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# Somatotype Variations in a High-Altitude Environment: a Cross-Sectional Study among Young Himalayan Populations in Ladakh, India

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## Abstract

**Introduction:** Somatotyping is a globally used standard method that provides a quantitative morphological representation of an individual. This technique is widely used to understand human biological variation and to make meaningful comparisons of human physique across different ethnic groups, sexes, and age groups. **Methods:** A cross-sectional study was carried out among the native highlanders residing in Leh, Ladakh, India. All the required anthropometric measurements were taken by a trained anthropometrist. Somatotype assessment was performed by using Heath and Carter standard somatotype methods. **Results**: In this study the mean somatotype of the study population (both male and female) was 3.5-2.7-3.2. The present data disclosed statistically significant differences in endomorphy ($\chi^2$ = 15.43, p <0.001) and ectomorphy ($\chi^2$ = 7.94, p <0.05) but no significant difference in mesomorphy across different age group categories. Females had relatively higher endomorphy whereas mean ectomorphy was higher among male participants. Total 13 somatotype categories were recognized, the majority of the participants showed balanced ectomorph (13.30%) followed by ectomorphic endomorph (12.0%) and mesomorphic endomorph (12.0%). The presence of all somatotype categories indicates somatotype diversity in the study population. A large section showed low and moderate relative categories for all the three components. **Conclusion:** the present study highlights the diversity of somatotype components among high-altitude Ladakhi adolescents and young adults, that will help researchers to understand the somatotype patterns and human biological variation during adolescence and early adulthood at a high-altitude environment.

**Keywords:** Somatotype, Endomorphy, Mesomorphy, Ectomorphy, High-altitude.

## Resumen

**Introducción**: La somatotipia es un método estándar utilizado a nivel mundial que proporciona una representación morfológica cuantitativa de un individuo. Esta técnica se emplea ampliamente para comprender la variación biológica humana y realizar comparaciones significativas del físico humano entre diferentes grupos étnicos, sexos y grupos de edad. Métodos: Se llevó a cabo un estudio transversal entre habitantes nativos de zonas de gran altitud residentes en Leh, Ladakh (India). Todas las mediciones antropométricas requeridas fueron realizadas por un antropometrista capacitado. La evaluación del somatotipo se efectuó utilizando los métodos estándar de Heath y Carter. **Resultados:** En este estudio, el somatotipo promedio de la población analizada (tanto hombres como mujeres) fue 3,5-2,7-3,2. Los datos revelaron diferencias estadísticamente significativas en endomorfia ($\chi^2$ = 15,43; p < 0,001) y ectomorfia ($\chi^2$ = 7,94; p < 0,05), pero no en mesomorfia, entre las distintas categorías de edad. Las mujeres presentaron una endomorfia relativamente mayor, mientras que la ectomorfia promedio fue más alta entre los participantes masculinos. Se identificaron un total de 13 categorías de somatotipo; la mayoría de los participantes se clasificaron como ectomorfos equilibrados (13,30 %), seguidos por los endomorfos ectomórficos (12,0 %) y los endomorfos mesomórficos (12,0 %). La presencia de todas las categorías de somatotipo indica diversidad somatotípica en la población estudiada. Una gran parte de la muestra presentó categorías relativas bajas y moderadas para los tres componentes. **Conclusión:** El presente estudio destaca la diversidad de los

componentes del somatotipo entre adolescentes y adultos jóvenes de Ladakh residentes en zonas de gran altitud; esto ayudará a los investigadores a comprender los patrones de somatotipo y la variación biológica humana durante la adolescencia y el inicio de la edad adulta en entornos de gran altitud.

**Palabras Clave:** Somatotipo, Endomorfia, Mesomorfia, Ectomorfia, Gran altitud

## Introduction

Globally the Human body shows substantial variation in shape, size, and composition among different ethnic groups, reflecting the collective effect of heredity, environment, and lifestyle factors (B. Bogin 2020). Somatotyping is a standard method that provides a quantitative morphological portrayal of an individual. This technique is widely used to make meaningful comparisons of body build variation across different populations, sexes and age groups. William H. Sheldon first conceptualized somatotyping later this method of understanding body type was standardized by Heath and Carter using an anthropometric and statistical approach. The overall somatotype score of an individual is represented by three-digit combination of endomorphy-mesomorphy-ectoporphy (Adhikari & Dash, 2020), in which endomorphy represents relative predominance of adiposity, mesomorphy represents musculoskeletal robustness and ectomorphy reflects relative linearity or slenderness of an individual (Carter & Heath, 1990). These somatotype components are scored by values from 0.5 to 12+ (Carter & Heath, 1990). It is well documented that somatotype components vary throughout different growth periods of life, especially during adolescence when rapid changes happen in height and weight and sexual dimorphism occurs (Ji & Ohsawa, 1996). Many studies have reported sex-specific differences in somatotype, where females mostly show relatively higher endomorphy and males have a tendency to display higher ectomorphic and mesomorphic pattern (Gakhar & Malik, 2002; Subramanian et al., 2016). Along with sex and age-groups human body is also shaped by environmental and biocultural factors for instance altitude, nutrition and lifestyle (Das et al., 2021). Ladakh, is an integral part of India, located in the Indian Himalayan Region (IHR) which characterized by extreme environmental conditions such as hypoxia, extreme cold temperature with low humidity, excessive ultraviolet (UV) exposure, and relatively challenging daily life due to high altitude (Singh et al., 2013). Studies on Somatotype in this region is not widely explored due to its challenging topography. This current study aims to evaluate the different somatotype characteristics of Ladakhi adolescents and young adults using the Heath and Carter somatotype method. The findings will help to understand the somatotype pattern during adolescents and early adulthood and human biological variation.

## Materials & Methods

### Area & People

The present study followed a cross sectional design among the 75 native highlanders residing in Leh, Ladakh, India. Ladakh is one of India's union territories and an integral part of Indian Himalayan Region.

### Inclusion and Exclusion Criteria

In this present study, researchers included apparently healthy participants. Permanent residents of Ladakh who had completed all the anthropometric measurements for Heath & Carter somatotyping were included. Individuals who had any chronic disease or any serious physical issues were excluded from this study.

### Anthropometric Measurements

Anthropometric measurements, including height, weight, 5 skinfold thicknesses, circumference and girth measurements were measured following standard techniques formulated by the International Society for the Advancement of Kinanthropometry (ISAK) to assess the somatotype of each individual (ISAK, 2011). All the required measurements for somatotyping were taken on the same day by an ISAK-accredited anthropometrist for every individual to avoid any technical error. Before taking any measurements, a written informed consent was obtained from each participant and for minors, their parents or legal guardians provided a verbal consent. Technical Error of Measurements (TEM) was measured and that was determined to be within acceptable limits. All the measuring tools were calibrated at the time of field work by an anthropometrist before taking any measurements. Height (cm) was measured using a Martin's anthropometric rod at the nearest 0.1 cm. Weight (kg) was measured at nearest 0.1kg with minimum clothing using an Omron HBF 214 digital weighing machine. Five skinfold thickness measurements such as biceps, triceps, sub-scapula, suprailiac and medial calf were taken using a skinfold calliper at the nearest 0.1 mm. Two circumference measurements including calf circumference (CC) and mid-upper-arm circumference (MUAC-both relaxed and flexed) were measured with the help of a non-stretchable measuring tape (Seca 201) at the nearest 0.1 cm following standard protocol. Using a sliding caliper two girth measurements including biepicondylar breadth (cm) of the humerus and femur were also measured from each participant.

Somatotype assessment was done by following Heath and Carter standard somatotype method (Heath & Carter 1967; Carter & Heath, 1990; Carter 2002). Endomorphy, Mesomorphy, Ectomorphy, X and Y coordinates were calculated using following standard equations.

$$\text{Endomorphy} = -0.7182 + 0.1451 \times \sum SF - 0.00068 \times \sum SF^2 + 0.0000014 \times \sum SF^3$$

In this equation SF stands for sum of three skinfold measurements (Triceps, Sub-scapular, Supra-spinale) subsequently adjusted for height with phantom model (170.18/height in cm of the individual).

$$\text{Mesomorphy} = 0.858 \times H + 0.601 \times F + 0.188 \times A + 0.161 \times C - \text{Height} \times 0.131 + 4.5$$

Where H = Humerus breadth, F = Femur breadth, A = corrected arm girth [arm girth (cm) – triceps skinfold(mm)/10], C = corrected calf girth [calf girth (cm) – medial calf skinfold (mm)/10].

Ectomorphy = $0.732 \times HWR - 28.58$ (if $HWR \geq 40.75$), $0.463 \times HWR - 17.63$ (if $HWR < 40.75$ and $> 38.25$) and if $HWR \leq 38.25$ then Ectomorphy = 0.1

Here HWR = Height (cm)/Weight$^{1/3}$ (kg)

X coordinate = Ectomorphy - Endomorphy

Y coordinate = 2 × Mesomorphy – (Endomorphy + Ectomorphy)

## Statistical analysis

All the statistical assessment was executed using STATA version 16 software. Quantitative variables including somatotype components were presented using descriptive statistics where continuous variables were presented with mean, ȷstandard deviation (SD), minimum and maximum values. Kruskal-Wallis H test has been carried out to assess statistical differences across various age group categories.

## Results

**Table 1. Descriptive statistics of continuous variables of the study population**

| Variables | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|
| Age (Years) | 18.6 | 2.5 | 14.0 | 22.0 |
| Height (cm) | 162.3 | 9.4 | 146.9 | 192.5 |
| Weight (kg) | 53.6 | 9.0 | 39.6 | 77.7 |
| MUAC relaxed (cm) | 24.14 | 2.65 | 18.2 | 33.7 |
| MUAC flexed (cm) | 27.37 | 2.97 | 22.3 | 35.4 |
| Biceps skinfold (mm) | 5.9 | 3.9 | 2.0 | 23.0 |
| Triceps skinfold (mm) | 11.0 | 5.4 | 4.0 | 29.5 |
| Sub-scapular skinfold (mm) | 12.5 | 6.2 | 3.2 | 34.0 |
| Supra-spinale skinfold (mm) | 9.7 | 5.1 | 3.5 | 24.0 |
| Front-thigh skinfold (mm) | 16.05 | 9.5 | 5.5 | 55.0 |
| Medial calf skinfold (mm) | 9.31 | 6.09 | 3.0 | 32.0 |
| Femur breadth (cm) | 8.1 | 1.3 | 5.4 | 10.3 |
| Humerus breadth (cm) | 6.1 | 0.8 | 4.5 | 9.0 |
| Endomorphy | 3.5 | 1.6 | 1.2 | 7.8 |
| Mesomorphy | 2.7 | 1.4 | 0.2 | 7.3 |
| Ectomorphy | 3.2 | 1.5 | 0.1 | 8.0 |

Descriptive statistics of continuous variables have been presented (Table 1). The mean (±SD) age of the study population was 18.6 (±2.5) years with a range of 14 to 22 years. The mean (±SD) height and weight were

162.3 (±9.4) cm and 53.6 (±9.0) kg, respectively. Table 1 also showed the mean (±SD) of skin fold thicknesses of the study population. The overall mean (±SD) somatotype components observed for endomorphy, mesomorphy and ectomorphy were 3.5 (±1.6), 2.7 (±1.4) and 3.2 (±1.5) respectively. The study population showed an average somatotype of 3.5-2.7-3.2.

There was an increasing trend for endomorphy and mesomorphy with age. The Kruskal-Wallis H test was performed to observe statistically significant mean differences of somatotype components among three age groups (Table 2). This test highlighted a significant difference in endomorphy ($\chi^2 = 15.43$, $p<0.05$) and ectomorphy ($\chi^2 = 7.9$, $p<0.05$) but no significant difference in mesomorphy ($\chi^2 = 1.89$, $p>0.05$) in different age-group categories.

**Table 2.** Variation in somatotype components across different age groups (Kruskal-Wallis H test)

| Somatotype Components | Group I 14–16 (N=20) | Group II 17–19 (N=24) | Group III 20–22 (N=31) | $\chi^2$ | P value |
|---|---|---|---|---|---|
| Endomorphy | 21.65 | 42.96 | 44.71 | 15.43 | <0.001*** |
| Mesomorphy | 42.55 | 33.54 | 38.52 | 1.89 | 0.388$^{NS}$ |
| Ectomorphy | 49.75 | 34.17 | 33.39 | 7.94 | 0.019* |

Values represent mean ranks in this table. $\chi^2$ significance represented as ***(p<0.001); *(p<0.05); $^{NS}$ (Not significant).

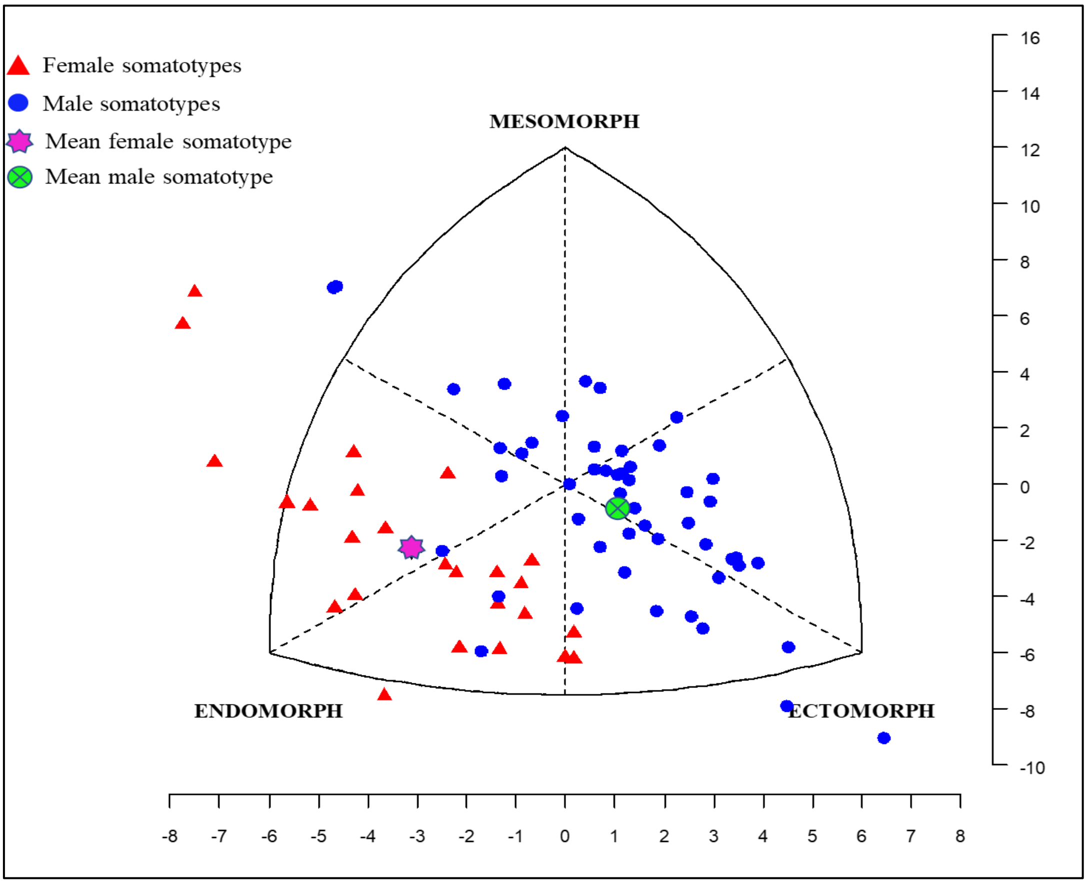


**Figure 1.** Sex specific somatotype of the study population plotted on somatochart separately.

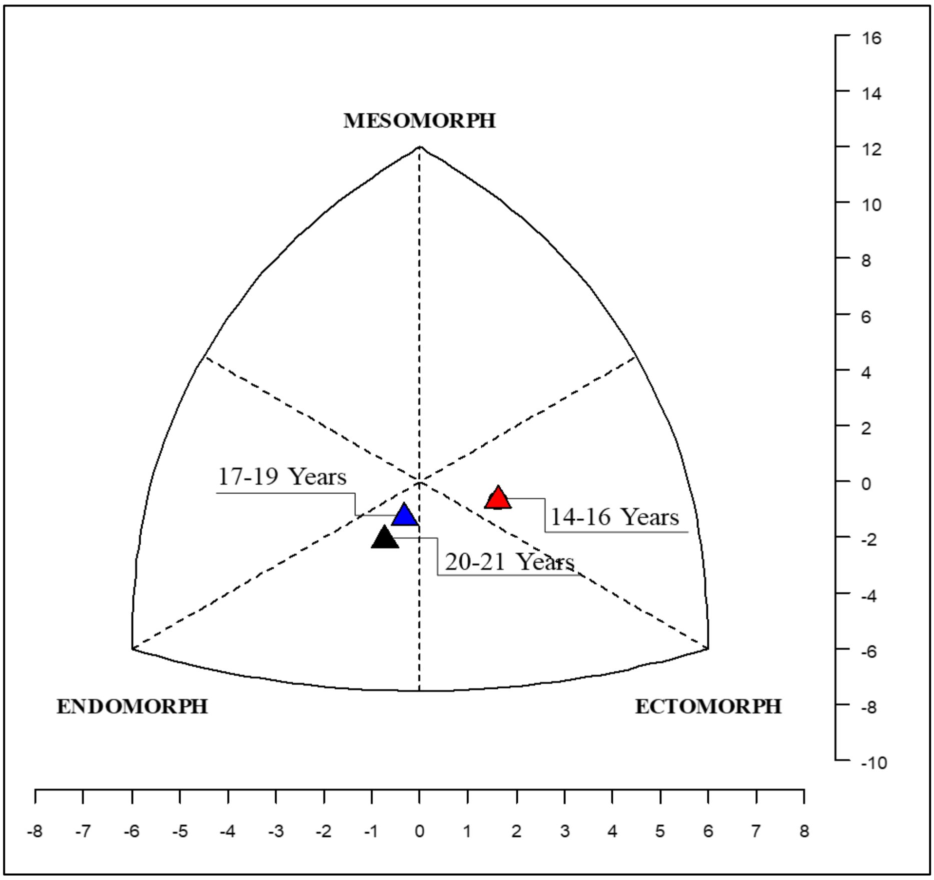


**Figure 2**. Somatochart representing mean somatotype of three age groups of the study population.

Along with the age group differences in somatotype, sex-specific differences are displayed in (Table 3), where the mean somatotype of boys was 2.63-2.75-3.70 categorized as balanced ectomorph and the mean somatotype of girls was 5.17-2.32-2.06 represented as a balanced endomorph somatotype.

**Table 3.** Sex-specific differences of somatotype in the studied population

| Somatotype categories | Sex | Mean ± SD | Min-Max | N |
|---|---|---|---|---|
| Endomorphy | F | 5.17 ± 1.26 | 3.55 - 7.84 | 25 |
| | M | 2.63 ± 1.04 | 1.24 - 5.27 | 50 |
| Mesomorphy | F | 2.32 ± 1.67 | 0.57 - 7.27 | 25 |
| | M | 2.75 ± 1.27 | 0.21 - 6.34 | 50 |
| Ectomorphy | F | 2.06 ± 1.19 | 0.10 - 4.05 | 25 |
| | M | 3.70 ± 1.40 | 0.20 - 7.97 | 50 |

In this study in Ladakh a total of 13 somatotype categories were recognized and presented in (Table 4). The most common somatotype category was balanced ectomorph (13.30%) followed by the ectomorphic endomorph (12.0%) and mesomorphic endomorph (12.0%). All the somatotype categories indicated the diversity of somatotype in the study population.

**Table 4.** Different somatotype categories in the studied population

| Si No | Somatotype categories | (%) |
|---|---|---|
| 1. | Balanced Ectomorph | 13.30 |
| 2. | Ectomorphic Endomorph | 12.00 |
| 3. | Mesomorphic Endomorph | 12.00 |
| 4. | Endomorphic Ectomorph | 10.67 |
| 5. | Mesomorphic Ectomorph | 8.00 |
| 6. | Ectomorph Mesomorph | 8.00 |
| 7. | Balanced Endomorph | 8.00 |
| 8. | Endomorphic Mesomorph | 5.33 |
| 9. | Mesomorph Endomorph | 5.33 |
| 10. | Central | 8.00 |
| 11. | Endomorph Ectomorph | 5.33 |
| 12. | Balanced Mesomorph | 2.67 |
| 13. | Ectomorphic Mesomorph | 1.33 |

Moderate relative category for all three components, mainly endomorphy (44.59%) and mesomorphy (49.33%) followed by ectomorphy (58.90%) were more common in this population. The low relative category was also common especially for mesomorphy (45.33%), along with this distribution, high relative and extreme high relative were also presented in (Table 5).

**Table 5.** Distribution of relative adiposity (endomorphy), relative musculo-skeletal robustness (mesomorphy) and relative linearity (ectomorphy) of the study population

| Relative levels | Endomorphy (%) | Mesomorphy (%) | Ectomorphy (%) |
|---|---|---|---|
| Low relative | 35.14 | 45.33 | 31.51 |
| Moderate relative | 44.59 | 49.33 | 58.90 |
| High relative | 16.22 | 4.00 | 8.22 |
| Extreme high relative | 4.05 | 1.33 | 1.37 |

## Discussion

The present study showed different somatotype components among adolescents and people in early adulthood residing in the high-altitude area of Ladakh, India. The study's overall results showed a relatively balanced somatotype profile with a small ectomorphy and endomorphy predominance over mesomorphy. Similar patterns have been seen in previous studies that non-athletic groups often tend to show moderate somatotype values rather than extreme categories (Carter & Heath, 1990). Similar results are consistent among the Indian population, where diverse environmental, lifestyle and nutritional conditions have led to mixed somatotype categories (Lohe et al., 2021; Drywień et al., 2016; Das et al., 2024) [Figure 3]. Statistically significant differences for endomorphy and ectomorphy across three age groups have been observed, whereas mesomorphy showed no significant difference.

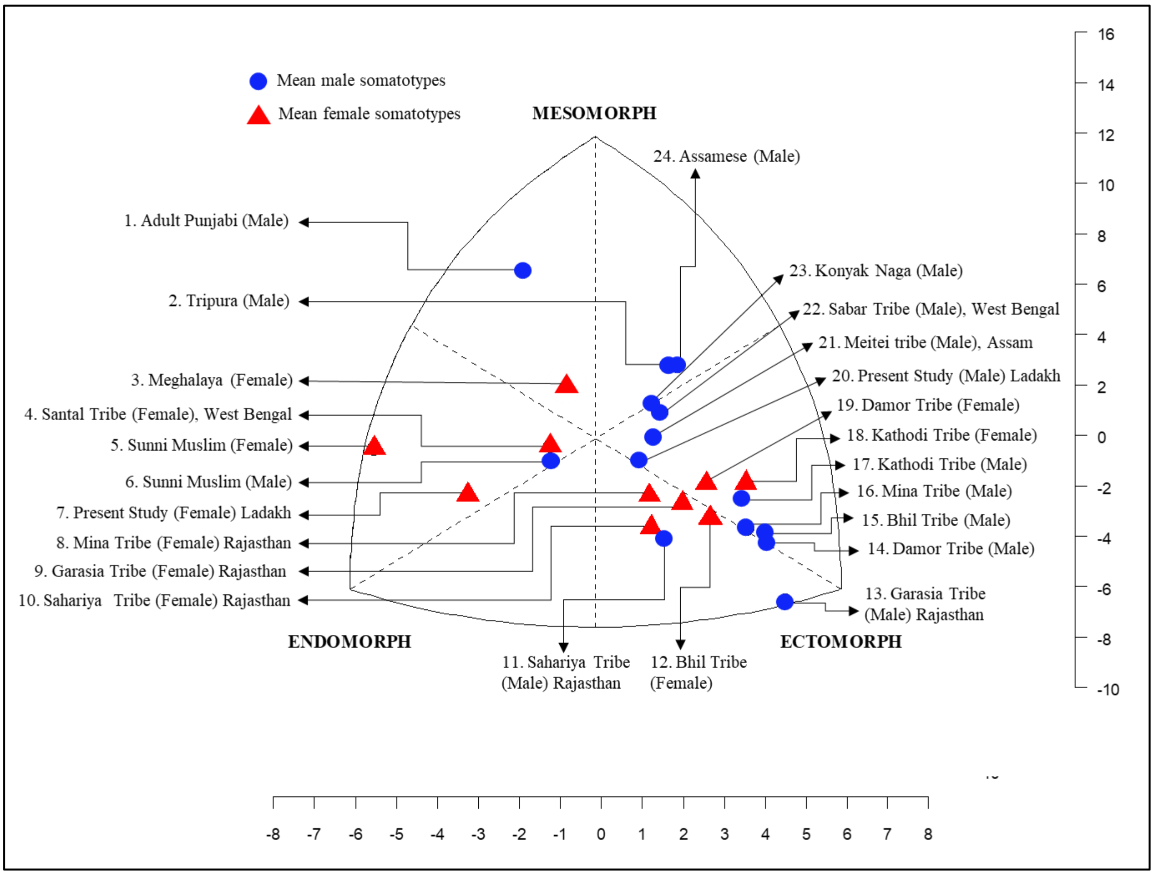


**Figure 3.** Comparison of somatotypes of the present study with other populations in India.

**Source**: For serial no. 1. (Thapliyal & Kumar, 2019), 2. (Sarkar & Sil, 2014), 3. (Dkhar, 2023), 4. (Adhikari & Ghosh, 2025), 5. & 6. (Shimrah et al., 2020), 7. & 20. Present study, 8.-19. (Bhasin & Jain, 2007), 21. (Singh, 2013), 22. (Das et al., 2021), 23. (Soni & Gautam, 2024), 24. (Lohe et al., 2021)

These patterns highlight how somatotype varies across different age groups, where endomorphy and ectomorphy components differ between younger and older participants [Figure 2]. Previous studies showed age related somatotype variation across different populations. (Yi et al., 2022; Gil et al., 2010). In a study of 400 Garhwali men somatotype assessment showed that the tendency to have endomorphic components were relatively higher among 30+ men than their younger counterparts (Gaur & Singh, 1997). Previous studies among Indian, Chinese, and Himalayan populations showed similar age category wise variation in endomorphy and ectomorphy using the Heath and Carter somatotype method (Bhasin & Jain, 2007; Singh et al., 2007). The mean somatotype of the present population was 3.5-2.7-3.2 indicating no significant dominance of any single somatotype component. Moreover, females showed relatively higher endomorphic components than their male counterparts and males showed relatively higher linearity or ectomorphic components. Previous research conducted in India has also revealed similar findings among school children aged 12-17 years in Pondicherry, with females having higher endomorphic components, while ectomorphic components were predominant among male participants (Subramanian et al. 2016; Peeters et al., 2003). Another study conducted in Himachal Pradesh demonstrated that Brahmin and Rajput boys were more ectomorphic and had less endomorphic components (Ghosh & Malik, 2004). Relatively higher endomorphy among female participants shows greater relative fat mass, which is consistently observed in many studies (Subramanian et al. 2016). This sex-specific variation of body composition among different sexes is considered a common biological adaptation associated with hormonal influence during adolescence, which effects fat and lean mass accumulation in the body (Loomba-albrecht & Styne, 2009). From an adaptive angle, Somatotype variations shaped by several biosocial and environmental factors including genetics, lifestyle, nutrition among different population (Norton & Olds, 2001; Carter & Heath, 1990). In the high-altitude region like Ladakh somatotype components may signify adaptive responses to environmental stress, energy availability, and habitual physical activity (Singh et al., 2007). The distribution of different somatotype categories in this study shows considerable variation in somatotype among this Ladakhi population. The prevalence of mixed categories in somatotype especially balanced ectomorph (13.30%), ectomorphic endomorph (12.0%), mesomorphic endomorph (12.0%) and endomorphic ectomorph (10.67%) suggests that most individuals have intermediate combinations of somatotype components. Considerable diversity has also been reported in a study among the Sabar tribe in West Bengal, India where 11 somatotype categories have been identified, with mesomorphic ectomorph emerging as the most prevalent category (34.7%) (Das et al., 2021). Distribution of relative adiposity, musculo-skeletal robustness and linearity showed less percentage of any extreme components, which is a common pattern amongst general population, whereas extreme categories are often linked with specific athletic groups (Martínez-Mireles et al., 2025; Gutnik et al., 2015). The results of this study as a whole support that somatotype is an age and population specific trait which help to understand human biological variation. This study provided knowledge on somatotype characteristics in high-altitude Indian populations in Ladakh, which will be a useful for future studies in this region.

## Conclusion

In conclusion, Age category wise somatotype variation was observed. Furthermore, total 13 somatotype categories were also identified. the combined effect of age, sex, and environmental context is reflected in the somatotype patterns seen among adolescents and young adults in Ladakh. The mixed somatotype categories reflect somatotype flexibility and adaptive variability than a fixed physique type.

## Strengths and limitations

The major strength of this study lies in its focus on a relatively less explored population from Ladakh in a high-altitude Himalayan setting, which will act as an important baseline study for future researches. The application of the standardized Heath & Carter anthropometric method for somatotyping enhanced its reliability. However, certain limitations should be acknowledged, the small sample size may affect the broader generalizability in these populations. The absence of information related to dietary patterns, physical activity levels, and socioeconomic conditions and the effect of these variables on somatotype was one of the main limitations of this study.

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## Author's contribution

The study concept and design were framed by SB and AB. AB, SN and DW did the field work and collected the data. SB, AB & KPM completed the data analysis part. AB prepared the first draft. SN, DW and KPM contributed to the writing and revision of the manuscript. All authors read and agreed the final manuscript.

## Data availability

The datasets which are used and/or analyzed during this study are available from the corresponding author upon practical request.

## Ethics statement

Before taking any measurements written (verbal for minors) informed consent was taken from all the research participants or their parents. They were informed about the study objectives and the procedures involved. The present study was approved by the Institutional Ethics Committee (IEC) of Sidho-Kanho-Birsha University, Purulia, West Bengal on 10$^{th}$ October 2024, (Memo No: R/IEC/1583/SKBU/24).

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## Conflicts of Interest

The authors declare no conflict of interest for this manuscript.

## Informed Consent Statement

All the  participants included in the study provided written informed consent.

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