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Variability of Vertical Body Proportions in Adult Women: Relationships between Stature, Hip Height and Navel Height

Varijabilnost vertikalnih tjelesnih proporcija odraslih žena: povezanost tjelesne visine, visine kukova i pupka

Scientific paper / Znanstveni rad

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Abstract
Anthropometric research is important for understanding variability in the human body and forms the basis for the development of sizing systems, clothing design and other areas of applied anthropometry. The aim of this paper was to analyse the relationships between body height, navel height and hip height as indicators of vertical body proportions, and to determine the deviations of actual female body proportions from the idealised golden ratio model. The research was conducted on a sample of 297 women aged 18 to 34 years. Body height (Bh), navel height (Nh) and hip height (Hh) were measured, with hip height determined by the anthropometric point trochanterion. Descriptive statistics, Pearson correlation analysis and a one-sample t-test were applied. The results showed a strong correlation between body height and hip height ($r = 0.822$; $p < 0.001$), but also significant individual variability in vertical body proportions. The ratio of hip height to body height (Hh/Bh) indicated that 13.5% of respondents had relatively shorter and 15.5% had relatively longer legs compared with the sample average. Analysis of proportions in relation to the golden ratio revealed statistically significant deviations of actual body proportions from the theoretical model ($p < 0.001$). It was further confirmed that people of the same body height can have different relationships between leg and torso length. The results confirm the existence of significant variability in vertical body proportions within the population of adult women and show that body height alone is not a sufficient indicator of the distribution of torso and lower limb length. The scientific contribution of this work lies in the quantification of the distribution of relative leg length using a standardised anthropometric indicator and in the analysis of deviations of actual body proportions from the idealised golden ratio model. The results contribute to the description of vertical body proportions in adult women and quantify the variability of relative leg length within the observed population.

Keywords: anthropometry; vertical body proportions; hip height; trochanterion; relative leg length; navel height; golden ratio.

Sažetak
Antropometrijska istraživanja važna su za razumijevanje varijabilnosti ljudskog tijela te predstavljaju osnovu za razvoj sustava veličina, dizajn odjeće i druga područja primijenjene antropometrije. Cilj ovoga

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rada bio je analizirati odnose između tjelesne visine, visine pupka i visine kuka kao pokazatelja vertikalnih tjelesnih proporcija te utvrditi odstupanja stvarnih proporcija ženskoga tijela od idealiziranog modela zlatnog reza. Istraživanje je provedeno na uzorku od 297 žena u dobi od 18 do 34 godine. Analizirane su tjelesna visina (Tv), visina pupka (Vp) i visina kuka (Vk), pri čemu je visina kuka određena antropometrijskom točkom trochanterion. Primijenjene su metode deskriptivne statistike, Pearsonova korelacijska analiza i one-sample t-test. Rezultati su pokazali snažnu povezanost između tjelesne visine i visine kuka ($r = 0{,}822$; $p < 0{,}001$), ali i značajnu individualnu varijabilnost vertikalnih tjelesnih proporcija. Omjer visine kuka i tjelesne visine (Vk/Tv) pokazao je da 13,5 % ispitanica ima relativno kraće, a 15,5 % relativno dulje noge u odnosu na prosjek uzorka. Analiza proporcija u odnosu na zlatni rez pokazala je statistički značajna odstupanja stvarnih tjelesnih proporcija od teorijskog modela ($p < 0{,}001$). Dodatno je potvrđeno da osobe iste tjelesne visine mogu imati različite odnose između dužine nogu i trupa. Rezultati potvrđuju postojanje značajne varijabilnosti vertikalnih tjelesnih proporcija unutar populacije odraslih žena te pokazuju da tjelesna visina sama po sebi nije dostatan pokazatelj raspodjele dužine trupa i donjih ekstremiteta. Znanstveni doprinos rada ogleda se u kvantificiranju raspodjele relativne dužine nogu primjenom standardiziranog antropometrijskog pokazatelja te u analizi odstupanja stvarnih tjelesnih proporcija od idealiziranog modela zlatnog reza. Dobiveni rezultati predstavljaju osnovu za buduća istraživanja antropometrijskih klasifikacija, sustava veličina, dizajna i pristalosti odjeće.

Ključne riječi: antropometrija; vertikalne tjelesne proporcije; visina kuka; trochanter major; relativna dužina nogu; visina pupka; zlatni rez.

1. Introduction

Clothing fit is an important factor in functionality, aesthetics and user satisfaction. Numerous studies have shown that inappropriate clothing sizing often leads to consumer dissatisfaction and an increased number of product returns, especially in online sales [1–4]. At the same time, clothing, in addition to its protective function, plays an important role in shaping personal identity, self-confidence and the social perception of an individual [5–11]. Therefore, the development of sizing systems that more accurately reflect the anthropometric characteristics of the target population remains one of the key areas of research in the clothing industry. Modern sizing systems are based on anthropometric research and international standards, such as ISO 8559 and the European standard EN 13402, which define procedures for measuring the human body and labelling clothing sizes [12–17]. These systems rely on key body measurements, dominated by body height and chest, waist and hip circumferences. However, anthropometric research shows that people of the same height may have different relationships between individual body parts, especially the length of the trunk and lower extremities, which indicates substantial variability in vertical body proportions within the population. In contrast, vertical body dimensions and their proportional relationships have been studied much less frequently, although they represent an important aspect of human morphology. Of particular interest are the relationships between total body height, hip height and navel position, which allow assessment of the distribution of trunk and leg lengths within total body height. Additional interest in the study of vertical proportions stems from the fact that in art, design and fashion, the human body is often depicted according to idealised proportional models. One of the most famous such models is based on the golden ratio ($\varphi = 1.618$) [18], according to which the navel approximately divides the human body into two segments in an ideal proportional relationship. Although the golden ratio is often invoked in aesthetic interpretations of the human body, actual population deviations from such idealised models have not yet been sufficiently investigated. Therefore, the aim of this paper is to analyse the relationships between body height, navel height and hip height in adult women, and to examine the variability of vertical body proportions within the observed sample. Additionally, the aim is to determine the extent to which the actual proportions of the female body differ from the idealised model based on the golden ratio. Special attention is paid to hip height (trochanterion height) as an anthropometric indicator of the relative length of the lower extremities. The results of the study should contribute to a better understanding of the distribution of vertical body proportions in the adult female population and

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provide an anthropometric basis for future research related to clothing design, sizing systems and the assessment of clothing fit.

Anthropometric research forms the basis for the development of clothing size systems, the construction of patterns and the adaptation of clothing to the user's body dimensions. To standardise measurements and size labelling, international standards ISO 8559 and EN 13402 have been developed, which define anthropometric reference points, measurement methods and approaches to clothing size labelling [12–17]. The development of 3D body-scanning technology in recent decades has enabled the collection of large anthropometric databases and the study of human morphology in greater detail than was possible using traditional measurement methods [19–23]. These data have contributed to a better understanding of human body variability and to the development of more advanced approaches to the classification of body shapes and the determination of clothing sizes [23]. The classification of female body types is an important area of research in anthropology, ergonomics and the clothing industry. From the early somatotype models of Kretschmer, Sheldon, and Heath and Carter [24,25] to modern methods based on 3D anthropometric databases, the aim of research has been to identify groups of users with similar body characteristics for application in clothing design and production. Of particular importance are the FFIT method (Female Figure Identification Technique) and subsequent classifications developed on the basis of 3D body scans [26,19,20,27]. However, most existing systems for classifying the female body are based primarily on horizontal anthropometric measures, i.e. the ratios of chest, waist and hip circumferences [28–37]. On the basis of these measures, the best-known body types, such as hourglass, triangle, inverted triangle, rectangle and oval, have been defined. Such classifications successfully describe body shape, but provide limited information about vertical body proportions.
Recently, there has been growing interest in investigating vertical anthropometric dimensions and their interrelationships. Griffin et al. [38] have shown that individuals of similar size can have markedly different body proportions, while Petrova and Ashdown [39] and Yan et al. [23] have highlighted the importance of including additional anthropometric indicators in the analysis of body shapes. In the development of clothing size systems, body height is considered one of the key anthropometric measures because, together with other body dimensions, it helps differentiate body types and segment the population according to morphological characteristics. Including height in classification procedures allows a more precise definition of size groups and better adaptation of clothing to different body shapes [40]. Despite the growing number of studies, vertical relationships between individual body parts are still much less well studied than overall measures. In particular, there are few studies that analyse the relationship between body height, navel position, and hip height as indicators of the distribution of trunk and lower limb length. At the same time, idealised proportional models are often used in art, fashion, and visual representations of the human body, the most famous of which is the model based on the golden ratio.

The golden ratio was not used as a normative criterion of attractiveness or as a standard of correct body proportions. It was introduced solely as a historically important proportional model frequently referenced in art, design, and fashion illustrations. The comparison therefore serves as an exploratory analysis of how actual anthropometric proportions deviate from a commonly cited theoretical model.
The actual deviations of female body proportions from such idealised models, as well as the variability of vertical proportions within the female population, have not yet been sufficiently investigated. Therefore, a more detailed analysis is needed of the relationship between body height, navel height and hip height, and an assessment of the extent to which actual body proportions differ from theoretical proportion models.

2. Experimental part

2.1. Materials and methods

The study was conducted on a sample of 297 women aged 18 to 34. Its aim was to analyse the relationships between selected vertical anthropometric measurements of the female body, assess deviations from the theoretical model of the golden ratio, and consider the potential application of the results in the design and labelling of clothing sizes. Measurements were carried out in accordance with the procedures prescribed in the manual for measurers developed within the framework of the Croatian Anthropometric System project [41], using internationally recognised anthropometric definitions and reference anatomical landmarks defined by the ISO 7250-1 standard [42]. As a 3D body scanner was not available during the study, all measurements were taken manually using standard anthropometric procedures.

The subjects were measured barefoot, in an upright anatomical position, with their body weight evenly distributed. Vertical measurements were taken with an anthropometer as the distance from the floor to defined anatomical landmarks, fig.1.

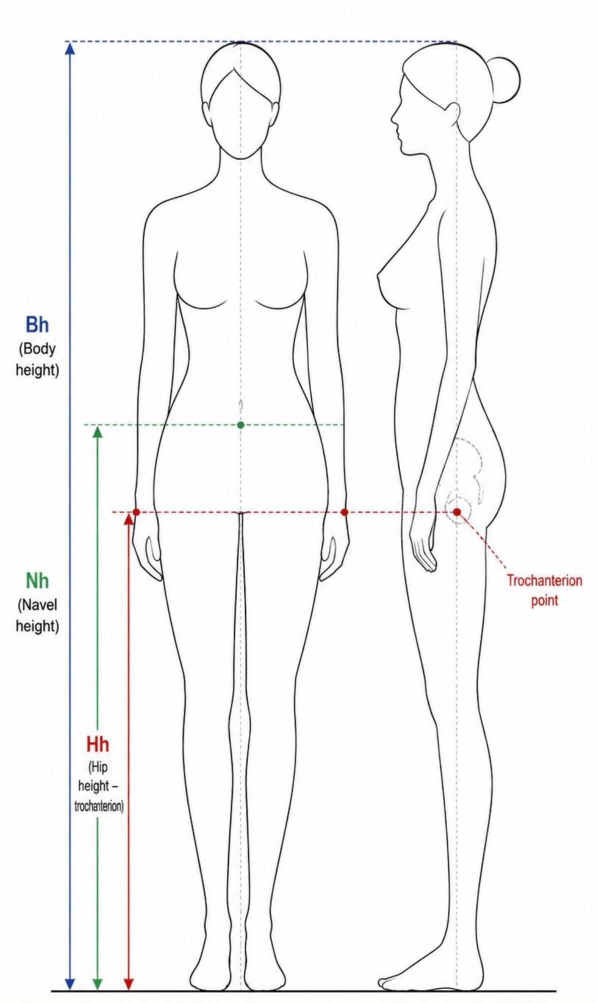

Figure 1. Anthropometric measurements and anatomical landmarks used in the study (Bh – body height; Nh – navel height; Hh – hip height measured from the trochanterion landmark).

Hip height was determined using the anthropometric point trochanterion (the highest point of the greater trochanter of the femur), identified by palpation according to Norton et al. [43]. The anthropometric landmark trochanterion is also defined by the international standard ISO 7250-1 as a reference bone point for anthropometric measurements of the human body [42]. In international anthropometric practice, it is used to determine hip height (trochanterion height) and as an indicator of the relative length of the lower extremities [42, 43]. Navel height was determined as the vertical distance from the geometric centre of the navel to the floor.

Measurements were conducted anonymously and voluntarily in the city of Zagreb.

The following anthropometric measures were analysed: • body height (Bh) – vertical distance from the floor to the vertex point; • navel height (Uh) – vertical distance from the centre of the navel to the floor; • hip height (Hh) – vertical distance from the trochanterion anthropometric point to the floor. To assess proportional leg length, the ratio of hip height to body height (Hh/Bh) was calculated.

The subjects were classified according to the Hh/Bh ratio using z-scores derived from the distribution of the observed sample. Values one standard deviation below and above the arithmetic mean were used as the classification limits. Subjects with values less than $\mu - 1$ SD were classified as people with relatively shorter legs, and subjects with values greater than $\mu + 1$ SD as people with relatively longer legs. Statistical analysis was performed in the SPSS software. Basic descriptive indicators were calculated and correlation analyses were conducted between body height and hip height. Deviation from the theoretical model of the golden ratio was assessed using the one-sample t-test, with the reference value determined according to the ratio $\varphi = 1.618$. Additional analyses were carried out within tertiles formed according to the subjects' body height. The level of statistical significance was set at $p < 0.05$.

3. Results and Discussion

To assess the deviation of actual body proportions from the theoretical model of the golden ratio ($\varphi = 1.618$), selected proportions were analysed using a one-sample t-test (Table 1).

Both analysed ratios deviated statistically significantly from the reference value of the golden ratio ($p < 0.001$). The first ratio had an average value of 1.667 (SD = 0.039), while the second ratio was 1.973 (SD = 0.070).

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Table 1. Deviation of body proportions from the value of the golden ratio (φ = 1.618)

Proportional ratio	Mean	SD	t-value	p-value	Deviation from φ
Ratio 1	1.667	0.039	21.659	<0.001	+0.049
Ratio 2	1.973	0.070	88.104	<0.001	+0.355

Note: φ = 1.618, representing the golden ratio.

Table 2. Descriptive statistics for body height and hip height measurements

Varijable (cm)	N	Min	Max	Mean	SD	Medijan	Skewness	Kurtosis
Body height (Bh)	297	152.0	184.0	166.64	6.32	166.0	0.254	-0.169
Hip height (Hh)	297	70.0	96.0	84.58	4.90	84.5	-0.001	-0.143

Note: N = sample size; M = mean; SD = standard deviation; Min = minimum value; Max = maximum value.

Table 3. Average anthropometric measurements by age group

Age group	N	Mean Bh (cm)	Mean Nh (cm)	Mean Hh (cm)	Mean Hh/Bh (cm)
18-22	218	166.40	100.18	84.47	0.507
23-34	79	167.28	99.52	84.89	0.507

Bh – Body height; Nh – Navel height; Hh – hip height.

Table 4. Distribution of subjects according to proportional leg length

Group	Criterion (Hh/Bh)	n	%
Relatively shorter legs	< 0,490	40	13,5
Average proportions	0,490–0,525	211	71,0
Relatively longer legs	> 0,525	46	15,5
Total		297	100,0

Table 5. Average values by tertiles

Tertile	Body height range (cm)	N	Mean Bh (cm)	Mean Nh (cm)	Mean Hh (cm)
I	≤ 164.0	107	160,23	95,72	80,36
II	164.5 – 169.0	97	166,59	99,96	84,46
III	≥ 169.5	93	174,06	104,97	89,56

Table 6. Percentage of deviations within tertiles

Tertile	N	Mean Nh	Mean Hh	Nh above sample mean (%)	Hh above sample mean (%)	Nh above the golden ratio reference (%)
I	107	95.72	80.36	0.9	8.4	4.7
II	97	99.76	84.46	44.3	46.4	5.2
III	93	104.97	89.56	93.5	91.4	16.1

The results show that the actual proportions of the subjects differ from the idealised model traditionally associated with aesthetically ideal proportions of the human body. The results indicate a consistent deviation of the observed proportions from the theoretical model of the golden ratio. Descriptive statistics for body height (Bh) and hip height (Hh) are shown in Table 2. The average body height of the subjects was 166.64 cm (SD = 6.32 cm), and the average hip height was 84.58 cm (SD = 4.90 cm). Both variables showed an approximately normal distribution, as indicated by low values of skewness and kurtosis. The relative ratio of hip

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height to body height (Hh/Bh), used as an indicator of proportional leg length, was on average 0.507 (SD = 0.018).

To explore possible age-related differences, the sample was further divided into two age groups. Only minor differences, Table 3, were observed between the groups, indicating relatively stable vertical body proportions across the studied age range.

Based on the Hh/Bh ratio, the subjects were classified into three groups using the criterion of one standard deviation below and above the arithmetic mean of the sample, as shown in Table 4. The majority of subjects (71.0%) belonged to the group with average proportions, while 13.5% had relatively shorter and 15.5% had relatively longer legs in relation to total body height. For a more detailed analysis, the subjects were divided into three tertiles according to body height. The average values of the measures analysed are shown in Table 5. As body height increased, both navel height (Nh) and hip height (Hh) increased. The average hip height rise from 80.36 cm in the first tertile to 89.56 cm in the third tertile. However, the distribution analysis showed that within all height groups there were respondents whose proportions deviated from their own group average. In the first tertile, 91.6% of respondents had a hip height lower than the overall sample average, while in the third tertile, 91.4% of respondents had a hip height higher than the average.

Comparison of the navel position with the theoretical value determined by the golden ratio showed that most subjects in all tertiles had a lower navel position than the theoretical value. The proportion of subjects who deviated from the idealised model was more than 80% in all height groups (Table 6). At the same time, it was shown that the largest number of subjects were relatively close to the theoretical value. Between 79.4% and 87.1% of the subjects were within ±5% of the ideal value, depending on the tertile. The results confirm the existence of significant variability in the vertical proportions of the female body and show that people of the same height can have different relationships between leg length and trunk length. The study results showed a strong correlation between body height and hip height, confirming that increasing body height also increases the vertical dimensions of the body. However, analysis of the ratio of hip height to body height showed that people of the same height do not necessarily have the same body proportions. Within the observed sample, subjects with relatively shorter and relatively longer legs in relation to total body height were identified, with almost 29% of subjects deviating from the average proportions by more than one standard deviation. The results confirm that total body height is not a sufficient indicator of the vertical proportions of the female body. Two individuals of the same body height may have different ratios between leg length and trunk length, indicating significant anthropometric variability within the same height group.

Analysis of proportions in relation to the theoretical model of the golden ratio showed that the actual proportions of the female body differ statistically significantly from the idealised proportions often used in art, fashion and visual representations of the human body. Although the position of the navel in some subjects was relatively close to the theoretical value, most subjects did not correspond to the idealised model, which implies relatively longer legs and a shorter torso. Such a finding should not be interpreted as a deviation from desirable or optimal proportions, but as confirmation that idealised models do not represent the actual distribution of body proportions in the observed population. Anthropometric data collected on real users are therefore of greater value for the development of a sizing system than theoretical or aesthetic models. The results also show that the proportional relationships between the torso and legs do not change linearly with increasing body height. Although taller subjects had higher hip height values on average, significant individual deviations were recorded within all height groups. The results suggest that vertical proportions could provide useful additional information in future studies of sizing systems.

4. Conclusion

The research showed a strong correlation between body height and hip height, but also significant individual variability in vertical body proportions. Analysis of the ratio of hip height to body height (Hh/Bh) showed that people of the same body height can have different relationships between leg length and trunk length. Using a criterion based on standard deviation, it was determined that 13.5% of respondents had relatively shorter legs, 15.5% had relatively longer

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legs, while 71.0% belonged to the group with average proportions. The results confirm significant variability in vertical body proportions within the population of adult women. Comparison with the theoretical model of the golden ratio showed statistically significant deviations of actual body proportions from the idealised proportional model, confirming that idealised aesthetic models do not fully reflect the distribution of proportions in the observed population. The scientific contribution of the work lies in the analysis of the relationships between body height, navel height and hip height, and in the quantification of the proportional distribution of leg length using a standardised anthropometric indicator.

The findings provide quantitative information on the distribution of relative leg length and vertical body proportions among adult women. Such information may be useful in future anthropometric studies focused on population segmentation, body classification, and the development of anthropometric databases. The proposed Hh/Bh indicator may also serve as an additional variable in future studies on clothing sizing systems, clothing design, and garment fit. Future research should directly link the anthropometric characteristics of users with objective and subjective indicators of clothing fit, in order to determine the extent to which differences in vertical body proportions affect the effectiveness of existing sizing systems and user satisfaction.

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