

# Human Growth Curves

## Distance, Velocity, Acceleration and Scammon's Growth Curves

The study of human growth is meaningful only when it is grounded in a **clear understanding of what growth is** and how it can be **interpreted through growth curves**. Growth refers to the **increase in size and dimensions of the body** that occurs as an individual ages. This process also includes **structural differentiation** and **changes in bodily form**. Development or maturity, on the other hand, refers to an **increase in functional capacity**, such as improved physiological efficiency and coordination.

To study growth at both the **individual and population level**, anthropologists integrate data from multiple sources and use a wide range of methods. Growth is most commonly measured using **anthropometric techniques**, which focus on external body dimensions such as:

- Height
- Weight
- Body circumferences
- Subcutaneous fat thickness

The study of growth and maturation involves observing the **outcomes of these processes**, including:

- Size attained at a given age
- Level of body fatness
- Degree of biological maturity

- Progress toward adulthood

These measurements are typically summarised in tables and graphs known as **growth curves**.

## **Age as a Critical Variable in Growth Analysis**

Growth curves are usually presented according to **chronological age**. In constructing these curves, children are grouped into age categories. However, the method of age grouping is not always uniform.

In earlier studies, children labelled as “six years old” were often grouped between **5.50 and 6.49 years**. In more recent studies, age groups are defined as **6.00 to 6.99 years**, with an average age of 6.5 years. Although this difference may appear small, it has important implications.

Age must not be taken for granted. Even a difference of **half a year** can significantly affect comparisons. For example, a group aged 6.00–6.99 years will, on average, be **older, taller, and heavier** than a group aged 5.50–6.49 years. Therefore, the way children are grouped by age can strongly influence growth comparisons and interpretations.

## **Concept of Growth Curves**

The amount of growth achieved by an individual depends on two factors:

1. **The duration of growth**
2. **The speed of growth per unit time**

When measurements taken at regular intervals on a single individual are plotted against age, they produce a **graph of growth progress**. This graph may represent the whole body or any of its components.

## **Distance Curve**

A graph that plots **size attained** (such as height or weight) against age is called a **distance curve**. Each point on the curve shows how far an individual has progressed along the path to maturity. As growth nears completion, the curve gradually **flattens into a plateau**, indicating the end of growth.

## Velocity Curve

A velocity curve shows the **rate of growth over time**. As growth slows and eventually stops, the velocity curve approaches **zero**. Velocity curves are particularly valuable because they reveal **changes in growth rate**, including periods of acceleration and deceleration.

## General and Differential Growth Patterns

Most skeletal and muscular dimensions follow the **general growth curve**, which closely resembles the growth pattern of height and weight. Some tissues and organs show **distinct growth patterns** that differ markedly from the general curve. These include:

- The **brain and skull**
- The **reproductive organs**
- The **lymphoid tissues**
- The **subcutaneous fat**

The systematic explanation of these different patterns was first provided by **Scammon**, and these patterns are collectively known as **Scammon's growth curves**.

## Historical Origin of Human Growth Curves

The scientific study of human growth curves began during the **Age of Enlightenment in eighteenth-century France**, a period marked by a strong commitment to empirical observation and measurement of the natural world.

This early work was shaped by the friendship between **Philibert Gueneau de Montbeillard** and **Comte de Buffon**, both of whom shared a deep interest in natural sciences. Their goal was to understand nature **as it truly was**, based on careful observation rather than speculation.

As part of this effort, **De Montbeillard systematically measured the growth of his son** at regular intervals. Beginning at birth in **1759**, he recorded his son's height **every six months** until the age of **18 years**, completing the record in **1777**. This produced one of the earliest and most detailed longitudinal records of human growth.

The measurements were originally recorded in the French units of the time—**pieds, pouces, and lignes**, roughly corresponding to the modern units of **feet, inches, and fractions of an inch**. These data were later converted into centimetres by the American anatomist **Richard E. Scammon**.

Scammon published this converted dataset in **1927** in the *American Journal of Physical Anthropology* under the title “**The First Seriatim Study of Human Growth.**” This publication marked a major milestone in the scientific analysis of human growth patterns. Building on this work, Scammon published further studies in **1930** on the **measurement of the body in childhood**, which laid the foundation for systematic discussion of **postnatal growth curves**.

This discovery established that human growth follows a **regular and predictable pattern**, forming the conceptual basis for the modern understanding of **distance and velocity curves** and later the formulation of **Scammon's growth curves**.

## **Distance Curve**

Human growth can be understood most directly by asking a simple question: **how much growth has been achieved at a given age?** A **distance curve** provides the answer to this question.

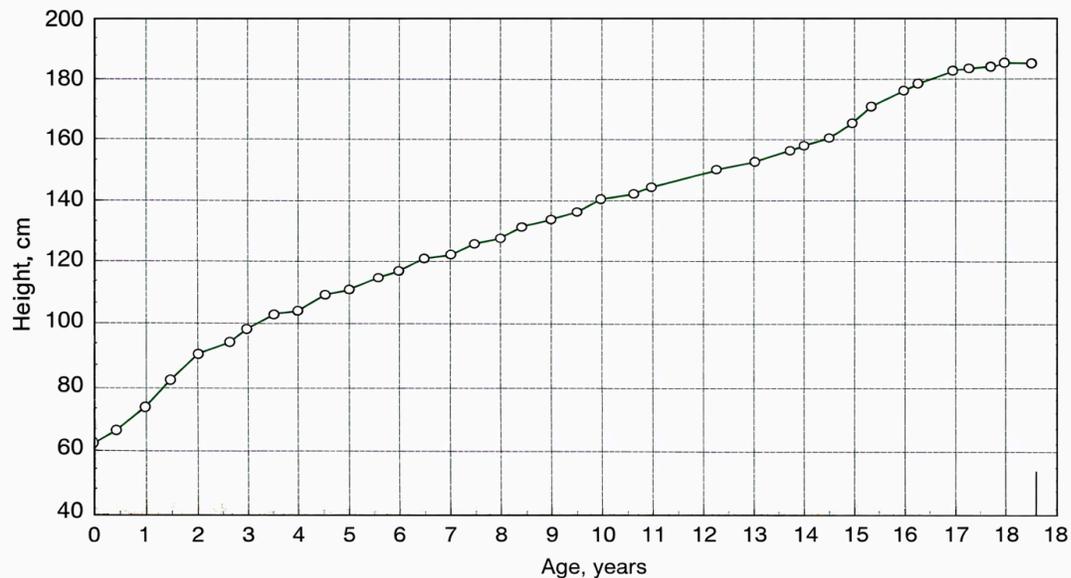


Fig. 3.1: The growth of De Montbeillard's son 1759–1777; Distance curve

Source: Tanner, J.M. 1962. Growth of Adolescence. 2<sup>nd</sup> ed. Oxford; Blackwell Science Publications.

A **distance curve** is a graph in which a body dimension—most commonly **height**, but also weight, limb length, or organ size—is plotted against **chronological age**. Each point on the curve represents the **size attained** at a specific age. The term *distance* is used because the curve reflects the **distance travelled toward adult size and maturity**. As growth approaches completion, the curve gradually **flattens into a plateau**, indicating the cessation of growth.

Distance curves therefore represent **growth as attainment**, not speed.

## **Classic Case Study: De Montbeillard's Son (1759–1777)**

***Title: The First Longitudinal Distance Curve of Human Growth***

The earliest and most influential distance curve in the history of growth studies comes from **De Montbeillard's son**, measured in eighteenth-century France during the Enlightenment period.

## Method

- Height measured **every six months**
- From **birth in 1759 to 18 years of age in 1777**
- Measurements later converted into **centimetres**
- Data plotted as a **height-for-age distance curve**

## Key Outcomes and Findings

1. **Smooth and continuous growth** Regular six-monthly measurements produced a **smooth curve**, without long periods of no growth followed by sudden jumps.
2. **Growth is not linear** Height did not increase by the same amount each year. The rate of growth changed with age.
3. **Four clearly visible growth phases**
  - **Infancy:** very rapid growth
  - **Childhood:** steady and almost linear growth
  - **Adolescence:** sharp acceleration due to pubertal growth spurt
  - **Late adolescence:** slowing and eventual plateau
4. **Magnitude of human growth**
  - Approximate height at birth: **~60 cm**
  - Height at adulthood: **over 180 cm**
  - Most absolute growth occurred in **infancy and childhood**
  - Most visible body transformation occurred during **adolescence**

## 5. Cessation of growth

- Height growth ended around **18–19 years**

This case established that **human growth follows a regular and predictable pattern**. Individuals may differ in:

- Final adult height
- Timing of pubert
- Growth velocity

But the **overall shape of the distance curve remains consistent** under normal environmental conditions. This insight laid the foundation for all later growth curve analysis.

## General Characteristics of the Distance Curve

1. **Growth is continuous but uneven** Growth proceeds continuously but at **changing rates**.
2. **Growth is non-linear** Annual increments vary across life stages.
3. **Four universal phases of growth**
  - Infancy
  - Childhood
  - Adolescence
  - Maturity
4. **Large overall change** Human stature more than **triples** from birth to adulthood.
5. **Predictable endpoint** Adult height is usually reached by the **late teenage years**.

## Shape of the Distance Curve Across Life Stages

When distance curves are constructed from **six-monthly longitudinal data**, they show characteristic shapes:

- **Birth to ~5 years:** Smooth curve with gradually declining slope (rapid early growth slowing over time)
- **~5 to 10 years:** Nearly straight, indicating steady growth
- **~10 to 18 years:** **S-shaped (sigmoid)** curve due to pubertal growth spurt

This variation in shape reflects underlying **hormonal, metabolic, and developmental processes**.

## Velocity Curve

While a distance curve shows **how much growth has been achieved**, a **velocity curve** shows **how fast growth is occurring** at different ages.

A **velocity curve** is constructed by plotting the **increments of growth**—for example, centimetres gained per year—against **chronological age**. It therefore represents the **rate of growth over time**. As growth slows and finally stops, the velocity curve gradually approaches **zero**.

The changing pattern of growth rates is best understood as the **rate of change of body size with time**, commonly termed **growth velocity**, and more specifically **height velocity** when linear growth is measured. This terminology was formalised by **J. M. Tanner**, drawing on the theoretical insights of **D’Arcy Wentworth Thompson (1860–1948)**.

In his influential biological work ***Growth and Form***, Thompson clearly distinguished between growth as size and growth as movement. He observed that while the **distance curve** represents a “continuous succession of varying magnitudes,” the curve depicting the **rate of change of height with time**

reveals a “succession of varying velocities.” This conceptual distinction forms the intellectual foundation of velocity curve analysis in human growth studies.

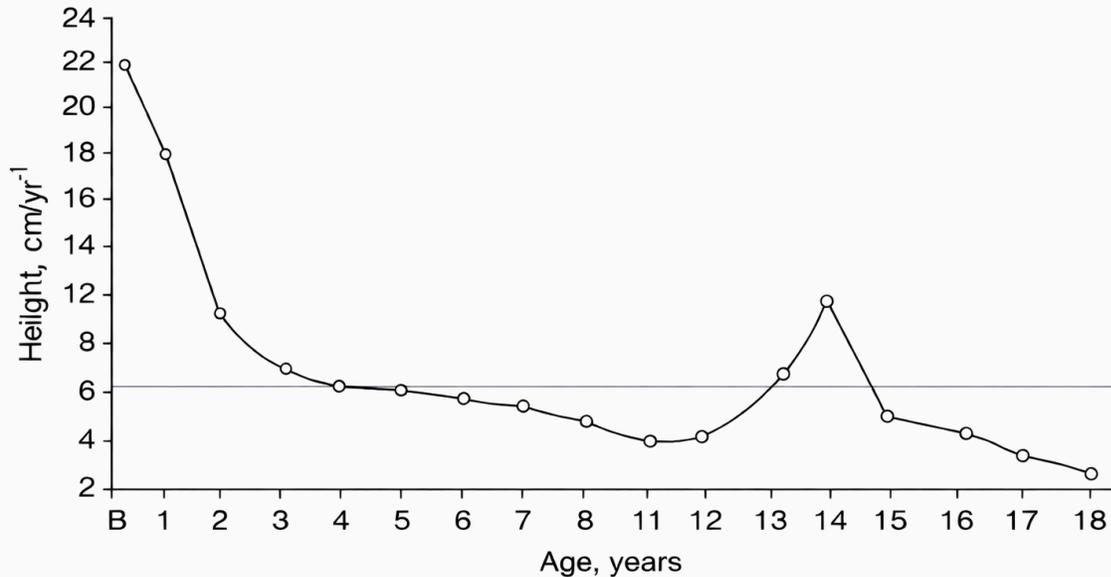


Fig. 3.2: The growth of De Montbeillard’s son 1759–1777; Velocity curve

Source: Tanner, J.M. 1962. *Growth of Adolescence*. 2<sup>nd</sup> ed. Oxford; Blackwell Publications.

## Conceptual Significance of the Velocity Curve

- Distance curve → shows **attainment**
- Velocity curve → shows **tempo and timing**

## Case Study: De Montbeillard’s Son (1759–1777)

*Title: The First Empirical Velocity Curve of Human Growth*

### Method and Data Structure

- Height measured **every six months** from birth to **18 years**
- Growth increments calculated in **cm per year**
- Velocity plotted against chronological age

## Key Outcomes and Quantitative Patterns

### 1. Overall Trend

- Very high velocity at birth
- Gradual decline in growth rate through childhood
- Near-zero velocity at adulthood

### 2. Identification of Three Growth spurts

- **Prenatal spurt**
  - Peak foetal length velocity at approximately **4 months of gestation**
  - Foetal weight velocity peaks at **30–40 weeks**
- **Juvenile (mid-growth) spurt**
  - Occurs between **6–8 years**
  - Moderate but distinct rise in height velocity
- **Adolescent growth spurt**
  - Occurs between **11–18 years**
  - Most dramatic postnatal increase in growth rate

### 3. Biological Meaning

- Growth is not smooth or linear
- Spurts represent **biologically programmed accelerations**
- Growth rate is highest when biological demands are greatest

## Case Study: Harpenden Growth Study (United Kingdom)

*Title: Velocity Curves and the Biology of Puberty*

## Method

- Longitudinal study of British children
- Repeated height measurements from childhood to adulthood
- Calculation of annual and semi-annual height velocity

## Key Quantitative Findings

### 1. Peak Height Velocity (PHV)

- Girls: approximately **8–9 cm/year** at around **12 years**
- Boys: approximately **9–10 cm/year** at around **14 years**

### 2. Timing Differences

- Girls enter the adolescent growth spurt **about two years earlier**
- Boys show a **higher peak velocity** and **longer duration of growth**

### 3. Individual Variation

- Age at PHV varied by **±2 years** among healthy children
- Final adult height was less variable than growth tempo

## Interpretative Insights

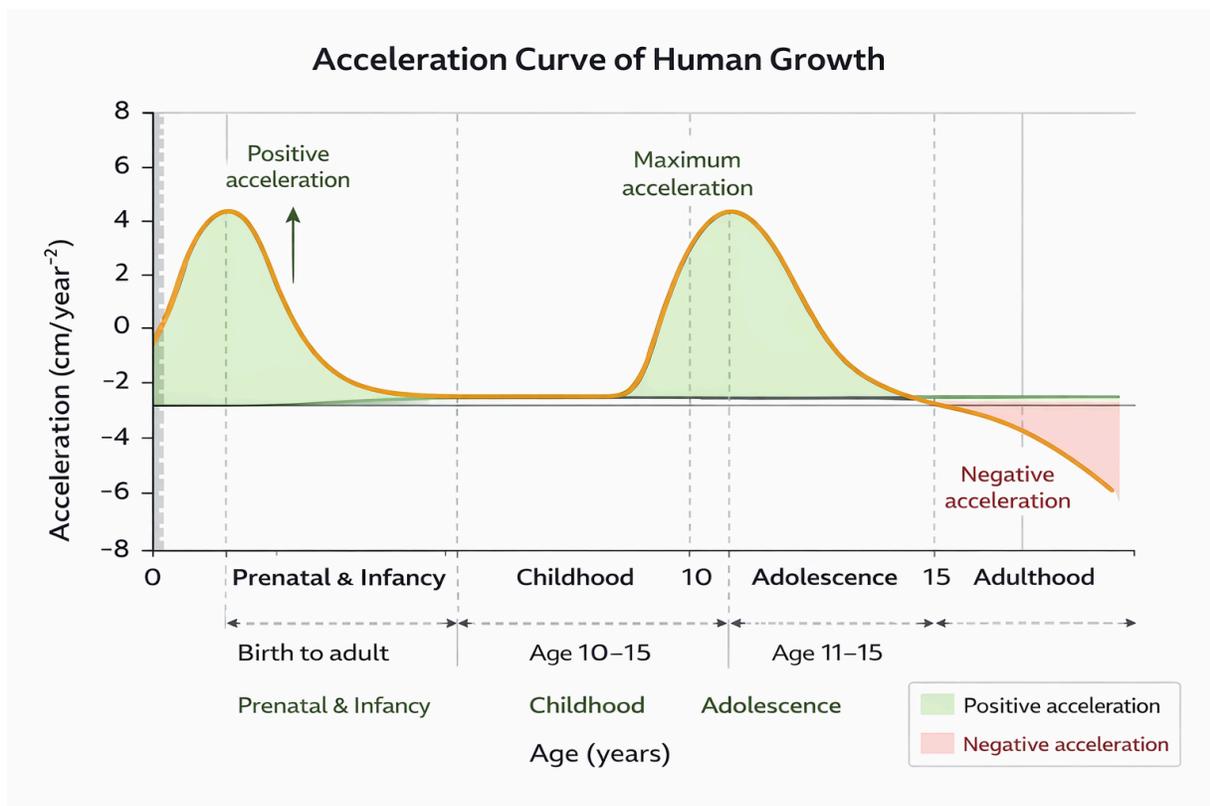
- Puberty is best understood as a **process**, not a single event
- Velocity curves distinguish:
  - Early maturers
  - Average maturers
  - Late maturers
- Growth timing is **biologically regulated but environmentally influenced**

## Acceleration Curve

While distance curves show **how much growth has been achieved** and velocity curves show **how fast growth is occurring**, **acceleration** explains **how the speed of growth itself changes over time**. In simple terms, acceleration refers to the **increase or decrease in growth velocity with age**.

Acceleration is therefore the **change in growth rate**, and it plays a crucial role in identifying:

- **The onset of growth spurts** (when growth suddenly speeds up)
- **The peak of rapid growth** (when growth rate reaches its maximum)
- **The decline toward growth cessation** (when growth rate slows down and stops)



## 4. Mathematical formulation

Let:

- **d(t)** = Distance curve (e.g., height in cm at age  $t$ )
- **v(t)** = Velocity curve
- **a(t)** = Acceleration curve

### **Distance**

$$d = \text{height}/t$$

### **Velocity (first derivative of distance)**

$$v = d/t$$

→ cm/year

### **Acceleration (second derivative of distance)**

$$a = \Delta v/\Delta t$$

→ change in cm/year/year

### **Acceleration Curve Trajectory**

#### **Prenatal & Infancy**

- **Positive acceleration early** (velocity increasing)
- Then **negative acceleration** as infancy growth slows

#### **Childhood**

- Near-zero acceleration (stable velocity)

#### **Adolescence**

- **Strong positive acceleration** → onset of pubertal spurt
- **Zero acceleration at PHV** (velocity highest, but no longer increasing)
- **Negative acceleration after PHV** → deceleration toward growth cessation

## Adulthood

- Acceleration → zero (no growth)

## Biological Meaning of Acceleration

Positive acceleration indicates that growth velocity is **increasing**, as seen at the **beginning of infancy or puberty**.

Zero acceleration indicates **maximum velocity**, such as at **peak height velocity (PHV)**. Negative acceleration indicates **deceleration**, marking the **end of a growth spurt** and the approach toward adult size.

Thus, acceleration helps anthropologists identify **critical transition points** in growth that may not be clearly visible on distance curves alone.

## Study: De Montbeillard–Scammon Longitudinal Analysis

*Title: Acceleration Patterns in the First Serial Study of Human Growth*

### Design

- Longitudinal height data measured **every six months**
- From birth to **18 years**
- Growth velocity calculated year-by-year
- Acceleration inferred from changes in velocity between successive ages

### Key Outcomes (Data-Based)

- **Strong positive acceleration** observed in:
  - Early infancy (first 1–2 years)
  - Onset of adolescence (~11–13 years)
- **Peak height velocity (PHV)** occurred around:

- **13–14 years**
- **Zero acceleration** at PHV indicated the transition from increasing to decreasing growth rate
- **Negative acceleration** after ~15–16 years marked rapid slowing of growth
- Growth velocity approached **0 cm/year by 18–19 years**, indicating growth cessation

### **Significance**

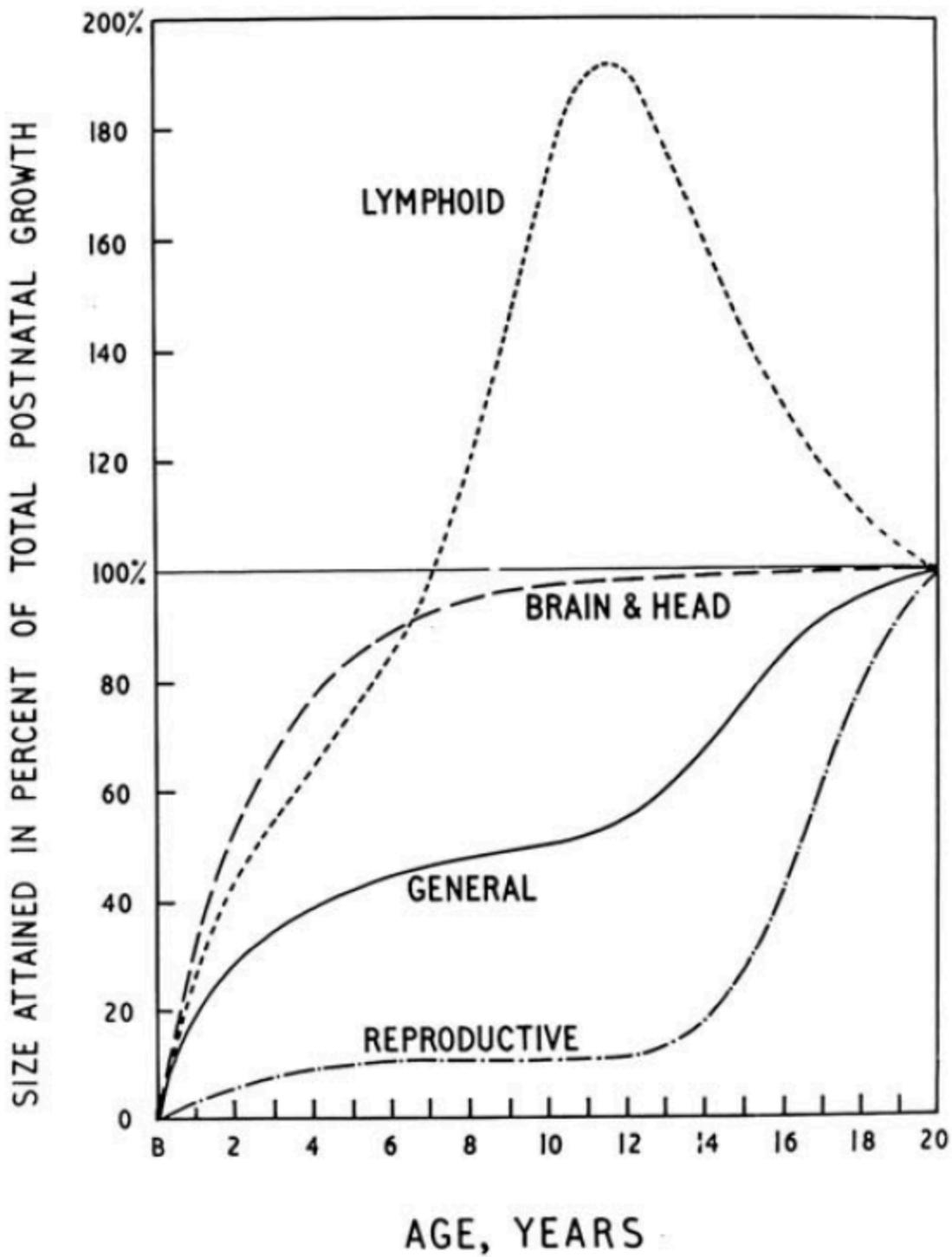
This analysis demonstrated that **growth spurts are not sudden events**, but the result of **gradual acceleration followed by deceleration**. It showed that acceleration is essential for identifying **the beginning and end of pubertal growth**, not just its peak.

### **Why Acceleration Matters More Than Distance Alone**

- A child may appear short on a distance curve but show **positive acceleration**, indicating recovery.
- Another child may appear average in height but show **negative acceleration**, signaling growth failure.
- Therefore, acceleration provides **early warning signals** of growth disruption.

### **Scammon's Growth Curves: Differential Growth of Tissues**

Not all parts of the body grow in the same way or at the same time. Based on analysis of tissue and organ weights, **Scammon** proposed that postnatal growth follows **four distinct patterns**, expressed as a percentage of total growth achieved between birth and 20 years.



**General (Body) Growth Curve**

The **general growth curve**, also called the **body growth curve**, describes the growth pattern of the **human body as a whole**. It represents changes in **stature, body weight, muscle mass, and most external body dimensions** over time.

This curve is characteristic of **most organ systems**, including:

- **Skeletal system** (except parts of the skull and upper face)
- **Muscular system**
- **Respiratory system**
- **Cardiovascular system** (heart and blood vessels)
- **Digestive system**
- **Urinary system**

Because these systems grow in a broadly similar way, their growth can be represented by a **single, generalized curve**.

## **Shape and Phases of the General Growth Curve**

The general growth curve follows a **sigmoid or S-shaped pattern**, reflecting changes in growth speed at different life stages. It can be divided into **four distinct phases**:

1. **Rapid Growth in Infancy and Early Childhood** Growth velocity is very high immediately after birth. Body size increases quickly as organs and tissues expand to support survival outside the womb.
2. **Steady Growth during Middle Childhood** From early childhood to the pre-pubertal years, growth continues at a **slow but constant rate**. Increases in height and weight are regular and predictable.
3. **Rapid Growth during Adolescence** The **adolescent growth spurt** marks a second phase of rapid growth. Height and weight increase sharply

due to hormonal changes, especially the action of growth hormone and sex steroids.

4. **Slow Growth and Cessation after Adolescence** After puberty, growth rate declines. **Linear growth stops** once epiphyseal fusion occurs, although slight increases in body mass and muscle may continue into the **early third decade of life**.

## **Case Study: Scammon's Systematic Growth Analysis**

**Title: General Growth Pattern in Human Postnatal Development**

### **Key Findings (Standard Data Outcomes)**

- Height increases from approximately **50–60 cm at birth** to an average adult stature of **160–180 cm**
- Growth velocity is highest in:
  - **Infancy**
  - **Adolescence**
- During middle childhood, height increases at an average rate of **5–6 cm per year**
- Peak height velocity during adolescence occurs:
  - Around **11–12 years in females**
  - Around **13–14 years in males**
- Growth in height usually **ceases by 18–19 years**, though body mass may increase slightly into the twenties

## **Neural Growth Curve**

The **neural growth curve** describes the growth pattern of the **brain, nervous system, and closely related structures**. These include the **eyes, upper**

**part of the face, cranial vault, and parts of the skull** that protect and support the brain.

Unlike the general body curve, neural tissues grow **very rapidly in early life** and reach maturity much earlier.

## **Pattern of Neural Growth**

Neural growth is characterized by **early rapid expansion**, followed by a long period of minimal change.

### **Key Features**

- Neural tissues show **maximum growth during infancy and early childhood**
- About **95% of total neural growth** (from birth to adulthood) is completed by around **7 years of age**
- After 7 years, growth continues at a **very slow rate**
- A **small adolescent spurt** occurs, mainly due to:
  - Thickening of skull bones
  - Development of air sinuses
  - Scalp and cranial tissue growth

This means that the increase during adolescence is **structural**, not due to major brain enlargement.

## **Growth of Head and Face**

- The **head as a whole** is much closer to adult size at birth compared to the rest of the body
- The **upper part of the skull** (brain case and eyes) matures earlier

- The **face grows more slowly** and follows a pattern **between the neural curve and the general body curve**
- Within the face:
  - The **mandible (lower jaw)** shows the **largest adolescent growth spurt**
  - This contributes to visible changes in facial shape during adolescence

Thus, the **upper face and brain mature early**, while the **lower face continues to grow longer**.

## **Case Study: Scammon's Neural Growth Analysis**

**Title: Neural Growth Pattern in Human Postnatal Development**

### **Key Data Outcomes**

- Brain weight at birth: **~350–400 g**
- Brain weight at 7 years: **~90–95% of adult size**
- Adult brain weight: **~1,300–1,400 g**
- Minimal increase in brain size after childhood
- Adolescent changes mainly involve **cranial thickening**, not brain volume increase

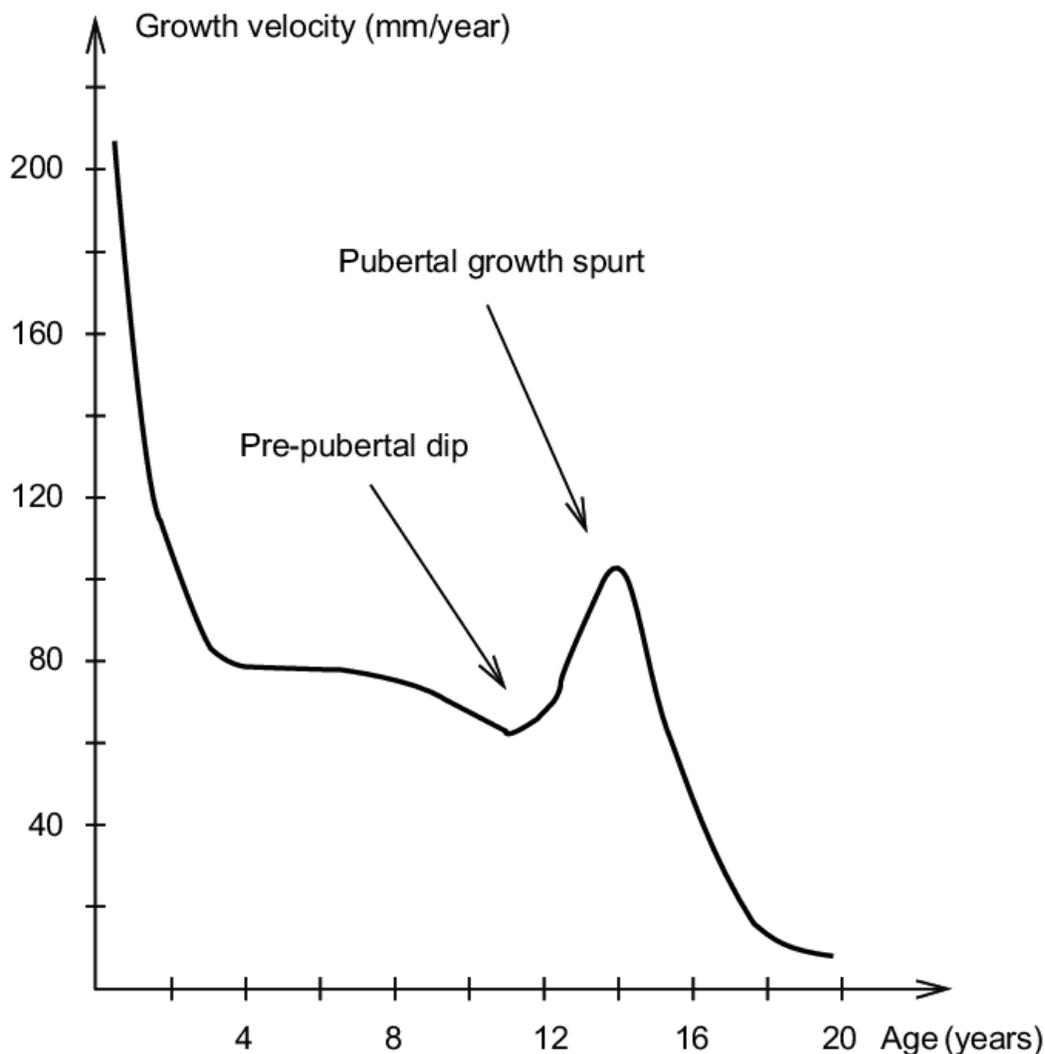
### **Significance**

This study demonstrated that **neural growth follows a unique curve**, distinctly different from general body growth. It explained why **early childhood is a critical period for brain development**, learning, and cognitive foundation.

## **Genital Growth Curve**

Among the various patterns of human growth, the **genital growth curve** is the most distinctive because it reflects the body's preparation for **reproductive adulthood** rather than early survival or learning. This curve describes the growth of the **reproductive organs** and the development of **sex-specific physical traits**, both of which remain largely inactive for many years and then change rapidly within a short span of life.

Unlike the general or neural growth curves, the genital curve shows **minimal growth in childhood** and **intense growth during adolescence**, underscoring the biological logic that reproduction is postponed until the body is sufficiently mature.



## Primary Sexual Characteristics

**Primary sexual characteristics** refer to the organs that are **directly involved in reproduction**. These structures are already present at birth, but they are **small, immature, and functionally inactive** throughout childhood.

- **In females**, the primary sexual organs include the **ovaries, fallopian tubes, uterus, and vagina**. The ovaries contain immature eggs from birth, but ovulation does not begin until puberty. The uterus and associated structures also remain underdeveloped during childhood.
- **In males**, the primary sexual organs include the **testes, seminal vesicles, prostate gland, and penis**. Although the testes are formed early, sperm production does not begin until adolescence, and accessory glands remain functionally dormant.

The genital growth curve shows that these organs experience only **slight enlargement in infancy**, followed by a **long latent phase** during childhood.

## Secondary Sexual Characteristics

**Secondary sexual characteristics** are physical traits that distinguish males and females but are **not directly involved in reproduction**. Their role is largely related to **sexual identification, attraction, and social signaling**.

- **In females**, secondary sexual characteristics include **breast development** and changes in body fat distribution.
- **In both sexes, pubic hair and axillary (underarm) hair** appear during puberty.
- **In males**, additional secondary traits include **facial hair**, increased muscle mass, and **growth of the larynx**.

The growth of the **larynx** in males causes the vocal cords to lengthen, leading to **voice deepening**, one of the most recognizable signs of male adolescence.

These features appear **suddenly and rapidly**, in sharp contrast to their near absence during childhood.

## The Latent Phase of Childhood

A defining feature of the genital growth curve is the **long latent period** that extends from early childhood to the onset of puberty. During this phase:

- Reproductive organs remain small
- Sex hormones are present at very low levels
- No visible sexual differentiation progresses

From an anthropological perspective, this latent phase allows the body to **allocate energy toward growth, brain development, immune function, and learning**, rather than reproduction.

## Adolescent Growth Spurt and the HPG Axis

The dramatic changes of the genital growth curve occur during **adolescence**, driven by the activation of the **hypothalamic–pituitary–gonadal (HPG) axis**.

The **HPG axis** is a hormonal communication system linking the brain to the reproductive organs:

- The **hypothalamus** begins releasing **gonadotropin-releasing hormone (GnRH)** in a rhythmic pattern.
- GnRH stimulates the **pituitary gland**, which releases **luteinizing hormone (LH)** and **follicle-stimulating hormone (FSH)**.
- These hormones act on the **gonads**:
  - The **testes** produce **testosterone**
  - The **ovaries** produce **estrogen and progesterone**

This hormonal cascade triggers:

- Rapid growth of primary reproductive organs
- Development of secondary sexual characteristics
- Onset of reproductive capability

The genital tissues that remained almost unchanged for years now grow **rapidly and intensively**, producing the characteristic **adolescent genital growth spurt**.

## **Case Study: Scammon's Analysis of Genital Growth**

### *Growth Pattern of Human Reproductive Tissues*

Scammon's systematic analysis of tissue growth demonstrated that:

- Genital tissues remain at **less than 10% of adult size** throughout most of childhood
- Rapid growth occurs:
  - Around **11–13 years in females**
  - Around **13–15 years in males**
- Males experience a **later but stronger growth spurt**, contributing to larger adult reproductive structures
- Completion of genital growth closely coincides with **sexual maturity**

This study clearly established that genital growth follows a **unique and delayed trajectory**, distinct from neural and general body growth.

## **Lymphoid Growth Curve**

The **lymphoid growth curve** represents the growth pattern of the body's **immune-related tissues**, which play a central role in protecting the child from infections and disease. Unlike most other tissues, lymphoid organs show **early**

**overgrowth followed by regression**, making this curve biologically unique. This curve reflects the idea that **immune defense is most critical during childhood**, a period when exposure to pathogens is high and immune memory is being built.

## What Are Lymphoid Tissues?

**Lymphoid tissues** are specialized structures involved in the production, maturation, and activation of immune cells, especially **lymphocytes**.

Major lymphoid tissues include:

- **Lymph glands (lymph nodes)**
- **Thymus gland**
- **Tonsils and adenoids**
- **Appendix**
- **Lymphoid patches in the intestine** (such as Peyer's patches)

Together, these tissues form the **immune infrastructure** of the growing child.

## Functional Meaning of Lymphoid Growth

The primary role of lymphoid tissues is to:

- Develop **immunological competence**
- Build **resistance to infectious diseases**
- Create **immune memory** through repeated exposure to pathogens

In early life, when children are frequently exposed to new infections, the immune system must expand rapidly. This functional demand explains the distinctive shape of the lymphoid growth curve.

## Pattern of the Lymphoid Growth Curve

The lymphoid curve follows a **three-phase pattern** that differs sharply from the general body curve.

### 1. Rapid Growth in Infancy and Childhood

- Lymphoid tissues expand quickly after birth
- The thymus, tonsils, and lymph nodes enlarge rapidly
- This supports the rapid production and training of immune cells

### 2. Peak Growth in Late Childhood

- Lymphoid tissues reach their **maximum size between 11 and 13 years of age**
- At this peak, children possess **approximately twice the amount of lymphoid tissue found in adults**
- This represents the period of **maximum immune responsiveness**

### 3. Decline During Adolescence

- During the second decade of life, lymphoid tissue size begins to decline
- This reduction is mainly due to:
  - **Involution (shrinking) of the thymus**
  - Reduction in the size of tonsils and adenoids

Despite this decline, immune function remains strong because the immune system has already developed extensive **memory and efficiency**.

## Hormonal and Developmental Basis of Lymphoid Decline

The decline in lymphoid tissue during adolescence coincides with:

- Rising levels of **sex hormones**

- Shifts in energy allocation toward **reproductive maturation**

The thymus, which is crucial for training immune cells in early life, becomes less active once immune competence is established.

## **Case Study: Scammon's Lymphoid Growth Analysis**

### *Growth Pattern of Human Lymphoid Tissues*

#### **Key Data Outcomes**

- Lymphoid tissues grow rapidly after birth
- Peak size reached at **11–13 years**
- Lymphoid tissue mass at peak is approximately **200% of adult levels**
- Gradual decline begins during adolescence due to thymic involution
- Adult immune function remains effective despite reduced tissue size

This study demonstrated that **maximum immune tissue size is required only during childhood**, when exposure to pathogens is greatest. It established the lymphoid curve as fundamentally different from neural, genital, and general growth curves.