

Upper Limb Span as a Reliable Predictor of Stature in Montenegrin Adolescents: Evidence from a Nationwide Sample

Envergadura de Miembros Superiores como Predictor Fiable de la Estatura en Adolescentes Montenegrin: Evidencia de una Muestra Nacional

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SUMMARY: The purpose of this research is to determine a regression equation for the estimation of stature from upper limb span measurements. This study was carried out on 1,200 subjects (604 males and 596 females) among the population of Montenegrin adolescents. Stature and arm span measurements were taken according to the ISAK protocol, and the data were statistically analyzed. Linear regression analysis was used to determine the predictive value of upper limb span on the criterion variable, body height, at a significance level of $p < 0.05$. The relationships are presented in the form of scatter diagrams. The analysis provided the coefficient of determination, multiple correlation coefficients, partial correlation coefficient, regression coefficients, t-test, and standardized beta coefficient. The results of this study confirmed that upper limb span reliably predicts stature in both sexes of Montenegrin adolescents and offers valuable insights for physical anthropologists and related professionals. A significant correlation between upper limb span and body height was observed (males: 62.3 %, females: 57.5 %).

KEY WORDS: Anthropometry; Prediction; Upper limb span; Montenegrin adolescents.

INTRODUCTION

The study of body proportions and their interrelationships represents an important area of contemporary anthropological and biomedical research, as it allows for a better understanding of the patterns of human growth and development, as well as variations observed between different populations (Vukotic, 2020). Anthropometry, as a scientific discipline focused on measuring human body dimensions, developed alongside advancements in anatomy and precise measuring instruments, while interest in ideal human body proportions was already present in the works of Renaissance artists. However, its systematic scientific application began only in the modern period, when anthropometric measurements became an indispensable part of biological and medical research at the end of the 19th and the beginning of the 20th century, anthropometry gained significant importance in clinical practice and public health, being used to assess physical status and overall health of individuals (Ana *et al.*, 2010; Vukotic, 2022). By measuring longitudinal body dimensions, it is possible to examine the influence of genetic and environmental factors on human growth and development, especially during sensitive periods such as

childhood and adolescence. Contemporary research confirms that anthropometric parameters provide a reliable basis for the quantitative assessment of morphological characteristics and for monitoring biological development.

Body height represents one of the fundamental anthropometric indicators and has wide applications in medicine, sports, and population studies (Vukotic *et al.*, 2021). It is used in the assessment of growth and development, standardization of functional and physiological variables, and clinical diagnostics. However, in certain situations, direct measurement of stature is either not possible or not sufficiently reliable, particularly in individuals with spinal deformities, amputations, fractures of the lower limbs, or chronic illnesses.

In such cases, upper limb span (also known as arm span or often called winspan) is highlighted as one of the most commonly used alternative anthropometric measures for estimating stature. Numerous studies have confirmed a very strong linear relationship between upper limb span and body height, which allows for the development of accurate

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regression models. Research conducted on a population of women in South India showed that arm span is an extremely reliable predictor of stature, with high correlation coefficients between the two variables (Mohanty *et al.*, 2001).

Similar results have been obtained in European populations. A study on the adult population in Serbia confirmed that body height can be accurately estimated based on upper limb span, demonstrating a strong association between these two anthropometric measures (Popovic *et al.*, 2013). Additionally, research on the adolescent population in Bosnia and Herzegovina indicated a high reliability of upper limb span as a predictor of stature, with certain sex-specific differences (Popovic *et al.*, 2015).

Further support for the universal applicability of upper limb span as a predictor of body height comes from a large multi-ethnic study that included participants of various age groups and ethnic backgrounds, showing that the relationship between upper limb span and stature remains stable throughout life, with variations conditioned by population-specific factors (Quanjer *et al.*, 2014). Earlier studies conducted on female populations also demonstrated that upper limb span is a reliable indicator of actual stature, regardless of age (Steele & Chenier, 1990; Arifi, 2018).

Given that the relationship between upper limb span and body height differs depending on sex, age, and ethnic background, it is evident that population-specific predictive models need to be developed. Accordingly, the general hypothesis of this study (H_g) assumes that there are specific patterns in the relationship between upper limb span and stature among the adolescent population of both sexes. The aim of the study is to examine the predictive value of upper limb span as a longitudinal anthropometric measure in estimating body height in adolescents, with a particular focus on sex differences.

MATERIAL AND METHOD

The sample in this research consisted of 1,200 adolescents, all in their final year of high school (604 males and 596 females) from the territory of Montenegro. Two main reasons guided the selection of this population: first, growth typically reaches its final stage at this age, and second, body weight is generally stable, minimizing potential confounding factors. The mean age of male subjects was 18.34 ± 6.35 years (age range 18–20), while the mean age of female subjects was 18.81 ± 3.43 years (age range 18–20). Adolescents with body deformities (e.g., scoliosis, kyphosis, lordosis), paralysis, fractures, amputations, or other significant medical conditions were excluded. The study was conducted in accordance with the Declaration of Helsinki.

Participants not originating from Montenegro were also excluded.

Anthropometric measurements, including body height and upper limb span, were taken following the protocol of the International Society for the Advancement of Kinanthropometry (ISAK) (Marfell-Jones *et al.*, 2006). Age was determined by asking participants to report their date of birth.

Data Processing

Statistical analysis was performed using SPSS version 25.0. For both anthropometric variables, central tendency and dispersion parameters were calculated, including minimum and maximum values, arithmetic mean, and standard deviation. Linear regression analysis was used to examine the predictive value of upper limb span on the criterion variable, body height, at a significance level of $p < 0.05$. Relationships were illustrated using scatter plots. The analysis included calculation of the coefficient of determination, multiple and partial correlation coefficients, regression coefficients, t-test, and standardized beta coefficients.

RESULTS

Descriptive anthropometric characteristics of the study sample by gender are presented in Table I. The male adolescents ($n = 604$) had a mean body height of 183.59 ± 6.28 cm, with values ranging from 164.1 to 203.4 cm. The mean arm span in males was 186.00 ± 7.61 cm, ranging from 170.2 to 206.3 cm. Female adolescents ($n = 596$) had a mean body height of 170.65 ± 3.43 cm, with a minimum value of 154.1 cm and a maximum value of 184.7 cm. The mean arm span among females was 171.00 ± 6.77 cm, with recorded values ranging from 150.1 to 199.4 cm. In both genders, arm span values were, on average, slightly greater than stature.

Table I. Anthropometric measurements of the study subjects.

Subjects	Body height range (cm) (Mean $\pm$ SD)	Upper limb span (cm) (Mean $\pm$ SD)
Male	164.1 - 203.4 (183.59 $\pm$ 4.28)	170.2 - 206.3 (186 $\pm$ 7.61)
Female	154.1 - 184.7 (170.65 $\pm$ 3.43)	150.1 - 199.4 (171 $\pm$ 6.77)

In male adolescents, arm span showed a strong and statistically significant correlation with body height ($R = 0.832$, $p < 0.001$). The coefficient of determination ($R^2 = 0.665$) indicated that 62.3 % of the variance in body height could be explained by arm span. The regression model was statistically significant ($t = 12.123$, $p < 0.001$), confirming arm span as a robust predictor of stature in male adolescents.

Table II. Results of linear regression analysis where the arm span predicts the stature.

Subjects	R	R Square (%)	Adjusted R Square	Std. Error of the Estimate	t-value	p-value
Male	0.832 ^a	.623	.665	25.343	12.123	.001*
Female	0.735 ^a	.575	.555	23.234	12.542	.001*

Table III. Results of coefficients regression analysis where the upper limb span predicts the stature.

Subjects	Coefficients Beta	Std. Error	95 % Confidence Interval Lower	Upper
Male	.554	.354	4.532	4.321
Female	.436	.265	4.134	4.244

Among female adolescents, a strong positive association between upper limb span and stature was also observed ($R = 0.735$, $p < 0.001$). Upper limb span explained 57.5 % of the variance in body height ($R^2 = 0.555$), and the regression model reached statistical significance ($t = 12.542$, $p < 0.001$) (Table II).

The strength and direction of the predictive relationship were further examined using standardized regression coefficients (b), as presented in Table III. In males, the standardized beta coefficient was $b = 0.554$, indicating a strong positive effect of upper limb span on stature. In females, the beta coefficient was $b = 0.436$, also demonstrating a statistically significant predictive effect (Figs. 1 and 2). The relatively low standard errors and narrow confidence intervals further confirm the stability and reliability of the regression models in both sexes.

DISCUSSION

The results of this study confirm that upper limb span is a reliable predictor of stature in adolescents of both sexes in Montenegro. The correlation coefficients between upper limb span and stature were 0.832 in males and 0.735 in females, indicating a strong positive association. In the male population, upper limb span explained 62.3 % of the variance in stature, while in female participants, it accounted for 57.5 % of the variance, confirming the high predictive power of this anthropometric parameter. Standardized beta coefficients ($\beta = 0.554$ for males and $b = 0.436$ for females) further highlight the significant influence of arm span on stature in both sexes (Popovic *et al.*, 2013). These findings are consistent with previous studies conducted in different populations. A study in Southern India on females reported a high correlation between stature and upper limb span (Mohanty *et al.*, 2001; Albrizio, 2007), similar to the findings in Montenegrin female adolescents. Research conducted in Serbia on the adult population also demonstrated a strong association between stature and upper limb span in both sexes (Popovic *et al.*,

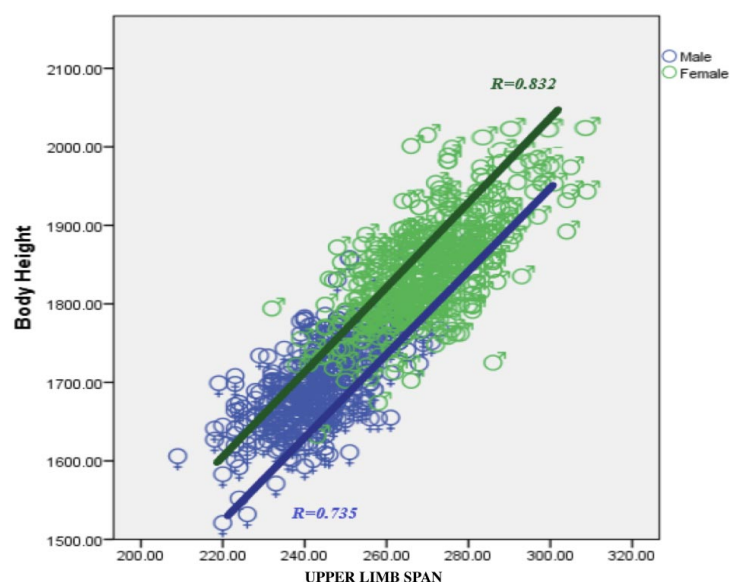


Fig. 1. Scatter diagram and relationship upper limb span measurements and upper limb among both sexes.

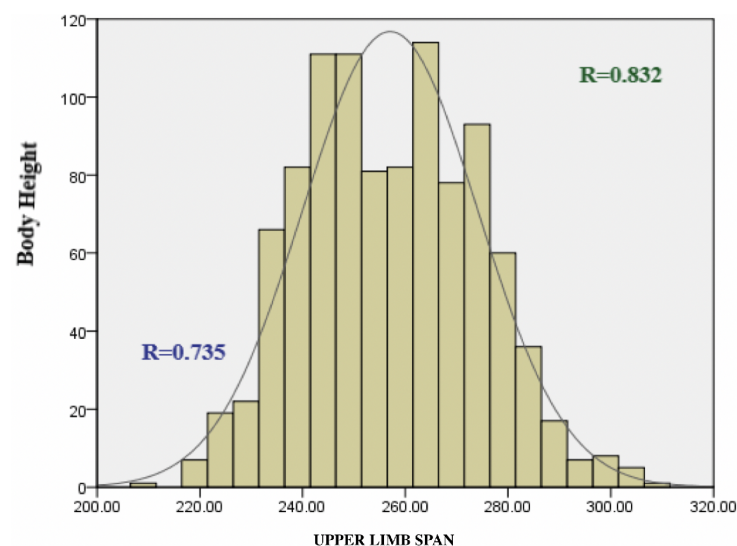


Fig. 2. Diagram and relationship between upper limb span measurements and body height among both sexes.

2013), consistent with our results in the male population. Studies among adolescents in Bosnia and Herzegovina likewise confirm the high reliability of upper limb span as a predictor of stature, with some sex-specific differences (Popovic *et al.*, 2015).

When comparing the results with Western European populations, it is observed that the average stature and upper limb span of Montenegrins are slightly higher. For example, the average height of adolescent males in the Netherlands is around 183 cm, while in our sample it was 183.59 cm. This difference may be attributed to genetic factors, nutrition, and lifestyle (Quanjer *et al.*, 2014). A multi diversified study showed that the relationship between stature and upper limb span remains stable throughout life, although population-specific variations exist (Quanjer *et al.*, 2014). For instance, Asian populations often show a shorter upper limb span relative to stature compared to European populations, consistent with the findings from Southern India (Mohanty *et al.*, 2001).

The results of this study also emphasize the importance of considering secular growth changes. The period of rapid growth during adolescence, particularly the growth tempo, aligns with studies conducted in Australia (Cole, 2012), where positive secular changes have been attributed to improvements in nutrition, healthcare, education, and general environmental and economic conditions (Cole, 2012; Quanjer *et al.*, 2014). Factors such as early hormonal changes and the onset of puberty at younger ages may also affect variations in stature. Adolescents undergo a complex series of biological changes during puberty, including height growth and the development of secondary sexual characteristics (Tanner, 1962; Marshall & Tanner, 1969).

Sexual development and maturation are crucial for the accurate assessment of growth and timely pubertal development in children and adolescents. The improvement of methods for monitoring secondary sexual characteristics can further validate the applicability of these models in population studies (Tanner, 1962; Marshall & Tanner, 1969). An obvious limitation of this study is that neither sex of the Montenegrin population has yet reached its full genetic potential, and positive secular changes could significantly alter the findings confirmed in this study (Agnihotri *et al.*, 2011). Therefore, continuous monitoring and proper control of anthropometric parameters in the population are necessary, taking into account predicted secular changes in stature in the coming decades, which may lead to a revision of current assumptions (Cole, 2012; Quanjer *et al.*, 2014).

In conclusion, the results of this study confirm the universal applicability of upper limb span as a predictor of

stature in adolescents, highlighting the need for population-specific models that consider sex (Mohanty *et al.*, 2001; Popovic *et al.*, 2013, 2015) genetic characteristics, socioeconomic, and environmental factors.

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RESUMEN: El objetivo de esta investigación fue determinar una ecuación de regresión para la estimación de la estatura a partir de la medición de la envergadura de los miembros superiores. Este estudio se realizó con 1200 sujetos (604 varones y 596 mujeres) de la población adolescente montenegrina. Las mediciones de estatura y envergadura de los miembros superiores (o mal llamado longitud de los brazos) se tomaron según el protocolo ISAK y los datos se analizaron estadísticamente. Se utilizó un análisis de regresión lineal para determinar el valor predictivo de la envergadura de los miembros superiores sobre la variable criterio, la estatura, con un nivel de significancia de $p < 0,05$. Las relaciones se presentan en forma de diagramas de dispersión. El análisis proporcionó el coeficiente de determinación, los coeficientes de correlación múltiple, el coeficiente de correlación parcial, los coeficientes de regresión, la prueba *t* y el coeficiente beta estandarizado. Los resultados de este estudio confirmaron que la envergadura de los miembros superiores predice de forma fiable la estatura en adolescentes montenegrinos de ambos sexos y ofrece información valiosa para antropólogos físicos y profesionales afines. Se observó una correlación significativa entre la envergadura de los miembros superiores y la estatura (hombres: 62,3 %, mujeres: 57,5 %).

PALABRAS CLAVE: Antropometría; Predicción; Envergadura de los miembros superiores; Adolescentes montenegrinos.

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