915.1 14.0 (62) | 914.7 14.0 (63) | 689.3 9.8 (58) | 1000.2 13.6 (63) | 805.7 11.8 (65) | 867.6 ± 107.6<br>12.8 ± 1.7 (62.3 ± 2.3) |
| Fat (g) g/kg BW % | 139.9 2.2 (22) | 158.1 2.4 (24) | 149.1 2.3 (23) | 139.1 2.0 (26) | 163.3 2.2 (23) | 118.5 1.7 (21) | 144.7 ± 16.0<br>2.1 ± 0.2 (23.2 ± 1.7) |
| Protein (g) g/kg BW % | 207.6 3.3 (15) | 204.4 3.1 (14) | 200.3 3.1 (14) | 194.4 2.8 (16) | 226.9 3.1 (14) | 173.8 2.5 (14) | 201.2 ± 17.4<br>3.0 ± 0.3 (14.5 ± 0.8) |
| Energy (kcal) | 5677 | 5947 | 5919 | 4856 | 6424 | 5043 | 5644.3 ± 593.1 |

BW, body weight; CHO, carbohydrate.

Table 3. Micronutrient intake during the Tour and comparison with RDA/AI

| | Cyclist ($n = 6$) | RDA/AI* | %RDA/AI* |
|---|---|---|---|
| Vitamins | | | |
| Vit A (μg/day) | 2699.3 ± 555.3 | 900 | 299.9 |
| Vit B1 (mg/day) | 3.7 ± 0.80 | 1.2 | 308.3 |
| Vit B2 (mg/day) | 3.3 ± 0.64 | 1.3 | 253.8 |
| Vit B6 (mg/day) | 4.0 ± 0.77 | 1.3 | 307.7 |
| Folic acid total (μg/day) | 374.9 ± 70.4 | 400 | 93.7 |
| B12 (μg/day) | 8.3 ± 1.2 | 2.4 | 345.8 |
| Vit C (mg/day) | 167.9 ± 69.0 | 90 | 186.6 |
| Vit D A (μg/day) | 23.7 ± 3.7 | 15 | 158 |
| Vit E (mg/day) | 18.0 ± 4.1 | 15 | 120 |
| Minerals | | | |
| Ca (mg/day) | 1528.3 ± 162.9 | 1000 | 152.8 |
| Fe (mg/day) | 26.7 ± 2.8 | 8 | 333.8 |
| Na (mg/day) | 3154.7 ± 429.1 | 1500* | 210.3* |
| K (mg/day) | 4288.9 ± 741.1 | 4700* | 91.3* |
| Zn (mg/day) | 34.6 ± 5.7 | 11 | 314.5 |
| Mg (mg/day) | 643.6 ± 106.7 | 400 | 160.9 |
| Se (μg/day) | 243.0 ± 30.6 | 55 | 441.8 |

An RDA is the average daily dietary intake level that is recommended as being sufficient to meet the nutrient requirements of nearly all (97–98%) healthy individuals in a group. The AI is believed to cover the needs of all healthy individuals in the groups, but lack of data or uncertainty in the data prevent specific conclusions on the proportion of the sample achieving AI from being reported.
AI, adequate intakes in ordinary type followed by an asterisk. RDA; Recommended Dietary Allowances in ordinary type.

Table 4. Anthropometric characteristics of the cyclists before and after the Tour

| | Before | After | *P* value |
|---|---|---|---|
| Measurement | | | |
| Height (cm) | 176.2 | 176.2 | 0.907 |
| Weight (kg) | 67.7 | 67.5 | 0.277 |
| BMI (kg/m$^2$) | 21.84 ± 1.01 | 21.77 ± 1.02 | 0.273 |
| Skinfolds (mm) | | | |
| Sum of 3 | 20.24 ± 3.00 | 19.24 ± 3.29 | 0.020* |
| Sum of 6 | 42.45 ± 6.94 | 40.02 ± 7.35 | 0.010* |
| Sum of 8 | 49.92 ± 7.70 | 47.01 ± 8.09 | 0.010* |
| Somatotype | | | |
| Endomorphy | 1.57 ± 0.266 | 1.45 ± 0.288 | 0.013* |
| Mesomorphy | 4.63 ± 0.907 | 4.65 ± 0.864 | 0.695 |
| Ectomorphy | 3.07 ± 0.753 | 3.08 ± 0.763 | 0.611 |

*$P < 0.05$.
BMI, body mass index.

Table 5. Differences between fat and muscle mass during the Tour

| | Before | After | *P* value |
|---|---|---|---|
| Durning & Womersley | | | |
| % fat | 10.41 ± 2.01 | 9.58 ± 2.29 | 0.020* |
| kg fat | 7.05 ± 1.35 | 6.46 ± 1.53 | 0.022* |
| kg muscle mass | 60.67 ± 3.58 | 61.04 ± 3.79 | 0.125 |
| Katch & McArdle | | | |
| % fat | 7.20 ± 1.08 | 6.83 ± 1.01 | 0.026* |
| kg fat | 4.87 ± 0.68 | 4.60 ± 0.66 | 0.016* |
| kg muscle mass | 62.85 ± 3.65 | 62.90 ± 3.70 | 0.829 |
| Sloan | | | |
| % fat | 6.42 ± 1.41 | 5.90 ± 1.44 | 0.012* |
| kg fat | 4.32 ± 0.81 | 3.96 ± 0.84 | 0.010* |
| kg muscle mass | 63.40 ± 4.06 | 63.54 ± 4.10 | 0.413 |
| Willmore & Behnke | | | |
| % fat | 10.00 ± 1.08 | 9.65 ± 0.88 | 0.047* |
| kg fat | 6.75 ± 0.62 | 6.50 ± 0.54 | 0.025* |
| kg muscle mass | 60.97 ± 3.69 | 61.00 ± 3.66 | 0.881 |
| Withers et al. | | | |
| % fat | 7.18 ± 0.97 | 6.72 ± 0.91 | 0.008** |
| kg fat | 4.84 ± 0.53 | 4.52 ± 0.54 | 0.006** |
| kg muscle mass | 62.87 ± 3.83 | 62.98 ± 3.80 | 0.598 |

*$P < 0.05$; **$P < 0.01$.

Table 6. Comparisons between the biochemical profiles before and after the Tour

| Parameters | Control | Before | After |
|---|---|---|---|
| Glucose | 70–100 mg/dL | 83.0 ± 6.2 | 85.0 ± 5.5 |
| Urea | 10–50 mg/dL | 47.5 ± 2.3 | 61.8 ± 3.5** |
| Creatinine | 0.7–1.2 mg/dL | 0.85 ± 0.01 | 0.92 ± 0.04 |
| Uric acid | 3.4–7.0 mg/dL | 4.0 ± 0.1 | 4.6 ± 0.3 |
| Sodium | 135–142 mEq/L | 126.0 ± 3.4 | 143.3 ± 3.5** |
| Chloride | 92–104 mEq/L | 89.6 ± 2.8 | 102.5 ± 2.2** |
| AST | 10–38 U/L | 34.5 ± 6.1 | 54.6 ± 4.6* |
| ALT | 5–41 U/L | 23.3 ± 3.4 | 39.0 ± 2.6** |
| LDH | 240–480 U/L | 395.6 ± 27.9 | 458.3 ± 31.4 |
| CK | 38–190 U/L | 282.5 ± 70.4 | 542.6 ± 102.3 |
| Myoglobin | 28–72 ng/mL | 63.5 ± 14.5 | 107.5 ± 11.9* |
| Total cholesterol | 100–200 mg/dL | 154.0 ± 7.3 | 161.1 ± 7.4 |
| Cholesterol HDL | > 40 mg/dL | 58.0 ± 2.6 | 73.9 ± 2.0*** |
| Cholesterol LDL | 50–125 mg/dL | 64.1 ± 1.7 | 73.6 ± 7.9 |
| Triglycerides | 50–150 mg/dL | 159.3 ± 35.9 | 99.0 ± 6.8 |

*$P < 0.05$; **$P < 0.01$; ***$P < 0.001$.
ALT, alanine aminotransferase; AST, aspartate aminotransferase; CK, creatine kinase; HDL, high-density lipoprotein LDH, lactate dehydrogenase; LDL, low-density lipoprotein.

Sum of skinfolds (3, 6, and 8) significantly decreased ($P = 0.020$, 0.010, and 0.010, respectively) after the tour. All cyclists had an ectomorphic mesomorph somatotype (in which mesomorphy dominates but ectomorphy is more apparent than endomorphy), apart from one cyclist who is mesomorphic ectomorph (ectomorphy is dominant but mesomorphy is more apparent endomorphy). The endomorph component significantly decreased ($P = 0.013$) after the Tour, with the other components remaining unchanged. Percentage of body fat and fat weight significantly decreased ($P < 0.05$) after the Tour of Andalusia independent of the equation method used for calculations. These results together with the decrease in the sum of skinfolds confirm a lower level of adiposity after the Tour. The weight of muscle mass remained unchanged after the Tour (Table 5).

Table 6 compared biochemical profile before and after the Tour. Concentrations of urea (47.5 ± 2.3 mg/dL vs 61.8 ± 35 mg/dL), aspartate aminotransferase (34.5 ± 6.1 U/L vs 54.6 ± 4.6 U/L), alanine aminotransferase (23.3 ± 3.4 U/L vs 39.0 U/L), creatine kinase (282.5 ± 70.4 U/L vs 542.6 ± 102.3 U/L), myoglobin (63.5 ng/mL vs 107.5 ± 11.9 ng/mL), and high-density lipoproteins (58.0 ± 2.6 mg/dL vs 73.9 ± 2.0 mg/dL) significantly increased ($P < 0.05$) after the Tour.

## Discussion

The main findings of the present study were that these elite cyclists maintained body weight over a 4-day competition. However, they significantly reduced their fat mass in response to racing. Micronutrient and macronutrient intake approximated the recommended daily amounts, except for protein for which intake was slightly higher than what is recommended for an extreme exercise program (Rodriguez et al., 2009). The cyclists also experienced a biochemical change in some parameters after racing.

CHO intake recommended by the American College of Sport Medicine (Rodriguez et al., 2009) for athletes ranges from 6 to 10 g/kg of body mass (BM) per day, these values have evolved into the recommended carbohydrate intake for optimal muscle glycogen recovery. However other studies have shown that well-trained cyclists undertaking 2 h of training each day have higher muscle glycogen stores when consuming 12 g/kg of BM of CHO as opposed to consuming 10 g/kg of BM of CHO over a week (Coyle et al., 2001). In this context, Burke et al. (2004) revised guidelines for the intake of CHO for average everyday intake, training intake, and to sustain extreme exercise program (4–6 + h per day): 10–12 + g/kg BM/day. Daily CHO intake during the 4-day competition of the cyclists in the present study was 12.8 ± 1.7 g/kg BM/day (62.3 ± 2.3% of the total energy intake), which is slightly higher than the current recommendations. Similar CHO intakes have been observed in the Tour of Southland (Rehrer et al., 2010), a 6-day cycling stage race with a daily CHO intake of 12.9 ± 1.4 g/kg BM/day. Another study in the Tour of France (Saris et al., 1989) reported CHO consumptions of 12–13 g/kg BM/day.

Protein intake was 3.0 ± 0.3 g/kg BM/day, which exceeds the protein recommendations for endurance- and strength-trained athletes (Rodriguez et al., 2009), range: 1.2 to 1.7 g/kg BM/day. Previous reports indicated that endurance athletes generally consume more protein than thought to be required. A study (Carlsohn & Müller, 2014) with six German elite mountain runners showed that mountain runners consumed relatively large amounts of protein on the day before the race and 4.0 ± 3.2 g per hour (95% CI: 0.7–7.3 g/h) during competition. A study with cyclists (Rehrer et al., 2010) showed similar results to the present with a protein intake of 2.9 ± 0.3 g/kg BM/day. Although protein intake was higher than the recommendation, several studies have suggested that a CHO/protein ratio of around 4:1 can enhance glycogen recovery, as well as protein balance, tissue repair, and adaptations of new protein (Kerksick et al., 2008). Taking this into account, further studies are needed to analyse whether an increase in protein recommendation could be beneficial in longer sporting events and whether satiety and *ad libitum* energy intake would be affected (Bowen et al., 2006).

Fat intake should range from 20% to 35% of total energy intake. Consuming < 20% of energy from fat does not benefit performance (Rodriguez et al., 2009) and could harm the correct absorption of fat soluble vitamins while failing to provide the correct quantity of essential fatty acids. All cyclists participating in the current study met recommendation with a mean of 23.2 ± 1.7% of energy from fats. Similar results were reported in the Tour of France study (Saris et al., 1989) with a 23% and Tour of Spain study (Garcia-Roves et al., 1998) with a 25.5%. Lower percentages were reported in cyclists during a 24-h team relay race (Bescós et al., 2012) with a 17.4 ± 5.6% or in a 6-day cycling stage race (Rehrer et al., 2010) with a 17.3%.

The intake of all vitamins and minerals exceeded their respective RDA or AI, except for folic acid and vitamin K for which percentages were slightly lower (93.7, 91.3%, respectively). Exercise stresses many of the metabolic pathways where micronutrients are required and exercise training may result in muscle biochemical adaptation that increases micronutrient needs (Driskell, 2006). The most common vitamins and minerals to be of concern for athletes are calcium, vitamin D, C, E, and B complex, as well as iron, zinc, magnesium, and selenium (Driskell, 2006). Our study showed an excess of these micronutrients relatively to the RDA or AI.

Mean energy intake was 5,644.3 ± 593.1 kcal/day. Similar results were reported by top-class cyclists in the most important Tour races, for example, during the Tour of France (Saris et al., 1989), energy intake was 5903 kcal/day, while during the Tour of Spain (Garcia-Roves et al., 1998) energy intake was 5616 ± 430 kcal/day. Body weight did not have change significantly over the race period, indicating that during the race, each cyclist was not far from energy balance.

The somatotypes presented by the cyclists were 1.57, 4.63, and 3.07. These results are similar to those reported by Foley et al. (1989) for road cyclists (2.1, 4.8, 3.5). Male professional road cyclists show a wide range of values in their physical characteristics. The average age of members of a typical professional cycling team is 26 years, ranging from 20 to 33 years. There is also large variability in the values for height (mean 180 cm, range 160 to 190 cm), body mass (mean 68.8 kg, range 53 to 80 kg), and percentage body fat (reported to be about 8%, ranging between 6.5% and 11.3%; Mujika & Padilla, 2001). These values are similar to those obtained in the present sample and similar to the data obtained from an all terrain group of male road junior cyclists at different performance levels for which a with a height of 176 ± 5 cm, weight of 64.5 ± 4.2 kg, BMI of 29.9 ± 1.3 kg/m$^2$, and body fat of 6.4 ± 1.6% was reported (Menaspà et al., 2012).

No significant changes in body mass were observed in cyclists during the race. However, they experienced a significant reduction in fat mass ($P < 0.05$) without changes in muscle mass. Similar results were reported in a 6-day cycling stage race (Rehrer et al., 2010). A recent study of an ultra-cycling race showed similar results with reductions in fat alongside reductions in body mass and without evidence of exercise-induced skeletal muscle damage (Knechtle et al., 2009). Former findings supported the assumption that an ultra-endurance performance lead to a decrease in body mass, mainly because of a decrease in fat mass (Bischof et al., 2013). Reductions in muscle mass cannot be explained by ultra-endurance cycling because cycling mainly requires concentric strains with only negligible eccentric movements which generally do not cause any significant muscle damage (Williams, 1985).

Biochemical changes were also analyzed before and after the Tour of Andalusia. Significantly higher values were observed for HDL cholesterol (HDL-c) after the Tour. It has been reported that both aerobic and anaerobic exercise increase circulating HDL-c (Kontush et al., 2003). Serum urea concentration has also been shown to increase after the Tour. These findings have been reported in previous studies after marathon races (Reid et al., 2004). Increases in these parameters after exercise are very well described (Clarkson et al., 2006). They are thought to reflect increases in secondary degradation of amino acids after muscle cell damage. Other changes detected in plasma after racing include change to creatine kinase and myoglobin, which can suggest minor damage to skeletal muscle.

## Perspectives

To our knowledge, this is the first study to describe both nutritional intake and the body and biochemical composition of a sample of professional road cyclists during a top-class cycling race. Nutritional intake was generally adequate in terms of macronutrients and micronutrients. However, protein intake exceeded the protein recommendations which could result in dehydration should it not be controlled. Cyclists' diets should be assessed before supplementing with protein. Micronutrient intake exceeded all RDI recommendations, except for folate and potassium. These micronutrients should be controlled in order to avoid possible anemia, cramp, or a decrease in performance. The cyclists showed low body fat percentage and experienced changes in biochemical parameters during the race. Sport nutritionists should consider the types of food provision carefully for these stage competitions.

**Key words:** Nutrition, body composition, biochemical profile, professionals.

## Acknowledgements

We are grateful to the cyclists and Deporinter for their availability and logistics of the study. The authors also thank Dr. Emily Knox for revising the English language.

## References

Bescós R, Rodríguez F, Iglesias X, Knechtle B, Marina M, Padullés JM, Torrado P, Vazquez J, Rosemann T. Nutritional behavior of cyclists during a 24-hour team relay race: a field study report. J Int Soc Sports Nutr 2012: 9: 3.
Bischof M, Knechtle B, A.Rüst C, Knechtle P, Rosemann T. Changes in skinfold thicknesses and body fat in ultra-endurance cyclists. Asian J Sports Med 2013: 4: 15–22.
Bowen J, Noakes M, Trenerry C, Clifton PM. Energy intake, ghrelin, and cholecystokinin after different carbohydrate and protein preloads in overweight men. J Clin Endocrinol Metab 2006: 91: 1477–1483.
Burke LM. Nutritional practices of male and female endurance cyclists. Sports Med 2001: 31: 521–532.
Burke LM, Cox GR, Cummings NK, Desbrow B. Guidelines for daily CHO intake: do athletes achieve them? Sports Med 2001: 31: 267–299.
Burke LM, Kiens B, Ivy JL. Carbohydrates and fat for training and recovery. J Sports Sci 2004: 22: 15–30.
Carlsohn A, Müller W. Anthropometry and dietary intake before and during a competition in mountain runners. J Nutr Metab 2014: 893090.
Carter JEL, Heath BH, eds. Somatotyping: development and applications. Cambridge: Cambridge University Press, 1990.
Clarkson PM, Kearns AK, Rouzier P, Rubin R, Thompson PD. Serum creatine kinase levels and renal function measures in exertional muscle damage. Med Sci Sports Exerc 2006: 38: 623–627.
Coyle EF, Jeukendrup AE, Oseto MC, Hodgkinson BJ, Zderic TW. Low-fat diet alters intramuscular substrates and reduces lipolysis and fat oxidation during exercise. Am J Physiol Endocrinol Metab 2001: 280: E391–E398.
Currell K, Jeukendrup AE. Superior endurance performance with ingestion of multiple transportable carbohydrates. Med Sci Sports Exerc 2008: 40: 275–281.
Dressendorfer RH, Wade CE. Effects of a 15-d race on plasma steroid levels and leg muscle fitness in runners. Med Sci Sports Exerc 1991: 23: 954–958.
Driskell J. Summary: vitamins and trace elements in sports nutrition. In: Driskell J, Wolinsky I, eds. Sports nutrition. Vitamins and trace elements. New York: CRC/Taylor & Francis, 2006: 323–331.
Durnin JV, Womersley J. Body fat assessed from total body density and its estimation from skinfold thicknesses measurement on 481 men and women aged 16–72 years. Br J Nutr 1974: 32: 77–97.
Foley JP, Bird SR, White JA. Anthropometric comparison of cyclists from different events. Br J Sports Med 1989: 23: 30–33.
Garcia-Roves PM, Terrados N, Fernandez SF, Patterson AM. Macronutrients intake of top level cyclists during continuous competition-change in the feeding pattern. Int J Sports Med 1998: 19: 61–67.
Katch FI, McArdle WD. Prediction of body density from simple anthropometric measurements in college-age men and women. Hum Biol 1973: 45: 445–455.
Kerksick C, Harvey T, Stout J, Campbell B, Wilborn C, Kreider R, Kalman D, Ziegenfuss T, Lopez H, Landis J, Ivy JL, Antonio J. International Society of Sports Nutrition position stand. Nutrition and athletic performance. J Am Diet Assoc 2008: 5: 17.

Knechtle B, Enggist A, Jehle T. Energy turnover at the Race Across America (RAAM) – a case report. Int J Sports Med 2005: 26: 499–503.
Knechtle B, Müller G, Willmann F, Kotteck K, Eser P, Knecht H. Fat oxidation in men and women endurance athletes in running and cycling. Int J Sports Med 2004: 25: 38–44.
Knechtle B, Wirth A, Knechtle P, Rosemann T. An ultra-cycling race leads to no decrease in skeletal muscle mass. Int J Sports Med 2009: 30: 163–167.
Kontush A, Chantepie S, Chapman MJ. Small, dense HDL particles exert potent protection of atherogenic LDL against oxidative stress. Arterioscler Thromb Vasc Biol 2003: 23: 1881–1888.
Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB. Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr 2000: 72: 796–803.
Lun V, Erdman KA, Reimer RA. Evaluation of nutritional intake in Canadian high-performance athletes. Clin J Sport Med 2009: 19: 405–411.
Marfell-Jones M, Olds T, Stewart A, Carter L, eds. International standards for anthropometric assessment. Potchefstroom, South Africa: ISAK, 2006.
Menaspà P, Rampinini E, Bosio A, Carlomagno D, Riggio M, Sassi A. Physiological and anthropometric characteristics of junior cyclists of different specialties and performance levels. Scand J Med Sci Sports 2012: 22: 392–398.
Mujika I, Padilla S. Physiological and performance characteristics of male professional road cyclists. Sports Med 2001: 31: 479–487.
Rehrer NJ, Hellemans IJ, Rolleston AK, Rush E, Miller BF. Energy intake and expenditure during a 6-day cycling stage race. Scand J Med Sci Sports 2010: 20: 609–618.
Reid SA, Speedy DB, Thompson JM, Noakes TD, Mulligan G, Page T, Campbell RG, Milne C. Study of hematological and biochemical parameters in runners completing a standard marathon. Clin J Sport Med 2004: 14: 344–353.
Reynolds RD, Lickteig JA, Deuster PA, Howard MP, Conway JM, Pietersma A, De Stoppelaar J, Deurenberg P. Energy metabolism increases and regional body fat decreases while regional muscle mass is spared in humans climbing Mt. Everest. J Nutr 1999: 129: 1307–1314.
Rodriguez NR, Di Marco NM, Langley S. American College of Sports. Medicine position stand. Nutrition and athletic performance. Med Sci Sports Exerc 2009: 41: 709–731.
Saris WHM, Van Erp-Baart MA, Brouns F, Westerterp KR, ten Hoor F. Study on food intake and energy expenditure during extreme sustained exercise: the Tour de France. Int J Sports Med 1989: 10 (Suppl. 1): 26–31.
Siri WE. Body composition from fluid space and density. In: Brozek J, Hanschel A, eds. Techniques for measuring body composition. Washington, DC: National Academy of Science, 1961: 223–224.
Sloan AW. Estimation of body fat in young men. J Appl Physiol 1967: 23: 311–315.
Waśkiewicz Z, Kłapcińska B, Sadowska-Krępa E, Czuba M, Kempa K, Kimsa E, Gerasimuk D. Acute metabolic responses to a 24-h ultra-marathon race in male amateur runners. Eur J Appl Physiol 2012: 112: 1679–1688.
Williams KR. The relationship between mechanical and physiological energy estimates. Med Sci Sports Exerc 1985: 17: 317–325.
Wilmore JH, Behnke AR. An anthropometric estimation of body density and lean body weight in young men. J Appl Physiol 1969: 27: 25–31.
Withers RT, Craig NP, Bourdon PC, Norton KI. Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol Occup Physiol 1987: 56: 191–200.

**Específicas:**

- Se han utilizado una variedad de técnicas antropométricas en la identificación de talentos en diferentes tipos deportes (individuales, de campo, de equipo y contacto, de sala, clasificados por el peso), teniendo en cuenta el crecimiento físico y la maduración, el tamaño absoluto y la proporcionalidad, el somatotipo y la composición corporal. Los datos sugieren que los atletas se caracterizan por una combinación de rasgos de composición/tamaño corporal que se cree que influyen en la probabilidad de éxito en un deporte dado. La medición cineantropométrica es una herramienta fundamental en la búsqueda de información para ayudar a los entrenadores y atletas en la búsqueda del éxito al más alto nivel en el deporte (**Aportación I**).

- Se han descrito las características antropométricas, la composición corporal y el somatotipo de los jugadores junior de tenis de elite (**Aportación II**). Esta información proporciona un marco de referencia para los entrenadores para controlar el proceso de entrenamiento con el fin de ayudar a mejorar el rendimiento de los atletas, y para mejorar la detección e identificación de talentos en el tenis.

- No se observaron diferencias significativas en ningún item medido entre los 12 primeros jugadores de tenis junior del ranking y los ranqueados más bajos. Por el contrario, se observaron diferencias significativas en la talla y en los diámetros de húmero y de fémur entre las 12 primeras tenistas ranqueadas y el resto, donde las 12 primeras fueron más altas y tuvieron mayores diámetros de húmero y de fémur que las jugadoras más bajas en el ranking. Estas diferencias podrían influir en el estilo de juego de las jugadoras junior (**Aportación II**).

- Se han establecido tablas de perfil antropométrico para los jugadores de tenis de elite (**Aportación II**).

- Se ha descrito el perfil antropométrico de los ciclistas de bicicleta de montaña olímpica de diferentes niveles competitivos (**Aportación III**).

- Los ciclistas de bicicleta de montaña elites y los campeones del mundo u olímpicos mostraron diferencias físicas con respecto a los sub-elites y los no campeones del mundo u olímpicos, respectivamente. Los elites tuvieron valores significativamente más bajos de BMI, porcentaje de grasa y área total del muslo y más altos de área muscular del muslo que los sub-elites, presentando valores significativamente más bajos del componente endomórfico y valores más altos del componente ectomórfico. Las comparaciones entre los que fueron campeones del mundo u olímpicos y los que no lo fueron mostraron que los primeros tuvieron unos valores significativamente mayores de masa corporal, envergadura, perímetro de brazo relajado, perímetro de brazo flexionado y tensionado, perímetro de pantorrilla, área total del brazo, y área muscular del brazo que los segundos. Una baja masa corporal y una alta masa muscular del brazo parecen ser buenos predictores del éxito en la bicicleta de montaña de especialidad olímpica (**Aportación III**).

- Los hábitos alimentarios de los ciclistas de categorías cadete/junior de la selección española de bicicleta de montaña no son los adecuados, considerándose mejores los de los sub-23/elites, aunque con importantes aspectos básicos a mejorar. Se requiere un mayor trabajo de formación nutricional, especialmente en los más jóvenes, así como un control y orientación a una adecuada alimentación de los deportistas a lo largo de la temporada y especialmente en los periodos no competitivos. Se debe implicar tanto a los ciclistas como a las familias (**Aportación IV**).

- Se ha descrito la ingesta nutricional, la composición corporal y el perfil bioquímico de ciclistas profesionales durante una carrera de cuatro etapas **(Aportación V)**.

- La ingesta de todos los micronutrientes excedieron las recomendaciones dietéticas, excepto en el caso del folato y del potasio (**Aportación V**).

- El porcentaje de grasa corporal y el peso de grasa disminuyeron significativamente, mientras que el peso de la masa muscular se mantuvo sin cambios después de la vuelta. El componente endomorfo disminuyó significativamente después del Tour, mientras los otros componentes permanecieron inalterados. Las concentraciones de urea, aspartato, aminotransferasa, alanina aminotransferasa, la creatina kinasa, mioglobina y lipoproteínas de alta densidad aumentaron significativamente después de la vuelta (**Aportación V**).

**General:**

Los resultados de la presente memoria de Tesis ponen de manifiesto la importancia, la utilidad y la necesidad de la determinación y la evaluación de los perfiles antropométricos y nutricionales para el rendimiento y la salud en el deporte. Para ello, a) se han determinado las características antropométricas, composición corporal y somatotipo de deportistas de elite de tenis y bicicleta de montaña de la especialidad olímpica de diferentes niveles competitivos, proveyendo un marco de referencia para los entrenadores para el control del proceso de entrenamiento con el fin de ayudar a mejorar el rendimiento de los atletas, y para mejorar la detección e identificación de talentos en estos deportes; y b) se ha realizado una evaluación precisa de los hábitos alimentarios y de la ingesta dietética de los atletas de diferentes deportes durante el entrenamiento y la competición para comparar la energía ingerida, los nutrientes y la hidratación con las recomendaciones para el deporte en cuestión y proporcionar un asesoramiento nutricional adecuado para la mejora del rendimiento y el mantenimiento de la salud del deportista de elite.

## CONCLUSIONS

**Specific:**

- A variety of anthropometric techniques were used in talent identification in different sports types (individual sports, field sports, contact team sports, court sports, weight classified sports), taking into consideration physical growth and maturation, absolute size and proportionality, somatotyping and body composition. The data suggest that athletes are characterized by a combination of body composition/body size traits which are believed to influence the chance of success in any given sport. The measurement of kinanthropometry is a crucial tool in the search for information to assist coaches and athletes in the quest for success at the highest level in sport (**Contribution I**).

- The anthropometric characteristics, body composition and somatotype of elite male and female junior tennis players according to performance are presented (**Contribution II**). This information provides a reference frame for coaches to control the training process in order to help improve athletes' performance, and to improve talent detection and identification in tennis.

- No significant differences were observed in any measured item for the males between the first 12 and the lower ranked elite male junior tennis players. By contrast, significant different were observed in height and humeral and femoral breadths between the first 12 and the lower ranked females, whereby the first 12 were taller and had wider humeral and femoral breadths than the lower ranked players. These differences could influence the playing style of junior female players (**Contribution II**).

- Anthropometric profile charts for elite junior tennis players are established (**Contribution II**).

- The anthropometric profiles of male Olympic cross country mountain bikers at different competitive levels are presented (**Contribution III**).

- Elite and world or Olympic champion riders showed physical differences from sub-elite and not world nor Olympic mountain bikers, respectively. Elite riders had significantly lower BMI, lower percentage of fat, total thigh area and larger thigh muscle area than the sub-elite riders, and presented significantly lower values for the endomorphic component and higher values for the ectomorphic component. Comparisons between of world or Olympic champion mountain bikers and not world nor Olympic champion riders, showed that the world or Olympic champion mountain bikers had a significantly higher values, body mass, arm span, upper arm girth relaxed and upper arm girth flexed and tensed, calf girth, total upper arm area, and upper arm muscle area than the not world nor Olympic champion riders group. A low body mass and a high upper arm muscle mass appear to be good predictors of success in XCO mountain biking (**Contribution III**).

- Feeding habits of the cadet/junior cyclists of Spanish national mountain bike team are considered inadequate, being significantly better for the Under-23/elite group, although also in this older group there are basic aspects to improve. Formation on nutrition, especially with the youngest, is required; also better control and orientation for adequate feeding habits of the athletes during the sport season and especially in the non-competing periods. Families and athletes should be involved on this matter (**Contribution IV**).

- The nutritional intake, body composition, and biochemical profile of the professional cyclists in a four-stage race are presented (**Contribution V**).

- Intake of all micronutrients, except for folate and potassium, exceeded the recommended dietary allowances (**Contribution V**).

- Percentage of body fat and fat weight significantly decreased while weight of muscle mass remained unchanged after the Tour. The endomorph component significantly decreased after the Tour, with the other components remaining unchanged. Concentrations of urea, aspartate aminotransferase, alanine aminotransferase, creatine kinase, myoglobin, and high-density lipoproteins significantly increased after the Tour (**Contribution V**).

**Overall:**

The results of the present Doctoral Thesis highlight the importance, usefulness and necessity of the determination and evaluation of anthropometric and nutritional profiles for performance and health in sport. So, a) the anthropometric characteristics, body composition and somatotype of elite athletes of tennis and cross country Olympic mountain biking at different competitive levels are determined, providing a reference frame for coaches to control the training process in order to help improve athletes' performance, and to improve talent detection and identification in these sports; and b) a precise evaluation of the feeding patterns and dietary intake of athletes in different sports during training and competition was performed, to compare energy intake, nutrients, and hydration recommendations for sport in question and provide advice and adequate nutritional approach for performance improvement and maintenance of health in elite athletes.

**Fortalezas:**

- **Aportación II**: El tamaño grande de muestra (123 elite tenistas junior, de los mejores equipos) es un activo de este estudio en comparación con los otros encontrados en la literatura. Además, el importante origen de la muestra, al tratarse de los mejores jugadores junior del mundo en el momento de la evaluación. Además, en el momento del estudio, los jugadores estaban participando en la competición más importante del mundo (la “Junior Davis Cup” y la “Fed Cup”), estando por lo tanto en un estado óptimo de forma.

- **Aportación III**: Los principales puntos fuertes de este estudio son: a) es la primera vez en la que se han medido las variables antropométricas, el somatotipo, y la composición corporal en el ciclismo de montaña olímpico; b) la calidad de los sujetos estudiados (los mejores ciclistas de montaña del mundo en el momento del estudio); c) se compararon a los mejores ciclistas con los más bajos en el ranking para determinar si podría ser encontrada alguna diferencia con lo que respecta a las variables antropométricas; d) el estudio se llevó a cabo durante una de las competiciones más importantes en el mundo para ciclistas de bicicleta de montaña, por lo que todos los ciclistas deberían estar al máximo estado de forma.

- **Aportación V**: Los principales puntos fuertes de este estudio son: a) la calidad de los sujetos estudiados (ciclistas profesionales en el momento del estudio); b) el estudio se llevó a cabo durante una importante competición del UCI World Tour.

**Debilidades:**

- **Aportación I**: El estudio sólo se ha hecho con jóvenes deportistas y no con una muestra de adultos, lo cual hubiera ampliado la información disponible.

- **Aportación II**: Se podría haber evaluado el estado de maduración biológica de los sujetos, ya que esta información nos permitiría discriminar el estado de maduración biológica de la edad cronológica.

- **Aportaciones II y III**: Los resultados tienen que ser tenidos en cuenta como un punto de referencia, pero no como un modelo obligatorio para un mejor rendimiento. De esta manera, los resultados presentados se pueden utilizar como una referencia estándar, pero deben ser interpretados con precaución de acuerdo con las características y necesidades individuales

**Futuras líneas de trabajo:**

- Realizar una investigación con la evolución de las características antropométricas, composición corporal y somatotipo de tenistas a nivel longitudinal.

- Realizar una evaluación del perfil nutricional, composición corporal y bioquímica en una prueba ciclista de 3 semanas, realizando un análisis objetivo y directo de los minerales, evitando las tablas de estimación (actualmente en desarrollo).

- Realizar la fase de escritura con los datos ya tomados para la determinación del perfil antropométrico, composición corporal y somatotipo de ciclistas de pista de elite: 116 sujetos evaluados durante el Campeonato del Mundo Pista 2013 y diferenciados por género, especialidad y nivel de rendimiento (actualmente en desarrollo).

- Realizar la fase de escritura con los datos ya tomados para la determinación del perfil antropométrico, composición corporal y somatotipo de ciclistas de trial bici de elite: 32 sujetos evaluados durante el Campeonato del Mundo Trial Bici 2009 y diferenciados por especialidad y nivel de rendimiento (actualmente en desarrollo).

- Realizar la fase de escritura con los datos ya tomados para la determinación del perfil físico y antropométrico de jugadores de padel de elite: 47 sujetos evaluados durante el “Padel World Tour” 2012 y diferenciados por nivel de rendimiento (actualmente en desarrollo).

## STRENGHTS, WEAKNESSES AND FUTURE DIRECTIONS

### Strenghts:

- **Contribution II**: The large sample size (123 elite junior tennis players of the best teams) is an asset of this study compared to the other studies found in the literature. In addition, the sample source was important as the subjects were the best junior players in the world at the time of testing. Furthermore, at the time of the study, the players were competing in the most important junior competitions in the world (the junior Davis Cup and Fed Cup), and were therefore in optimal shape.

- **Contribution III**: The main strengths of this study are that a) it is the first time that anthropometrical, somatotype, and body composition variables are measured in XCO mountain biking; b) the quality of the subjects studied (they were the best riders in the world at the time of study); c) the best riders were compared with lower ranked to ascertain if any difference could be found with regard to anthropometric variables; d) the study was carried out during one of the most important competitions in the world for elite riders, so all the cyclists should be in top physical shape.

- **Contribution V**: The main strengths of this study are that a) the quality of the subjects studied (they were professional cyclists at the time of study); b) the study was carried out during one important competition of the UCI World Tour.

### Weaknesses:

- **Contribution I**: The study has been carried out just with young athletes and not with adults, and this could provide valuable added information.

- **Contribution II**: Maturity status should have been assessed, because this could allow us to determine biological maturity and chronological age.

- **Contributions II y III**: The results have to be taken into account as a point of reference, but should not be taken as an obligatory model for better performance. In this way, the results presented can be used as a standard reference, but should be interpreted with caution according to individual characteristics and necessities.

**Future directions:**

- To investigate in a longitudinal way the anthropometry, body composition, and somatotype of tennis players of different competitive levels.

- To develop an assessment of the nutritional profile, body composition and biochemical values in a 3 week grand tour, using objective and direct analysis of minerals, avoiding estimation tables (in progress).

- To write a manuscript with the data already taken for the determination of the anthropometrical profile, body composition, and somatotype of track cycling elite cyclists: 116 subjects assessed during the 2013 track cycling world championships, according to gender, specialty, and competitive level (in progress).

- To write a manuscript with the data already taken for the determination of the anthropometrical profile, body composition, and somatotype of Trials cycling elite cyclists: 32 subjects assessed during the 2009 world championships, according to specialty, and competitive level (in progress).

- To write a manuscript with the data already taken for the determination of the anthropometrical profile, body composition, and somatotype of elite padel players: 47 subjects assessed during the 2012 “Padel World Tour”, according to competitive level (in progress).

# PHYSICAL PROFILE OF ELITE YOUNG MOTORCYCLISTS

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**Int J Sports Med 2011; 32:788-793**

**Annexe**

# Physical Profile of Elite Young Motorcyclists

Authors

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**Key words**
- motorsports
- young
- body composition
- somatotype
- strength

## Abstract

The aim of the study was to describe anthropometric and physical characteristics of elite young road-race motorcyclists (MC). 27 riders (15.6 ± 1.1 years, 54.6 ± 6.9 kg, 166.9 ± 6.7 cm) competing at international elite level participated in this study. Anthropometric variables, hand grip and lumbar isometric strength, and lower-body muscular strength were measured. Comparisons of the MC and a reference group of Spanish physically active adolescents (16.0 ± 0.6 years) showed that the riders were significantly lighter (−12.5 kg), and smaller (−4.7 cm). Riders also had significantly lower values for almost all skinfolds, and for all the measured girths (except forearm) than the reference group. Motorcyclists showed significantly less percent body fat (%BF) and higher muscle mass, and differences were observed for somatotype components compared to the reference group, except for the ectomorphy. Somatotype could be defined as mesomorphic-ectomorph (2.5–4.4–3.7). Mean (±SD) values of all riders were 34.8 ± 5.0 cm for vertical jump height, 402.1 ± 74.5 N for the right hand and 370.7 ± 77.5 N for the left hand strengths, and 120.6 ± 19.3 kg for lumbar isometric strength, respectively. Results demonstrate that MC are small and light, with lower body mass index, skinfolds, girth and breadth dimensions, and %BF than a reference group and other athletes, with high values of hand grip and lumbar isometric strength.

## Introduction

Road-race motorcycling is the most popular modality of motorcycling characterized as a high-speed event. Road Racing World Championship Grand Prix is the premier championship of motorcycle road racing currently divided into 3 classes: 125-cc, Moto2 (600-cc) and MotoGP (800-cc). The 125-cc class uses a 2-stroke engine while Moto2 and MotoGP use 4-stroke engines.

Although road-race motorcycling performance depends on the characteristics of the motorcycle as well as on the capabilities of the riders, research has focused mainly on the technology advances of the motorbikes and riding equipment [8,23], pattern of injuries [16,28,29], and safety [20,21]. At the present, there are few scientific data on the physical and physiological load in training and competition [2,6,7,10,13], and there is no information on the anthropometric and physical characteristics of road-race motorcyclists.

Therefore, the purposes of this study were 1) to describe the anthropometric and physical characteristics of elite young road-race motorcyclists, and 2) to establish an anthropometric and physical profiles chart for elite young road-race motorcyclists, in order to be used for the detection and identification of talents or to plan training programs.

accepted after revision
April 28, 2011

**Bibliography**
**DOI** http://dx.doi.org/10.1055/s-0031-1279722
Published online: September 12, 2011
Int J Sports Med 2011; 32: 788–793 © Georg Thieme Verlag KG Stuttgart · New York
ISSN 0172-4622

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## Materials and Methods

### Subjects

27 elite young road-race motorcyclists (MC) with a mean (±SD) age of 15.6 ± 1.1 years took part in this study. They were all the participants of the Red Bull MotoGP Rookies Programme, an international talent scout initiative, created jointly by Red Bull and Moto GP (DORNA). All riders took part in Red Bull MotoGP Rookies Cup, a competition open to young road-race motorcyclists from all over the world that constitutes the most important step to enter Grand Prix motorcycle racing. A control group of Spanish physically active male adolescents (16.0±0.6 years) was also studied in order to make comparisons between the riders and a normal population of similar age. All subjects received a clear explanation of the

study, including the risks and benefits of participation, and written consent was obtained for those responsible for the program. The study was approved by the Ethics Committee of the University of Granada and was carried out in accordance with the ethical standards proposed by Harriss and Atkinson [15].

### Experimental design

All testing were carried out during a competition of the Red Bull MotoGP Rookies Cup, coinciding with a race of the FIM Road Racing World Championship Grand Prix (MotoGP) which took place in Brno (Czech Republic) in 2009. Standard anthropometry (height, weight, BMI, 8 skinfolds, 5 girths, and 2 breadths), lower-body muscular strength, hand grip strength, and lumbar isometric strength were the tests selected. All subjects were assessed on the same day, and the tests were performed in the same order.

### Anthropometric variables and body composition

Anthropometric variables were performed following the protocol developed by the International Society for Advancement of Kinanthropometry (ISAK) [22]. All anthropometric measurements were conducted by the same experienced evaluator, a Level 2 ISAK anthropometrist. The technical error of measurements was less than 5% for skinfolds and less than 1% for the other measurements. Anthropometric variables included weight, height, 8 skinfolds (biceps, triceps, subscapular, suprailiac, supraspinal, abdominal, thigh and medial calf), 5 girths (upper arm relaxed, upper arm flexed and tensed, forearm, thigh and medial calf), and 2 breadths (humeral and femoral). Height was measured to the nearest 0.1 cm using a stadiometer (GPM, Seritex, Inc., Carlstadt, New Jersey), and weight was measured to the nearest 0.1 kg using a portable scale (model 707, Seca Corporation, Columbia, Maryland). Skinfold thickness were obtained using a Holtain skinfold caliper (Holtain Ltd., Crymych, UK) and recorded to the nearest 0.2 mm, and the girths were performed using a flexible anthropometric steel tape (Holtain Ltd., Crymych, UK) to the nearest 0.1 cm. Skinfolds were taken 3 times and the mean of 3 measurements was used in the analyses. The sum of 3 skinfolds (triceps, subscapular, and supraspinal), 6 skinfolds (sum of 3 and suprailiac, abdominal, and thigh), and 8 skinfolds (sum of 6 and biceps, and medial calf) were also calculated. Body mass index (BMI) was calculated as weight/height$^2$ where weight was expressed in kilograms (kg) and height in metres (m). 5 different equations [9,18,27,31,32] were used to estimate body density, and body fat percentage (%BF) was determined by the Siri's equation [25]. Muscle mass (MM) was determined in kg using the methods of Lee and colleagues [19]. Somatotype characteristics were determinate according to the Carter and Heath method [5].

### Lower-body muscular strength

After determining the anthropometric variables subjects performed a warm-up consisting in the implementation of several submaximal jumps. Lower-body muscular strength was assessed using the Infrared Platform Ergo Jump Plus-Bosco System (Byomedic, S.C.P., Barcelona, Spain). Each rider completed 3 maximal countermovement jumps (CMJs) with 3 min rest allowed between trials, recording the better value. All CMJs were completed keeping the hands on the iliac crest to avoid the influence of the upper limbs on jump performance, and the starting position was standing straight. Then subjects flexed their knees to the squat position (90°) and performed a maximal vertical jump. Measured height was expressed in centimeters and was converted to power (w) using the González-Badillo and Gorostiaga equation [14]: Power (w) = Weight (kg) × 9.81 × √[2 × 9.81 × jump height (m)].

### Hand grip strength

A Digimax electronic dynamometer (Mechatronic GmbH, Darmstadt, Germany) was used to determine hand grip strength in both right and left hands. The dynamometer was adjusted for each subject's hand size and the riders were kept in stand position with the arms parallel to the ground and with the elbow joint maintained at 90° flexion. The subjects were instructed to perform a maximal isometric contraction. Each subject was allowed 3 trials with a 1 min rest between trials, and the highest value was recorded.

### Lumbar isometric strength

A lumbar extension dynamometer (Takei Kiki Kogyo, Tokyo, Japan) was used to determine lumbar isometric strength. The subject stood on the platform with the knees extended and the trunk flexed to an angle of 150°. Holding the bar with a pronated grip, the subject pulled it slowly but vigorously, extending the lower back. The best score of 3 trials with 1 min recovery between each was recorded and used in the analyses. The values obtained by the Takei were converted from kg to N.

### Statistical methods

Standard descriptive statistics (means, SD, range) were used to present the characteristics of the subjects for all variables, including the values for MC in relation to the reference group. All variables were checked for normality using the Shapiro-Wilk test. Differences in the physical and anthropometric variables between the group of MC and the reference group (Spanish boys aged 15.0–17.0 years) were compared using an independent *t*-test. For all analyses, 5% was adopted as the significance level. A profile chart with norms, using percentiles (values of 5, 10, 25, 50, 75, 90, 95) was constructed for the group of MC. All statistical analyses were carried out with the SPSS statistical package (version 18.0; SPSS, Inc, Chicago, Illinois, USA).

## Results

▶ **Table 1** gives the means (±SD) and ranges for the anthropometric and physical characteristics for the MC and the reference groups, as well as the percentiles (P) of the MC in relation to the reference group. Comparisons of the MC and the normative reference group showed that the riders were significantly lighter (−12.5 kg), and smaller (−4.7 cm). The riders also had significantly lower values for the triceps (−3.9 mm), biceps (−1.8 mm), subscapular (−3.7 mm), suprailiac (−6.9 mm), supraspinale (−4.6 mm), abdominal (−7.6 mm), thigh (−4.6 mm), and calf (−3.6 mm) skinfolds. Motorcyclists also had significantly lower values for the upper arm relaxed girth (−2.6 cm), upper arm flexed and tensed girth (−2.2 cm), thigh girth (−5.2 cm), medial calf (−5.3 cm), and femur breadth (−0.7 mm) than the normative reference group. The forearm girth was significantly lower for the elite young road-race motorcyclists (−2.3 cm). Motorcyclists showed significantly lower %BF and higher MM, and also significant differences were observed for somatotype compared to the reference group (lower in MC, except for the ectomorphic component of the somatotype which was higher). Only non-

**Table 1** Mean, standard deviation, range, and percentiles in comparison to a reference group, for the anthropometric and physical characteristics of elite young road-race motorcyclists.

| | Road-race riders Group (n = 27) | | Reference Group (n = 27) | | |
|---|---|---|---|---|---|
| **Variable** | **Mean ± SD** | **Range** | **Mean ± SD** | **Range** | **Percentile#** |
| age (yr) | 15.6 ± 1.1 | 13.7–17.8 | 16.0 ± 0.6 | 15.0–17.0 | |
| height (cm) | 166.9 ± 6.7* | 153.3–178.4 | 171.6 ± 6.1 | 161.1–183.5 | P24 |
| weight (kg) | 54.6 ± 6.9** | 39.4–73.7 | 67.1 ± 15.4 | 44.9–102.5 | P18 |
| BMI (kg/m²) | 19.5 ± 1.5* | 16.8–23.3 | 22.7 ± 4.4 | 15.5–32.8 | P29 |
| triceps skinfold (mm) | 8.0 ± 2.4* | 4.4–13.4 | 11.9 ± 6.4 | 5.0–29.2 | P32 |
| biceps skinfold (mm) | 3.6 ± 1.0* | 2.6–6.2 | 5.4 ± 3.3 | 2.8–15.6 | P36 |
| subscapular skinfold (mm) | 7.0 ± 1.3* | 5.0–10.0 | 10.7 ± 5.6 | 5.0–29.4 | P24 |
| suprailiac skinfold (mm) | 10.1 ± 3.7* | 5.2–20.4 | 17.0 ± 9.9 | 6.2–40.0 | P33 |
| supraspinale skinfold (mm) | 6.5 ± 2.5* | 4.2–13.8 | 11.1 ± 6.8 | 4.2–29.0 | P34 |
| abdominal skinfold (mm) | 8.9 ± 3.8** | 4.2–20.4 | 16.5 ± 9.5 | 6.4–39.4 | P28 |
| thigh skinfold (mm) | 9.9 ± 2.3* | 5.4–16.2 | 14.5 ± 7.6 | 7.0–37.0 | P27 |
| calf skinfold (mm) | 8.0 ± 1.8* | 4.6–12.0 | 11.6 ± 8.4 | 4.2–41.0 | P36 |
| upper arm girth (cm)† | 26.1 ± 1.8* | 21.7–30.1 | 28.7 ± 4.3 | 21.7–37.9 | P39 |
| upper arm girth (cm)†† | 28.4 ± 1.9* | 23.3–33.1 | 30.6 ± 3.9 | 23.6–38.9 | P31 |
| forearm girth (cm) | 25.0 ± 1.3* | 22.4–28.9 | 27.3 ± 3.2 | 22.6–26.1 | P30 |
| thigh girth (cm) | 45.9 ± 3.0* | 39.3–53.5 | 51.1 ± 7.4 | 38.7–70.1 | P29 |
| calf girth (maximum) (cm) | 32.0 ± 2.0** | 27.4–36.7 | 37.3 ± 4.4 | 31.3–49.9 | P5 |
| humerus breadth (cm) | 6.8 ± 0.3 | 6.0–7.5 | 6.8 ± 0.4 | 6.0–8.0 | P50 |
| femur breadth (cm) | 9.5 ± 0.4* | 8.3–10.3 | 10.2 ± 1.0 | 8.8–13.4 | P22 |
| sum of 3 skinfolds (mm) | 25.0 ± 6.7* | 16.4–42.2 | 33.8 ± 18.4 | 15.8–85.8 | P38 |
| sum of 6 skinfolds (mm) | 53.9 ± 15.4* | 34.0–99.2 | 81.7 ± 43.9 | 36.0–194.0 | P36 |
| sum of 8 skinfolds (mm) | 65.5 ± 17.3* | 41.2–117.4 | 98.8 ± 54.6 | 44.2–233.0 | P36 |
| % body fat | | | | | |
| Durnin and Womersley [9] | 13.1 ± 3.5* | 7.8–20.9 | 18.3 ± 7.0 | 8.9–33.3 | P32 |
| Katch and McArdle [17] | 8.5 ± 2.1* | 5.9–13.8 | 13.0 ± 6.4 | 6.4–31.3 | P32 |
| Sloan [25] | 7.5 ± 1.8* | 4.2–12.2 | 12.3 ± 7.4 | 5.7–32.9 | P20 |
| Wilmore and Behnke [29] | 11.1 ± 1.7** | 9.1–16.6 | 14.8 ± 4.8 | 9.6–26.7 | P27 |
| Whiters and colleagues [30] | 9.2 ± 2.2* | 6.0–15.8 | 14.5 ± 8.0 | 6.7–34.8 | P28 |
| muscle mass (kg) [18] | 47.9 ± 3.1* | 43.1–57.7 | 44.5 ± 6.4 | 31.7–57.2 | P69 |
| somatotype | | | | | |
| endomorphy | 2.5 ± 0.8* | 1.6–4.4 | 3.2 ± 1.6 | 1.4–7.4 | P39 |
| mesomorphy | 4.4 ± 0.7* | 3.0–5.7 | 5.4 ± 1.9 | 2.2–9.4 | P33 |
| ectomorphy | 3.7 ± 0.8* | 1.9–5.0 | 2.6 ± 1.9 | − 1.0–6.5 | P66 |
| hand grip strength | | | | | |
| right hand (N) | 402.1 ± 74.5 | 237.3–547.2 | | | |
| left hand (N) | 370.7 ± 77.5 | 231.4–503.1 | | | |
| lumbar isometric strength (N) | 1 182.7 ± 189.3 | 764.9–1 163.2 | | | |
| lower-body muscular strength | | | | | |
| CMJ height (cm) | 34.8 ± 5.0 | 26.8–44.1 | | | |
| CMJ power (W) | 1 399.4 ± 232.8 | 956.3–1 932.1 | | | |

* p < 0.05; ** p < 0.001

† Relaxed; †† Flexed and tensed. # Values for elite young motorcyclist in relation to the reference group

significant differences between groups (p > 0.05) were observed for humeral breadth.

The mean somatotype for the MC (2.5–4.4–3.7) demonstrates that these athletes were predominantly mesomorphic, being characterised as ecto-mesomorphic according to Carter and Heath [5]. **Fig. 1** shows the somatoplots for all the individual riders as well as mean for this athletes group.

The mean (± SD) vertical jump height, hand grip strength and lumbar isometric strength of all MC were 34.8 ± 5.0 cm, 402.1 ± 74.5 N for the right hand and 370.7 ± 77.5 N for the left hand, and 1 182.7 ± 189.3 N, respectively. An anthropometric and physical profile is given in **Table 2**. The scores for 18 anthropometric dimensions and 3 performance tests are located on the chart together with the corresponding percentile values.

## Discussion

Most of the studies on road-race motorcycling in the scientific literature are focused on the technological advances of motorbikes and riding equipment [8, 23], pattern of injuries [16, 28, 29], and safety [20, 21]. A few recent studies have examined physical and physiological load in training and competition [2, 6, 7, 10, 13], and to our knowledge this is the first study that attempts to describe anthropometric and physical characteristics on MC.

A comparison with previously published results for adult motorcycle riders of different events is given in **Table 3**. Ascensão and colleagues [3] analyzed physiological and functional changes induced by a simulated off-road motocross heat in a sample of 15 male off-road motocross riders. The elite off-road motocross riders were taller and heavier than the elite young road-race motorcyclists of the present study (mean ± SD) 169.8 ± 4.0 cm vs. 166.9 ± 6.7 cm, 71.1 ± 7.0 kg vs. 54.6 ± 6.9 kg, respectively). Similarly, the 7 off-road male motorcyclists with international race experience evaluated in the study of Gobbi and colleagues [13] were taller and heavier than the Red Bull Rookies Cup riders (177.0 ± 9.0 cm vs. 166.9 ± 6.7 cm, 74.7 ± 8.1 kg vs. 54.6 ± 6.9 kg, respectively), and alike pattern when MC were compared to enduro riders (176.0 ± 7.0 cm vs. 166.9 ± 6.7 cm, 75.4 ± 9.0 kg vs. 54.6 ± 6.9 kg, respectively), or desert rally riders (176.0 ± 3.0 cm vs. 166.9 ± 6.7 cm, 79.2 ± 3.4 kg vs. 54.6 ± 6.9 kg, respectively). Also, the riders of the present study were smaller and thinner than road-race riders participating in the French Motorcycle Trophy [10] (166.9 ± 6.7 cm vs. 178.4 ± 8.4 cm, 54.6 ± 6.9 kg vs. 74.6 ± 7.1 kg, respectively). BMI presented by MC of our study was lower than those reported by motorcycle riders from other studies [3, 10, 13]. ▶ **Table 3** also shows the %BF of motorcycle riders from different events reported in the scientific literature. Most of the previous studies did not indicate the equation used

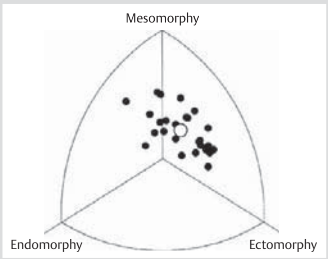


**Fig. 1** Somatotype distribution of elite men young road-race motorcyclists. ○: mean somatotype = 2.5–4.4–3.7.

**Table 2** Percentiles for the anthropometric and physical variables for elite young road-race motorcyclists.

| | Percentiles | | | | | | |
|---|---|---|---|---|---|---|---|
| **Variable** | **5** | **10** | **25** | **50** | **75** | **90** | **95** |
| height (cm) | 154.3 | 156.0 | 161.8 | 167.2 | 172.3 | 175.2 | 178.1 |
| weight (kg) | 41.0 | 44.4 | 50.0 | 55.9 | 58.9 | 60.7 | 68.7 |
| BMI (kg · m$^{-2}$) | 17.1 | 17.8 | 18.5 | 19.6 | 20.2 | 21.6 | 23.0 |
| triceps skinfold (mm) | 4.7 | 5.2 | 6.0 | 7.4 | 9.4 | 12.5 | 13.2 |
| biceps skinfold (mm) | 2.6 | 2.6 | 2.8 | 3.4 | 4.2 | 5.3 | 6.0 |
| subscapular skinfold (mm) | 5.2 | 5.4 | 6.2 | 6.6 | 8.0 | 9.0 | 9.7 |
| suprailiac skinfold (mm) | 5.3 | 5.9 | 7.2 | 9.2 | 12.2 | 15.1 | 19.8 |
| supraespinale skinfold (mm) | 4.4 | 4.6 | 4.8 | 5.7 | 7.4 | 11.2 | 12.8 |
| abdominal skinfold (mm) | 4.5 | 5.6 | 6.4 | 8.2 | 9.6 | 15.8 | 18.8 |
| thigh skinfold (mm) | 6.2 | 7.4 | 8.4 | 9.4 | 11.2 | 13.4 | 15.3 |
| calf skinfold (mm) | 5.2 | 6.0 | 6.4 | 7.2 | 9.8 | 10.6 | 11.5 |
| upper arm girth (cm)† | 22.2 | 23.9 | 24.8 | 26.1 | 27.3 | 28.3 | 29.7 |
| upper arm girth (cm)†† | 23.9 | 26.0 | 27.4 | 28.4 | 29.7 | 30.3 | 32.1 |
| forearm girth (cm) | 22.5 | 23.0 | 24.2 | 25.3 | 25.6 | 26.0 | 28.0 |
| thigh girth (cm) | 39.9 | 42.2 | 44.6 | 45.7 | 48.2 | 49.9 | 52.1 |
| calf girth (maximum) (cm) | 28.1 | 29.6 | 31.2 | 31.9 | 33.2 | 35.3 | 36.2 |
| humerus breadth (cm) | 6.2 | 6.5 | 6.6 | 6.8 | 7.1 | 7.2 | 7.5 |
| femur breadth (cm) | 8.5 | 9.1 | 9.3 | 9.5 | 9.7 | 9.8 | 10.1 |
| hand grip strength | | | | | | | |
| right hand (N) | 255.0 | 297.1 | 351.1 | 398.1 | 457.0 | 508.0 | 534.5 |
| left hand (N) | 241.2 | 256.0 | 306.0 | 375.6 | 437.4 | 465.8 | 492.3 |
| lumbar isometric strength (N) | 800.2 | 888.5 | 1 073.8 | 1 181.7 | 1 274.9 | 1 451.4 | 1 572.0 |
| lower-body muscular strength | | | | | | | |
| CMJ height (cm) | 27.2 | 28.4 | 30.7 | 33.9 | 39.0 | 42.6 | 43.9 |
| CMJ power (W) | 991.7 | 1 086.0 | 1 216.8 | 1 377.5 | 1 575.6 | 1 715.5 | 1 851.4 |

† Relaxed; †† Flexed and tensed

**Table 3** Summary table of studies examining age, height, weight, BMI, body fat percentage and hand grip strength of motorcyclists of different events (mean ± SD).

| Study | N | Gender | Age (yr) | Height (cm) | Weight (kg) | BMI (kg · m$^{-2}$) | body fat (%) | Right hand grip (N) | Left hand grip (N) | Event |
|---|---|---|---|---|---|---|---|---|---|---|
| Ascensão and colleagues [3] | 15 | Male | 28.3 ± 7.9 | 169.8 ± 4.0 | 71.1 ± 7.0 | –$^{\#}$ | 14.9 ± 3.3 | 467.5 ± 61.7 | 393.0 ± 65.7 | Motocross |
| Filaire and colleagues [10] | 12 | Male | 22.2 ± 1.3 | 178.4 ± 8.4 | 76.4 ± 7.1 | 24.0 ± 0.8 | 12.3 ± 2.1 | –$^{\#}$ | –$^{\#}$ | Road-race |
| Gobbi and colleagues [13] | 7 | Male | 23.0 ± 4.0 | 177.0 ± 9.0 | 74.7 ± 8.1 | 23.7 ± 0.6 | 13.3 ± 3.1 | 511.0 ± 51.0 | 545.0 ± 61.0 | Motocross |
| | 10 | Male | 29.0 ± 6.0 | 176.0 ± 7.0 | 75.4 ± 9.0 | 24.5 ± 0.3 | 12.6 ± 3.7 | 506.0 ± 52.0 | 506.0 ± 47.0 | Enduro |
| | 10 | Male | 32.0 ± 3.0 | 176.0 ± 3.0 | 79.2 ± 3.4 | 25.7 ± 0.1 | 15.1 ± 3.4 | 500.0 ± 50.0 | 499.0 ± 53.0 | Desert rally |
| D'Artibale and colleagues [6] | 26 | Female | 30.8 ± 6.1 | 164.0 ± 4.0 | 56.5 ± 6.7 | 20.9 ± 2.3 | 21.6 ± 4.4† | 307.0 ± 32.0 | 281.0 ± 47.0 | Motocross |
| present study | 27 | Male | 15.6 ± 1.1 | 166.9 ± 6.7 | 54.6 ± 6.9 | 19.5 ± 1.5 | 13.1 ± 3.5†† | 402.1 ± 74.5 | 370.7 ± 77.5 | Road-race |

† Jackson and Pollock equation [16]; †† Durnin and Womersley equation [9]
–$^{\#}$ Data not available

to determine %BF or the one used was different from that used in the current study. This made it difficult to compare values and this is why we present 5 different equations. Finally, MC of the present study showed lower values of hand grip strength in both the right and the left hand (65.4–108.9 N; 22.3–174.3 N, respectively) than the motorcycle riders of the various events of previous studies [3, 10, 13]. The possible explanation for the lower values of the subjects measured in this study could be due to the differences in age (younger MC).

To our knowledge, contrary to what happens in other sports, there is no previous data in the scientific literature on the anthropometric characteristics of young motorcycle riders with which to compare those obtained in this study. With respect to the anthropometric data observed in elite junior tennis players [24] who participated in the 2005 and 2006 Davis Junior Cup, the elite young road-race motorcyclists of our study were smaller and thinner (166.9 ± 6.7 cm vs. 176.8 ± 6.4 cm, 54.6 ± 6.9 kg vs. 69.9 ± 6.8 kg, respectively), with lower BMI (19.5 ± 1.5 $kg \cdot m^{-2}$ vs. 22.3 ± 1.4 $kg \cdot m^{-2}$), skinfold thickness, girths, breadths, and %BF (13.1 ± 3.5 % vs. 15.8 ± 3.6 %, by Durnin and Womersley's equation [9]), and higher MM (47.9 ± 3.1 kg vs. 44.5 ± 6.4 kg, by Lee and colleagues [19]), than the elite tennis players. Similar findings were observed in weight when comparing the athletes of our study with elite men junior weightlifters [12], experienced men junior competitive climbers [30], and elite male junior rowers [4].

According to the results obtained in this study, when compared with previous published results for the Spanish adolescent population [1], road-race riders are smaller (166.9 ± 6.7 cm vs. 170.9 ± 8.6 cm) and lighter (54.6 ± 6.9 kg vs. 63.8 ± 12.9 kg), and have a lower BMI (19.5 ± 1.5 $kg \cdot m^{-2}$ vs. 21.7 ± 3.6 $kg \cdot m^{-2}$), and lower %BF when comparing both with Slaughter's equation [26] (14.2 ± 3.2 % vs. 19.7 ± 10.0 %). The lower %BF and the higher MM in these subjects in comparison with the normal population of the same age can be related to training and nutrition more than to genetics. We know that these subjects normally are much more active than the normal population of the same age, as well as they take care about their feeding and body weight to take more advantage in competitions. Nevertheless, we cannot know the relative importance of genetics as we did not make any specific analyses, although in this category it seems to be important to be thin and small. For safety, in road-race motorcycling the minimum weight of the motorbike is restricted according to the rules of the FIM (International Motorcycling Federation) depending on the number of cylinders. For MotoGP or 800-cc class the minimum weight is between 135 kg and 165 kg, for Moto 2 or 600-cc class the minimum weight is 135 kg, and for 125cc class the minimum weight checked is the total of the rider with full protective clothing plus the weight of the motorcycle (136 kg). Overweight is a handicap in regard to performance in motorcycling [6, 13] and optimal weight distribution on the motorbike is very important [11]. Less weight is a determining factor to get maximum acceleration out of each curve and more rapid deceleration in the breaking upon entering the curve, and normally the maximum speed for a given circuit is achieved by the lighter riders. Therefore, according to Gobbi and colleagues [13] the heavier rider requires more muscular force for optimal control of his motorcycle. On the other hand, although a low weight may compromise the grip on the exit of the curves, the low power of the motorcycles in this category (125-cc) makes the influence of the weight on the grip minimal. In this study it is important to point out that the weight of all the motorcycles was the same and the difference was just in the riders' weight.

The height of the road-race rider also has an influence on performance, but less than the weight. An excessive height increases the front area of the pilot-motorcycle combination and therefore the drag force increases, resulting in a decrease in speed. Then maximum height of the road-race rider should be the one that allows him to adapt behind the motorcycle fairing. On the other hand, when the rider is too small it is necessary to adapt the motorcycle's controls to allow optimum riding.

Technical and psychological variables clearly mediate sport performance and success, but physical condition and anthropometrical characteristics must be in the appropriate range. We argue that being light and small helps in this category (125-cc) in which the power of the motorcycle is limited, and these anthropometric characteristics can be a prerequisite rather than a disadvantage. In other categories such as Moto 2 and MotoGP to be small and light does not highly influence performance. So, we sustain that weight and height are predictor variables of performance in road motorcycling, especially in 125-cc category and less predictor variables in higher categories, although it has been argued that MotoGP motorcycles of some very light riders should be over weighted not to have a clear advantage (as for example is attributed to famous world champion pilots as Dani Pedrosa, Andrea Dovicioso, or Toni Elias). In fact, the success of the Red Bull Rookies Cup program working with these very young riders has become a reality because, from the subjects studied, 2 seasons later at least 10 riders are competing in the 125-cc elite class and some of them in the top 5 of the world.

In relation to strength values, higher scores were observed in the riders for hand grip strength (772.8 N vs. 687.4 N; sum of the average of both hands), in comparison to the values observed in a group of Spanish adolescents (n = 1 196) of similar age measured by Artero and colleagues [1]. So, the results of the present study suggest strongly that the sample of MC measured is different from of the above mentioned adolescents of the same age group.

Upper limb strength is an important factor in motorcycling [13]. Gobbi and colleagues [13] reported that in motocross riders there is a significant difference in hand grip strength between the left and right limb. The left arm was significantly stronger than the right arm (6 %, $p < 0.05$). According to their explanation, this difference may be due to the more frequent use in motocross of the clutch lever by the left hand. In the road-race riders of the present study, also significant differences were found in hand grip strength between the left and right limb, but contrary to motocross riders the right arm was significantly stronger than the left arm (8.5 %, $p < 0.00$). This difference may be due to less use of the clutch lever with respect to motocross and greater use of the front brake lever by the right hand in the habitual braking in road-race motorcycle competition.

For future research it would be very interesting to include an aerobic capacity test as for example the 20 m Shuttle run test. Also, it is necessary to measure further bike categories to determine if there is a different physical and/or anthropometric profile depending on the motorbike used.

In conclusion, these data appear to be the first of their kind obtained from elite road-race motorcyclists and provide information about anthropometric and physical characteristics of elite young road-race motorcyclists. These riders are small and light, with lower BMI, skinfold thickness, girth and breadth dimensions, and %BF than a reference group and other sports athletes of the same chronological age. The riders show high values of hand grip strength and lumbar isometric strength.

This study provides reference values of anthropometric and physical characteristics of elite young road-race motorcyclists. This information provides a reference frame for coaches to control the training process in order to improve athletes' performance, and to facilitate talent detection and identification in road-race motorcycling. Other complementary variables should be studied to obtain further knowledge about this sport in the area of physical training and performance such as psychological factors, physiological demands, muscular patterns in forearms and hands, as well as the effect of different training programs that could be compared in relation to balance, physical performance and competing result. In fact, up to now this sport has not been studied extensively and the opportunities to investigate are evident for researchers.

## Acknowledgements

The authors would like to thank DORNA and all the managers of the Red Bull Moto GP Rookies program for their permission to set up this study and for their full support and collaboration during the investigation, especially to the technicians Raúl Jara and Michaela Laserer. The authors also wish to thank all riders at the Red Bull Rookies Cup 2009 for their participation and cooperation in this study, and Francisco Vélez for his technical support. This research was funded with the PAQOL project ref. DEP2009-11850 (Ministry of Science and Innovation – Spanish Government – and European Regional Development Fund -ERDF-).

## References

1 *Artero EG, España-Romero V, Ortega FB, Jiménez-Pavón D, Ruiz JR, Vicente-Rodríguez G, Bueno M, Marcos A, Gómez-Martínez S, Urzanqui A, González-Gross M, Moreno LA, Gutiérrez A, Castillo MJ.* Health-related fitness in adolescents: underweight; and not only overweight, as an influencing factor. The AVENA Study. Scand J Med Sci Sports 2010; 20: 418–427
2 *Ascensão A, Ferreira R, Marques F, Oliveira E, Azevedo V, Soares J, Magalhães J.* Effect of off-road competitive motocross race on plasma oxidative stress and damage markers. Br J Sports Med 2007; 41: 101–105
3 *Ascensão A, Azevedo V, Ferreira R, Oliveira E, Marques F, Magalhães J.* Physiological, biochemical and functional changes induced by a simulated 30 min off-road competitive motocross heat. J Sports Med Phys Fitness 2008; 48: 311–319
4 *Bourgois J, Claessens AL, Vrijens J, Philippaerts R, Van Renterghem B, Thomis M, Janssens M, Loos R, Lefevre J.* Anthropometric characteristics of elite male junior rowers. Br J Sports Med 2000; 34: 213–216
5 *Carter JEL, Heath BH* (eds). Somatotyping: Development and Aapplications. Cambridge: Cambridge University Press; 1990
6 *D'Artibale E, Tessitore A, Tiberi M, Capranica L.* Heart rate and blood lactate during official female motorcycling competitions. Int J Sports Med 2007; 28: 662–666
7 *D'Artibale E, Tessitore A, Capranica L.* Heart rate and blood lactate concentration of male road-race motorcyclists. J Sports Sci 2008; 26: 683–689
8 *De Falco D, Della Valle S, Massa G, Pagano S.* The influence of the tyre profile on motorcycle behavior. Vehicle System Dynamics 2005; 43: 179–183
9 *Durnin JV, Womersley J.* Body fat assessed from total body density and its estimation from skinfold thicknesses measurements on 481 men and women aged 16–72 years. Br J Nutr 1974; 32: 77–97
10 *Filaire E, Filaire M, Le Scanff C.* Salivary cortisol, heart rate and blood lactate during a qualifying trial and an official race in motorcycling competition. J Sports Med Phys Fitness 2007; 47: 413–417
11 *Foale T* (ed). Motorcycle Handling and Chassis Design: The Art and Science. 2006
12 *Fry AC, Ciroslan D, Fry MD, LeRoux CD, Schilling BK, Chiu LZ.* Anthropometric and performance variables discriminating elite American junior men weightlifters. J Strength Cond Res 2006; 20: 861–866
13 *Gobbi AW, Francisco RA, Tuy B, Kvitne RS.* Physiological characteristics of top level off-road motorcyclists. Br J Sports Med 2005; 39: 927–931
14 *González-Badillo JJ, Gorostiaga-Ayestarán E* (eds). Foundations of strength training. Application to sport performance [In Spanish]. Barcelona: Inde; 1997
15 *Harriss DJ, Atkinson G.* International Journal of Sports Medicine – Ethical Standards in Sport and Exercise Science Research. Int J Sports Med 2009; 30: 701–702
16 *Horner CH, O'Brien AA.* Motorcycle racing injuries on track and road circuits in Ireland. Br J Sports Med 1986; 20: 157–158
17 *Jackson AS, Pollock ML.* Generalized equations for predicting body density of men. 1978. Br J Nutr 2004; 91: 161–168
18 *Katch FI, McArdle WD.* Prediction of body density from simple anthropometric measurements in college-age men and women. Hum Biology 1973; 45: 445–455
19 *Lee RC, Wang Z, Heo M, Ross R, Janssen I, Heymsfield SB.* Total-body skeletal muscle mass: development and cross-validation of anthropometric prediction models. Am J Clin Nutr 2000; 72: 796–803
20 *Leonard L, Lim A, Chesser TJ, Norton SA, Nolan JP.* Does changing the configuration of a motor racing circuit make it safer? Br J Sports Med 2005; 39: 159–161
21 *Lippi G, Salvagno GL, Franchini M, Guidi GC.* Changes in technical regulations and drivers' safety in top-class motor sports. Br J Sports Med 2007; 41: 922–925
22 *Marfell-Jones M, Olds T, Stewart A, Carter L* (eds.). International Standards for Anthropometric Assessment. Potchefstroom, South Africa: ISAK; 2006
23 *Meijaard JP, Popov AA.* Influences of aerodynamic drag, the suspension system and rider's body position on instabilities in a modern motorcycle. Vehicle System Dynamics 2006; 44: 690–697
24 *Sánchez-Muñoz C, Sanz D, Zabala M.* Anthropometric characteristics, body composition and somatotype of elite junior tennis players. Br J Sports Med 2007; 41: 793–799
25 *Siri WE.* Body composition from fluid space and density. In: Brozek J, Hanschel A (eds). Techniques for Measuring Body Composition. Washington, DC: National Academy of Science; 1961; 223–224
26 *Slaughter MH, Lohman TG, Boileau RA, Horswill CA, Stillman RJ, Van Loan MD, Bemben DA.* Skinfold equations for estimation of body fatness in children and youth. Hum Biol 1988; 60: 709–723
27 *Sloan AW.* Estimation of body fat in young men. J Appl Physiol 1967; 23: 311–315
28 *Tomida Y, Hirata H, Fukuda A, Tsujii M, Kato K, Fujisawa K, Uchida A.* Injuries in elite motorcycle racing in Japan. Br J Sports Med 2005; 39: 508–511
29 *Varley GW, Spencer-Jones R, Thomas P, Andrews D, Green AD, Stevens DB.* Injury patterns in motorcycle road racers: experience on the Isle of Man 1989–1991. Injury 1993; 24: 433–436
30 *Watts PB, Joubert LM, Lish AK, Mast JD, Wilkins B.* Anthropometry of young competitive sport rock climbers. Br J Sports Med 2003; 37: 420–424
31 *Wilmore JH, Behnke AR.* An anthropometric estimation of body density and lean body weight in young men. J Appl Physiol 1969; 27: 25–31
32 *Withers RT, Craig NP, Bourdon PC, Norton KI.* Relative body fat and anthropometric prediction of body density of male athletes. Eur J Appl Physiol 1987; 56: 191–200

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- Estancia de investigación en el Research Institute of Sport & Exercise Sciences, Liverpool John Moores University, Liverpool, United Kingdom. Del 09-09-2009 al 22-12-2009.
- Estancia de docencia-investigación en la Facultade de Motricidade Human, Universidade Técnica de Lisboa, Lisboa, Portugal. Del 18-05-2009 al 26-06-2009.
- Docencia oficial en el Departamento de Educación Física y Deportiva, Universidad de Granada:
  - Curso 2006/2007
    - Fundamentos y enseñanza del ciclismo (Libre configuración específica y reconocimientos): 1.5 créditos P.
    - Actividad física y salud (Lic. en CCAFD): 4 créditos P.
  - Curso 2007/2008
    - Fundamentos y enseñanza del ciclismo (Libre configuración específica y reconocimientos): 0.5 créditos P.
    - Actividad física y salud (Lic. en CCAFD): 4 créditos P.
    - Bases generales de la planificación y la gestión deportiva (Lic. en CCAFD): 1.5 créditos P.
  - Curso 2008/2009
    - Fundamentos y enseñanza del ciclismo (Libre configuración específica y reconocimientos): 2 créditos P.
    - Actividad física y salud (Lic. en CCAFD): 4 créditos P.
  - Curso 2009/2010
    - Fundamentos y enseñanza del ciclismo (Libre configuración específica y reconocimientos): 2 créditos P.
    - Actividad física y salud (Lic. en CCAFD): 4 créditos P.
  - Curso 2011/2012
    - Fundamentos deportes II: balonmano, baloncesto y gimnasia rítmica (Lic. en CCAFD): 2 créditos T.
    - Control y aprendizaje motor (Lic. en CCAFD): 2.5 créditos T.

- Curso 2012/2013
    - Fundamentos deportes I: voleibol, atletismo y natación (Grado en CCAFD): 6 créditos P.
    - Actividad física y salud (Lic. en CCAFD): 6 créditos P.
- Curso 2013/2014
    - Fundamentos deportes I: voleibol, atletismo y natación (Grado en CCAFD): 6 créditos P.
    - Fundamentos deportes IV: esquí o vela/ciclismo (Grado en CCAFD): 2 créditos T., 7 créditos P.
- Curso 2014/2015
    - Anatomía funcional del aparato locomotor (Grado en CCAFD y Ed. Primaria): 1.34 créditos T., 0.67 créditos P.
    - Fundamentos deportes I: voleibol, atletismo y natación (Grado en CCAFD): 7.97 créditos P.
    - Fundamentos deportes III: fúbol, judo y gimnasia deportiva (Grado en CCAFD): 6 créditos P.
    - Juegos, danza y deportes tradicionales y alternativos (Grado en CCAFD): 1.99 créditos P.
    - Música, ritmo y expresividad no verbal en la educación infantil (Grado en Ed. Infantil): 0.5 créditos T., 0.25 créditos P.
    - Expresión corporal y juegos (Grado en Ed. Primaria): 1 créditos T., 0.5 créditos P.

**PROYECTOS Y CONTRATOS DE INVESTIGACIÓN [RESEARCH PROJECTS Y CONTRACTS]**

1. TÍTULO: Aceleración de la maduración docente de los profesores principiantes universitarios y fomento de la autonomía del alumnado a través de diarios personales. ENTIDAD FINANCIADORA: Unidad para la Calidad de las Universidades Andaluzas (UCUA). ENTIDADES PARTICIPANTES: UCUA/ Universidad de Granada. DURACIÓN: 12 meses (20/01/2005-20/01/2006). INVESTIGADOR PRINCIPAL: Jesús Viciana Ramírez. NÚMERO DE INVESTIGADORES PARTICIPANTES: 7. GRADO DE RESPONSABILIDAD DEL SOLICITANTE: Colaborador.

2. TÍTULO: Formación del profesorado principiante en la Facultad de Ciencias de la Actividad Física y del Deporte. ENTIDAD FINANCIADORA: Universidad de Granada. ENTIDADES PARTICIPANTES: Servicio de Evaluación, Calidad y Planes de Estudio-Vicerrectorado para la Garantía de la Calidad. Universidad de Granada. DURACIÓN: 12 meses (15/09/2010-15/09/2011). INVESTIGADOR PRINCIPAL: Gracia López Contreras. NÚMERO DE INVESTIGADORES PARTICIPANTES: 10. GRADO DE RESPONSABILIDAD DEL SOLICITANTE: Colaborador.

3. TÍTULO: Soluciones Ergonómicas Integrales. Ref. 4PP0150472. ENTIDAD FINANCIADORA: Incentivo “CAMPUS” para el fomento de la innovación y el desarrollo empresarial en Andalucía. Agencia de Innovación y Desarrollo de

Andalucía (IDEA). Consejería de Innovación, Ciencia y Empresa. Junta de Andalucía. Línea de incentivo: Creación de empresas. Categoría: Proyectos de Empresa de Base Tecnológica (EBT). PERIODO: 13-04-2010 a 13-04-2012 (24 meses). INVESTIGADOR PRINCIPAL: Victor Manuel Soto Hermoso. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: 134000 €.

4. TÍTULO: Control, valoración y prescripción de entrenamiento para jugadores de tenis de competición. ENTIDAD FINANCIADORA: Real Federación Española de Tenis. PERIODO: 01-12-2011 a 31-11-2012. INVESTIGADOR PRINCIPAL: David Sanz Rivas. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador Colaborador. FINANCIACIÓN: 7000 €. 3

5. TÍTULO: Levantamento antropométrico das crianças das escolas do ensino básico do Barreiro. ENTIDAD FINANCIADORA: Departamento de Ciências da Motricidade (Universidade Técnica de Lisboa). PERIODO: 20-05-2009 a 22-12-2009 (7 meses). INVESTIGADOR PRINCIPAL: María Isabel Caldas Januário Fragoso. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: ND.

6. TÍTULO: Healthy Lifestyle in Europe by Nutrition in Adolescence (HELENA). ENTIDAD FINANCIADORA: European Comision: Research Directorate-General. PERIODO: 01-01-2004 a 31-12-2007 (48 meses). INVESTIGADOR PRINCIPAL: Manuel J. Castillo y Luis A. Moreno. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: 5.000.000 €.

7. TÍTULO: Physiological Benefits of Tennis. ENTIDAD FINANCIADORA: International Tennis Federation. PERIODO: 01-07-2006 a 31-07-2006 (1 mes). INVESTIGADOR PRINCIPAL: David Sanz Rivas y Jaime Fernández. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: ND.

8. TÍTULO: Estudio del perfil antropométrico de los jugadores de tenis: determinación del perfil en la categoría sub-16 y evolución del perfil en la categoría sub-14. ENTIDAD FINANCIADORA: Real Federación Española de Tenis (RFET). PERIODO: 01-01-2005 a 31-12-2005 (12 meses). INVESTIGADOR PRINCIPAL: David Sanz Rivas. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: 6.000 €.

9. TÍTULO: Análisis del perfil antropométrico de los jugadores sub-16 de nivel internacional. ENTIDAD FINANCIADORA: Real Federación Española de Tenis (RFET). PERIODO: 27-09-2005 a 02-10-2005 (1 mes). INVESTIGADOR PRINCIPAL: David Sanz Rivas. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: ND.

10. TÍTULO: Determinación del perfil antropométrico de los jugadores sub-16. ENTIDAD FINANCIADORA: Real Federación Española de Tenis (RFET) e International Tennis Federation (ITF). PERIODO: 27-09-2004 a 03-10-2004 (1 mes). INVESTIGADOR PRINCIPAL: David Sanz Rivas. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: ND.

11. TÍTULO: Determinación del perfil antropométrico de los jugadores de categoría infantil en España. ENTIDAD FINANCIADORA: Real Federación Española de Tenis (RFET). PERIODO: 01-10-2004 a 30-11-2004 (2 meses). INVESTIGADOR

PRINCIPAL: David Sanz Rivas. TIPO DE PARTICIPACIÓN DEL SOLICITANTE: Investigador colaborador. FINANCIACIÓN: 6.000 €.

Nota: la actividad profesional del doctorando desarrollada en la Real Federación Española de Ciclismo ha estado ligada a la Universidad de Granada mediante 6 contratos de investigación a través de la Fundación Empresa Universidad de Granada.

## ARTÍCULOS PUBLICADOS [PAPERS/ORIGINAL MANUSCRIPTS]

Revistas internacionales contempladas en el JCR (Journal Citation Report)

1. **Sánchez-Muñoz C**, Sanz D, Zabala M. Anthropometric characteristics, body composition and somatotype of elite junior tennis players. *Brit J Sports Med* 2007; 41(11): 793-799. (JCR: 2.463)

2. Ruiz JR, Ramírez-Lechuga J, Ortega FB, Castro-Piñero J, Benitez JM, Arauzo-Azofra A, **Sánchez C**, Sjöström M, Castillo MJ, Gutiérrez A, Zabala M. Artificial neural network-based equation for estimating VO2max from the 20 m shuttle run test in adolescents. *Artif Intell Med* 2008; 44(3): 233-245. (JCR: 1.825)

3. Zabala M, Requena B, **Sánchez-Muñoz C**, González-Badillo JJ, García I, Oöpik V, Pääsuke M. Effects of Sodium Bicarbonate Ingestion on Performance and Perceptual Responses in a Laboratory Simulated BMX Cycling Qualification Series. *J Strength Cond Res* 2008; 22(5): 1645-1653. (JCR: 1.393)

4. Fernández-Fernández J, Sanz-Rivas D, **Sánchez-Muñoz C**, Pluim BM, Tiemessen I, Méndez-Villanueva A. A Comparison of the Activity Profile and Physiological Demands Between Advance and Recreational Veteran Tennis Players. J Strength Cond Res 2009; 23(2): 604-610. (JCR: 1.393)

5. Zabala M, **Sánchez-Muñoz C**, Mateo M. Effects of the administration of feedback on performance of the BMX cycling gate start. *J Sports Sci Med* 2009; 8(3): 393-400. (JCR: 0.290)

6. Som A, **Sánchez-Muñoz C**, Ramírez-Lechuga J, Zabala M. Estudio de los hábitos alimentarios de los ciclistas de la selección española de Mountain Bike. *Nutr Hosp* 2010; 25(1): 85-90. (JCR: 1.096)

7. Serrano E, Venegas C, Escames G, **Sánchez-Muñoz C**, Zabala M, Puertas A, De Haro T, Gutiérrez A, Castillo M, Acuña-Castroviejo D. Antioxidant defence and inflammatory response in professional road cyclists during a 4-day competition. *J Sports Sci* 2010; 28(10): 1047-1056. (JCR: 1.619)

8. Fernández-Fernández J, Sánz-Rivas D, **Sánchez-Muñoz C**, González de la Aleja J, Buchheit M, Méndez-Villanueva A. Physiological responses to on-court vs

running interval training in competitive tennis players. *J Sports Sci Med* 2011; 10: 540-545. (JCR: 0.676)

9. **Sánchez-Muñoz C**, Rodríguez MA, Casimiro-Andújar AJ, Ortega FB, Mateo-March M, Zabala M. Physical profile of elite young motorcyclists. *Int J Sports Med* 2011; 32: 788-793. (JCR: 2.381)

10. Rodríguez-Pérez MA, Casimiro-Andújar AJ, **Sánchez Muñoz C**, Muros JJ, Zabala M. Hábitos alimentarios de los jóvenes pilotos de motociclismo de élite internacional. *Rev Int Med Cienc Act Fis Deporte* 2012; 12(46): 195-207. (JCR: 0.380)

11. Ramírez-Lechuga J, Muros JJ, Morente-Sánchez J, **Sánchez-Muñoz C**, Femia P, Zabala M. Efecto de un programa de entrenamiento aeróbico de 8 semanas durante las clases de educación física en adolescentes. *Nutr Hosp* 2012; 27(3):747-754 (JCR: 0.926)

12. Mateo-March M, Rodríguez-Pérez MA, Costa R, **Sánchez-Muñoz C**, Casimiro-Andújar AJ, Zabala M. Efecto de un programa de intervención sobre el estrés percibido, autoestima y rendimiento en jóvenes pilotos de motociclismo de elite. *Revista de Psicología del Deporte* 2013; 22(1): 1-9. (JCR: 0.897)

13. Rodríguez-Pérez MA, Casimiro-Andújar AJ, **Sánchez-Muñoz C**, Mateo-March M, Zabala M. Hábitos de entrenamiento en jóvenes pilotos de motociclismo de elite internacional. *Rev Int Med Cien Act Fis Deporte* 2013; 13(51): 615-625. (JCR: 0.380)

14. Morente-Sánchez J, Zandonai T, Mateo-March M, Sanabria D, **Sánchez-Muñoz C**, Chiamulera C, Zabala M. Acute effect of Snus on physical performance and perceived cognitive load on amateur footballers. *Scand J Med Sci Sports* 2015; 25(4): e423-31. doi: 10.1111/sms.12321. (JCR: 3.174)

15. **Sánchez-Muñoz C**, Zabala M, Muros JJ. Nutritional intake and anthropometric changes of professional road cyclists during a 4-day competition. *Scand J Med Sci Sports* 2015; doi: 10.1111/sms.12513. [Epub ahead of print] (JCR: 3.174)

Revistas nacionales e internacionales no contempladas en el JCR: 12

**PUBLICACIONES EN CONGRESOS [CONGRESS ABSTRACTS]:** 46

**CAPÍTULOS DE LIBRO [BOOK CHAPTERS]:** 6 (se destaca la aportación elaborada para la realización de la presente Tesis Doctoral: **Sánchez-Muñoz C**, Zabala M, Williams K. Anthropometric variables and its usage to characterise elite youth athletes. En: Preedy VR, editor. Handbook of anthropometry. Physical measures of human form in health and disease. Vol 3. New York: Springer; 2012. p. 1865-1888).

**PREMIOS Y RECONOCIMIENTOS [AWARDS AND RECOGNITIONS]**

1. Tercer Premio Nacional Fin de Carrera de Educación Universitaria 2003-2004 en los estudios de Ciencias de la Actividad Física y el Deporte, otorgado por el Ministerio de Educación y Ciencia.
2. Premio especial a la mejor comunicación titulada "Propuesta de tests específicos para la evaluación del piloto de BMX", otorgado por el comité organizador del III Congreso Nacional de Ciencias del Deporte: Nutrición, medicina y rendimiento en el joven deportista. Universidad de Vigo. Pontevedra, 21-31 de Marzo de 2007.

**BECAS DISFRUTADAS [GRANTS]**

1. Tipo de beca o ayuda: PREDOCTORAL. Finalidad de la beca o ayuda: INICIACION A LA INVESTIGACION. Entidad financiadora: UNIVERSIDAD DE GRANADA. Fecha de inicio y finalización: 14-05-2003 a 31-12-2003. Centro e institución donde disfrutó la beca: FACULTAD DE CIENCIAS DE LA ACTIVIDAD FISICA Y EL DEPORTE. UNIVERSIDAD DE GRANADA.
2. Tipo de beca o ayuda: PREDOCTORAL. Finalidad de la beca o ayuda: REALIZACION DEL MASTER UNIVERSITARIO EN ALTO RENDIMIENTO DEPORTIVO. Entidad financiadora: COMITÉ OLÍMPICO ESPAÑOL. Fecha de inicio y finalización: 19-11-2003 a 31-12-2005. Centro e institución donde disfrutó la beca: COMITÉ OLÍMPICO ESPAÑOL.
3. Tipo de beca o ayuda: PREDOCTORAL. Finalidad de la beca o ayuda: FORMACION DEL PROFESORADO UNIVERSITARIO. Entidad financiadora: MINISTERIO DE EDUCACIÓN Y CIENCIA. Fecha de inicio y finalización: 01-04-2006 a 01-04-2010. Centro e institución donde disfrutó la beca: FACULTAD DE CIENCIAS DE LA ACTIVIDAD FISICA Y EL DEPORTE. UNIVERSIDAD DE GRANADA.
4. Tipo de beca o ayuda: PREDOCTORAL. Finalidad de la beca o ayuda: REALIZACION DE LABORES DE DOCENCIA-INVESTIGACIÓN. Entidad financiadora: ORGANISMO AUTONOMO DE PROGRAMAS EDUCATIVOS EUROPEOS. Fecha de inicio y finalización: 18-05-2009 a 26-06-2009. Centro e institución donde disfrutó la beca: UNIVERSIDADE TECNICA DE LISBOA (LISBOA, PORTUGAL).
5. Tipo de beca o ayuda: PREDOCTORAL. Finalidad de la beca o ayuda: ESTANCIAS BREVES DE BECARIOS DEL PROGRAMA NACIONAL DE FORMACIÓN DE PROFESORADO UNIVERSITARIO DEL MINISTERIO DE EDUCACIÓN CON OBJETIVOS DE INVESTIGACIÓN. Entidad financiadora: MINISTERIO DE EDUCACIÓN. Fecha de inicio y finalización: 09-09-2009 a 22-12-2009. Centro e institución donde disfrutó la beca: RESEACH INSTITUTE FOR SPORT AND EXERCISE SCIENCE, LIVERPOOL JOHN MOORES UNIVERSITY (LIVERPOOL, REINO UNIDO).

**ACTIVIDAD PROFESIONAL [PROFESSIONAL ACTIVITY]**

1. Actividad desarrollada: PREPARADOR FISICO DEL EQUIPO NACIONAL DE BMX. Empresa o institución: REAL FEDERACION ESPAÑOLA DE CICLISMO. Fecha de inicio y finalización: 01-01-2005 A 01-03-2007.
2. Actividad desarrollada: PREPARADOR FISICO DEL EQUIPO NACIONAL DE MOUNTAIN BIKE. Empresa o institución: REAL FEDERACION ESPAÑOLA DE CICLISMO. Fecha de inicio y finalización: 01-01-2005 A 01-03-2007.
3. Actividad desarrollada: SELECCIONADOR NACIONAL ABSOLUTO DE MOUNTAIN BIKE. Empresa o institución: REAL FEDERACION ESPAÑOLA DE CICLISMO. Fecha de inicio y finalización: 02-03-2007 A 31-12-2008 y 01-01-2010 – Actualidad.
4. Actividad desarrollada: COORDINADOR RESPONSABLE DEL PROGRAMA NACIONAL DE TECNIFICACIÓN DEPORTIVA DE LA REAL FEDERACIÓN ESPAÑOLA DE CICLISMO. Empresa o institución: REAL FEDERACION ESPAÑOLA DE CICLISMO. Fecha de inicio y finalización: 01-01-2009 - Actualidad.
5. Actividad desarrollada: DIRECTOR TÉCNICO NACIONAL. Empresa o institución: REAL FEDERACION ESPAÑOLA DE CICLISMO. Fecha de inicio y finalización: 01-01-2013 –Actualidad.

## AGRADECIMIENTOS [ACKNOWLEDGEMENTS]

Me gustaría expresar mi agradecimiento a todas aquellas personas que de una forma u otra han contribuido a que esta Tesis Doctoral sea una realidad:

- A mi familia, que como he expuesto anteriormente en la dedicatoria de la presente Tesis Doctoral, no tengo palabras…
- A mi amigo y director Mikel Zabala, auténtico profesional y mejor persona, con quien desde que nos conocemos como compañeros de aula me ha permitido realizar junto a él un camino paralelo en el ámbito académico y profesional. Quién me ha demostrado que todavía existen los valores, teniendo siempre la ética, el trabajo y el esfuerzo muy presente. Sin ti nunca hubiera llegado a conseguir lo que he conseguido a nivel profesional, pero sobre todo quiero agradecerte haber sido un apoyo constante e incansable a nivel personal, a pesar de mi cabezonería, errores y no haber hecho lo que debería en determinadas ocasiones. Es un orgullo ser tu amigo!!
- A mi directora Karen Williams, por haberme acogido de la manera que lo hiciste en Liverpool y prestarme tu apoyo y conocimiento, aunque a veces tuviera la sensación de que no me entendías…
- A José Joaquín Muros, uno de los pilares fundamentales en el desarrollo y elaboración de la presente Tesis, sin el cual hubiera sido difícil su finalización. Moralmente sabes que también eres director de esta Tesis.
- A mis amigos Laura, Marta, Raquel, Richard, Irene, Charli, David, Félix, Jaime, quienes nunca se han cansado de escucharme hablar de la finalización de esta tesis y siempre me han animado para acabarla. Parecía que nunca iba a llegar este momento…

- A todos los deportistas que han tomado parte en las diferentes investigaciones, así como a los entrenadores, técnicos, e instituciones, quiénes sin su colaboración este trabajo nunca hubiera sido posible.

MUCHAS GRACIAS A TODOS