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Human Growth in Japanese Children: An Application of Triphasic Generalized Logistic Model

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Abstract

The longitudinal growth of stature for 509 boys and 311 girls from early childhood to adulthood was studied. A triphasic generalized logistic model (BTT model) was used through the software AUXAL for characterizing individual growth of stature. The default values of the population mean values and covariance matrix in AUXAL were substituted by estimated population mean values and covariance matrix values for the Japanese population. Biological variables are extracted from the fitted model and compared with those of other population of the world. Significant inter-correlations among the biological variables are also addressed. The following main results are found. 1) Comparing with other populations, Japanese boys and girls were characterized by earlier age at peak height velocity and shorter stature with medium peak height velocity. 2) The parameters in the BTT model decomposed that, on average, 47.8%, 38.7%, and 13.5% of the adult stature were completed during the early, middle and adolescent growth phases, respectively, for the Japanese boys. For the girls, these percentages were 44.0%, 42.9%, and 13.1%, respectively. 3) The distributions of average predicted statures from age 1 to 25 years with their respective velocities are estimated. The average predicted adult stature of Japanese boys is 172.59 cm and that of girls is 159.68 cm for Japanese population.

Key words: BTT model, growth, height, adolescence, growth spurt.

1 Introduction

Fitting curves to individual serial stature records permits the extraction of a maximum amount of information about the growth of the child, and of course, these curves can be compared and contrasted among individuals. Also, when parameters of fitted growth curves are available for a large number of children, the mean values and variances of these parameters are a convenient way to summarize a large amount of data for comparison of growth patterns between sexes or among populations (Thissen et al., 1976). Therefore, fitting curves provide a convenient means of characterizing individual or group differences in the pattern of growth.

Various growth models are reported (Count, 1943; Bock et al., 1973; Preece and Baines, 1978; Karlberg, 1987; Berkey and Reed, 1987; Jolicoeur et al., 1988; Jolicoeur et al., 1992). Excellent comparisons among growth models are reported by Jolicoeur et al. (1992). They declared that among the growth models, they compared, JPA-2 fitted best. The JPA-2 model, which is similar to the Preece-Baines model but extends to ages younger than one year, fits height measurements well over the entire growth range and detects adolescent peak height velocity and the preceding prepubertal minimum. Recently, Bock et al. (1994) proposed an 8-parameter growth model (Bock, Thissen & du Toit; BTT) that describes the mid-growth spurt together with other phases of the growth. To fit these models, a Bayesian method that is highly robust in the presence of irregular and incomplete data can be applied by the software AUXAL (Bock et al., 1994). Neither the JPA-2 model nor the BTT model requires a measurement of stature at maturity as they used Bayesian method of estimation.

The AUXAL software (Bock et al., 1994) has made it possible to apply the BTT model to longitudinal data from birth to maturity. But to apply it to populations other than the Fels Longitudinal Study population it is necessary to change some default population parameters such as the population mean values and covariance matrix of the prior distribution of the Bayes method, and the shape constants because in AUXAL they are estimated from Fels longitudinal data. These were not available, consequently they were estimated through the iteration process (see Appendix).

The purpose of the present study is to apply the BTT model to longitudinal data for statures of Japanese boys and girls to determine the mean values and variances of characterizing individual growth parameters, the relationships among the biological variables, and the sex differences in the patterns of growth.

2 Data and Methods

Data. Longitudinal data of 820 Japanese children and youths (male 509 and female 311), ranging in age from 0 to 20 years and born from 1967 to 1977, were collected from their personal records. Several universities from the Kanto District were selected and all students of some classes of those selected universities were included except those who had incomplete information (Here "incomplete" indicates that the lack of information of either district of birth place or missing of variables etc.). The Sample provides individual information applicable to all of Japan because the universities that were selected do not have entrance criteria based on place of residence. The present sample included children from every prefecture of Japan, but the Kanto region is better represented than other regions. Physical examinations of school children were made every year from April to June in Japan from kindergarten to university. It was possible to collect longitudinal growth information, but not the exact dates of all the examinations. Using birth dates, ages at examinations were calculated by taking the date of examinations as May 1 (median of April to June) for each year. Though the database includes serial data for many variables, including stature, weight, sitting height, and chest circumference, only stature was analyzed in this study.

Method. The BTT model is a continuous function in time and has derivatives of all orders. It is a strictly increasing function of age and approaches smoothly the horizontal asymptote that defines adult stature. The Bock-Thissen-du Toit (BTT) model is the sum of three generalized logistic terms of the form

$$\frac{a}{[1+exp(-(bt+c))]^{d}}$$

where t is the time (age) variable, a is the amount of growth contributed by the term, the quantity $z = bt + c$ in the exponential function is the "logit," b and c are its slope and intercept, respectively, and d is a fixed shape constant. Summing up three phases of growth; early, middle, and adolescent, Bock et al. (1994) described the triphasic generalized logistic model as:

$$y(t) = \frac{a_1}{[1+exp(-b_1t+c_1)]^{d_1}} + \frac{a_2}{[1+exp(-b_2t+c_2)]^{d_2}} + \frac{a_3}{[1+exp(-b_3t+c_3)]^{d_3}}$$

where the set of parameters (a_1, b_1, c_1), (a_2, b_2, c_2) and (a_3, b_3, c_3) refer to the parameters of early, middle, and adolescent phases of growth, respectively.

The velocity and acceleration of the BTT model can be written respectively as:

$$\begin{aligned}\frac{\partial y(t)}{\partial t} \quad = \quad & \frac{a_1d_1b_1e^{(-b_1t-c_1)}}{\left(1+e^{(-b_1t-c_1)}\right)^{d_1}\left(1+e^{(-b_1t-c_1)}\right)} + \frac{a_2d_2b_2e^{(-b_2t-c_2)}}{\left(1+e^{(-b_2t-c_2)}\right)^{d_2}\left(1+e^{(-b_2t-c_2)}\right)} \\ & + \frac{a_3d_3b_3e^{(-b_3t-c_3)}}{\left(1+e^{(-b_3t-c_3)}\right)^{d_3}\left(1+e^{(-b_3t-c_3)}\right)}\end{aligned}$$

and

$$\begin{aligned}\frac{\partial^2 y(t)}{\partial t^2} = & \frac{2a_1 d_1^2 \left(e^{(-b_1 t - c_1)}\right)^2 b_1^2}{\left(1+e^{(-b_1 t - c_1)}\right)^{d_1}\left(1+e^{(-b_1 t - c_1)}\right)^2} - \frac{2a_1 d_1 e^{(-b_1 t - c_1)} b_1^2}{\left(1+e^{(-b_1 t - c_1)}\right)^{d_1}\left(1+e^{(-b_1 t - c_1)}\right)} \\ & + \frac{2a_1 d_1 \left(e^{(-b_1 t - c_1)}\right)^2 b_1^2}{\left(1+e^{(-b_1 t - c_1)}\right)^{d_1}\left(1+e^{(-b_1 t - c_1)}\right)^2} + \frac{2a_2 d_2^2 \left(e^{(-b_2 t - c_2)}\right)^2 b_2^2}{\left(1+e^{(-b_2 t - c_2)}\right)^{d_2}\left(1+e^{(-b_2 t - c_2)}\right)^2} \\ & - \frac{2a_2 d_2 e^{(-b_2 t - c_2)} b_2^2}{\left(1+e^{(-b_2 t - c_2)}\right)^{d_2}\left(1+e^{(-b_2 t - c_2)}\right)} + \frac{2a_2 d_2 \left(e^{(-b_2 t - c_2)}\right)^2 b_2^2}{\left(1+e^{(-b_2 t - c_2)}\right)^{d_2}\left(1+e^{(-b_2 t - c_2)}\right)^2} \\ & + \frac{2a_3 d_3^2 \left(e^{(-b_3 t - c_3)}\right)^2 b_3^2}{\left(1+e^{(-b_3 t - c_3)}\right)^{d_3}\left(1+e^{(-b_3 t - c_3)}\right)^2} - \frac{2a_3 d_3 e^{(-b_3 t - c_3)} b_3^2}{\left(1+e^{(-b_3 t - c_3)}\right)^{d_3}\left(1+e^{(-b_3 t - c_3)}\right)} \\ & + \frac{2a_3 d_3 \left(e^{(-b_3 t - c_3)}\right)^2 b_3^2}{\left(1+e^{(-b_3 t - c_3)}\right)^{d_3}\left(1+e^{(-b_3 t - c_3)}\right)^2}\end{aligned}$$

The AUXAL program arbitrarily hypothesizes that adult stature, as calculated from the model, is reached at 25 years of age. The zeroes in acceleration curve imply the maxima or minima of the growth velocity curve.

The Bayes modal estimation method was used to estimate the parameters for fitting the growth model. This method of estimation is much better than the conventional least square method which requires a number of distinct observations greater than the number of parameters. Even when the number of observation is sufficient for the least square method, not all the parameters may be identifiable if the observations are poorly positioned. The Bayes modal estimation process chooses from among a specified population of growth curves the one that is most probable given the data (see Bock et al., 1994 for a detailed description of the method of estimation). The possible biological variables, extracted from distance and velocity curves of each subject (for example, see Figure 1), were age at early childhood minimum (AECM), stature at early childhood minimum (SECM), velocity at early childhood minimum (VECM), age at mid-childhood maximum (AMC), Stature at mid-childhood maximum (SMC), velocity at mid-childhood maximum (VMC), age at takeoff (ATO), Stature at takeoff (STO), velocity at takeoff (VTO), age at peak height velocity (APHV), stature at peak height velocity (SPHV), peak height velocity (PHV), predicted adult stature (PAS), and adolescent increment (AI=PAS-STO).

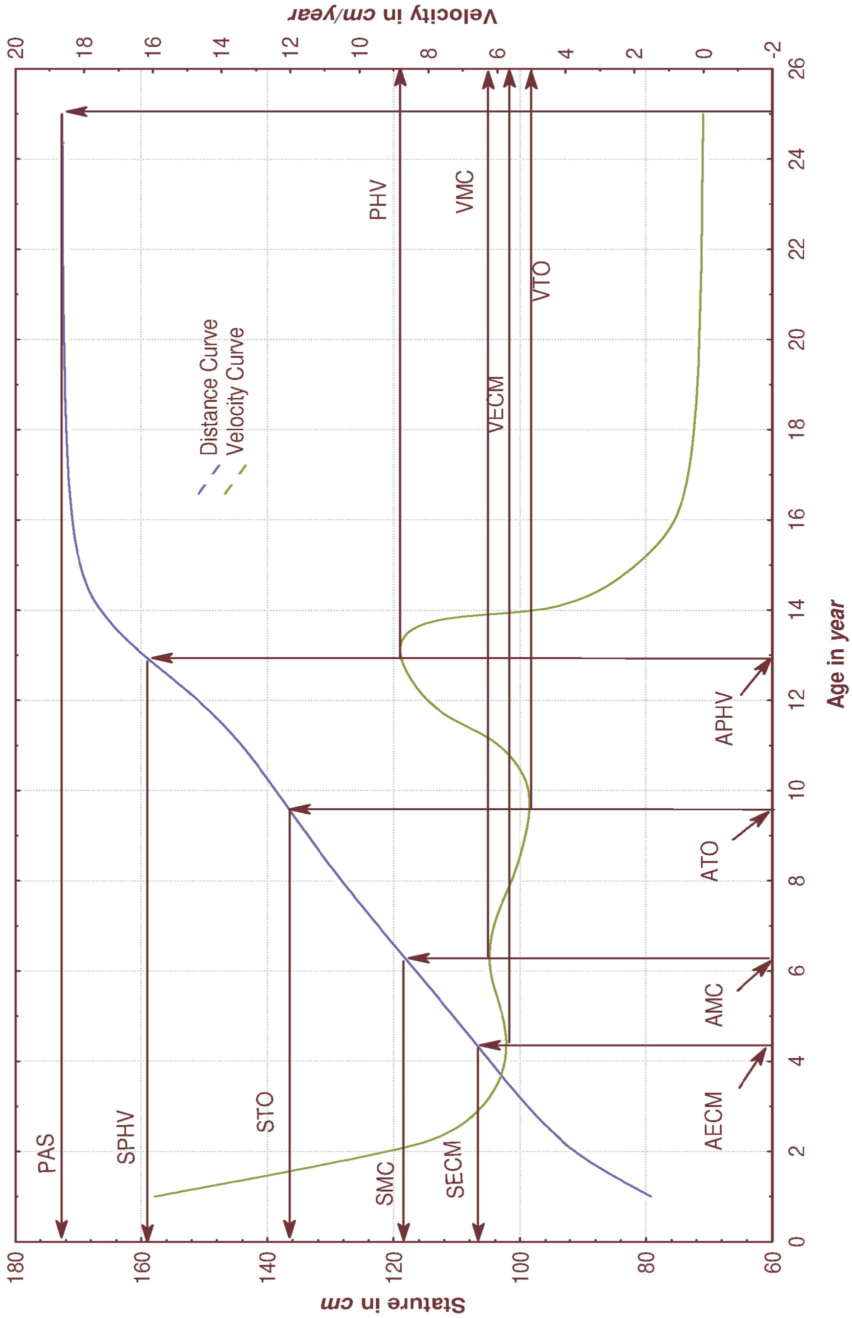

Figure 1 Fitted distance (stature) and velocity curves of a Japanese boy. The left Y-axis (stature in *cm*) is for distance curve (upper curve) and the right Y-axis (velovity in *cm/year*) is for velocity curve (lower curve). Notations are the same as in Table 2. Some of the biological variables, for example, were sketched through hand-drawing and should be considered as the approximate.

3 Results

After changing the default values of population mean vector and covariance matrix, the BTT model was run on the longitudinal stature data for each individual. Also, the defaulted value of the shape constants d_1, d_2, and d_3, and the scale c_1 are checked and found that they also fitted well to the Japanese population. The estimated population mean values, standard deviations (SD), and covariance matrix of the BTT model parameters, and the average root mean square error of the model estimates for Japanese boys and girls are shown in Table 1.

The parameters a_1, a_2, and a_3 in the BTT model decompose the amount of growth of stature contributed by the early, middle and adolescent growth phase, respectively. This study demonstrates that, on average, 47.8%, 38.7%, and 13.5% of the adult stature was completed during the early, middle and adolescent growth phases, respectively, for Japanese boys. For girls, these percentages were 44.0%, 42.9%, and 13.1%, respectively.

Summary statistics of the biological variables for the Japanese boys and girls are shown in Table 2. This table also shows that the average predicted adult stature of Japanese male was 172.59 cm and that of females was 159.68 cm. The 95% confidence limits imply that the onset of adolescence growths were started between the age intervals 9.5-9.7 for boys and 7.9-8.2 for girls. The peak adolescent spurt age intervals were 12.6-12.8 for boys and 10.6-10.9 for girls. This implies, the Japanese boys on average have adolescent spurt 0.6 year longer than Japanese girls.

The correlation matrix of the biological variables for the Japanese boys and girls is shown in Table 3. The values above the diagonal are for boys and those below the diagonal are for girls. The asterisks (*) indicate the correlation coefficients that were significant at 5% level. To estimate the correlation coefficients, pairwise deletions of missing data in the correlation matrices were considered. That is, a correlation between each pair of variables is calculated from all cases that have valid data on those two variables. Thus, the sample sizes are not the same for all correlation coefficients. The critical points to determine their rejection regions of null hypotheses also differ with respect to the pairs of variables.

Average growth curves for predicted stature and velocity of Japanese boys and girls are shown in Figure 2. This figure shows that the incremental growth in stature for Japanese boys and girls is significant after age 19 years.

Table 1. Estimated population mean, standard deviation (SD), and covariance of the BTT model parameters for Japanese boys and girls

Parameter		a_1	b_1	a_2	c_2	b_2	a_3	c_3	b_3
				Boys					
Mean (N=428)		82.46	1.07	66.82	-2.86	0.40	23.32	-18.88	1.44
SD		9.92	0.66	8.29	0.55	0.08	8.38	2.27	1.16
Covariance	a_1	98.33							
Matrix	b_1	-2.45	0.44						
	a_2	-26.12	0.17	68.74					
	c_2	-0.83	-0.24	-0.42	0.30				
	b_2	-0.55	0.04	0.16	-0.01	0.01			
	a_3	-49.25	1.31	-22.63	1.76	0.29	70.28		
	c_3	-12.08	0.21	6.57	0.31	0.08	4.62	5.17	
	b_3	1.01	-0.01	-0.48	-0.02	-0.01	-0.50	-0.27	0.02
Average root mean square error of the estimate: 0.7244									
				Girls					
Mean (N=263)		70.29	1.26	68.52	-2.45	0.44	20.88	-14.68	1.30
SD		8.82	0.75	11.22	0.45	0.13	7.07	3.34	0.33
Covariance	a_1	77.83							
Matrix	b_1	-1.03	0.57						
	a_2	-73.22	0.25	125.92					
	c_2	0.88	-0.33	-0.24	0.20				
	b_2	-0.14	0.02	-0.30	-0.01	0.02			
	a_3	1.23	-0.76	-38.49	0.30	0.56	49.92		
	c_3	-6.81	-0.23	5.11	0.10	0.08	6.80	11.14	
	b_3	1.08	0.00	-1.10	0.01	0.00	-0.49	-0.99	0.11
Average root mean square error of the estimate: 0.6717									

N.B. The sample sizes differ from those given in the data section, because some individual cases did not converge due to extreme outliers.

Table 2. Mean, standard deviation (SD), standard error of the estimate (SE), and 95% confidence limits of the biological variables of the Japanese boys and girls.

Biol.	Boys						Girls					
Var.	N	Mean	SD	SE	95% Confidence Limits		N	Mean	SD	SE	95% Confidence Limits	
					Lower	Upper					Lower	Upper
AECM	220	3.50	0.91	0.06	3.38	3.62	96	2.96	0.60	0.06	2.84	3.08
SECM	220	98.43	8.44	0.57	97.31	99.55	96	92.19	5.83	0.59	91.02	93.36
VECM	220	5.38	1.20	0.08	5.22	5.54	96	6.20	1.11	0.11	5.98	6.43
AMC	220	6.36	0.99	0.07	6.23	6.49	96	5.13	0.74	0.08	4.98	5.28
SMC	220	115.56	6.96	0.47	114.64	116.48	96	106.27	5.15	0.53	105.22	107.31
VMC	220	6.64	1.33	0.09	6.47	6.82	96	6.98	1.15	0.12	6.75	7.21
ATO	421	9.59	1.01	0.05	9.50	9.69	239	8.05	1.08	0.07	7.91	8.18
STO	421	134.59	6.91	0.34	133.93	135.25	239	125.33	6.93	0.45	124.45	126.22
VTO	421	4.87	0.83	0.04	4.79	4.95	239	5.05	0.87	0.06	4.94	5.17
APHV	423	12.66	1.03	0.05	12.56	12.76	243	10.77	1.00	0.06	10.64	10.90
SPHV	423	154.53	5.92	0.29	153.97	155.10	243	142.19	4.60	0.29	141.61	142.77
PHV	423	9.05	1.33	0.06	8.92	9.18	243	7.74	1.46	0.09	7.55	7.92
AI	421	38.01	6.44	0.31	37.39	38.62	239	34.36	11.01	0.71	32.96	35.76
PAS	426	172.59	6.10	0.30	172.01	173.17	262	159.68	4.79	0.30	158.53	159.74

The abbreviation of the notations were: age at early childhood minimum (AECM), stature at early childhood minimum (SECM), velocity at early childhood minimum (VECM), age at mid childhood maximum (AMC), stature at mid childhood maximum (SMC), velocity at mid childhood maximum (VMC), age at takeoff (ATO), stature at takeoff (STO), velocity at takeoff (VTO), age at peak height velocity (APHV), stature at peak height velocity (SPHV), peak height velocity (PHV), adolescent increment (AI), and predicted adult stature (PAS). The sample sizes among the biological variables vary due to 1) the absence of the biological variables of some individuals, and 2) the limitation of finding the growth phases by the soft package of AUXAL.

Table 3. Correlation coefficients among the biological variables for the Japanese boys and girls. The values above the diagonal are for boys; those below the diagonal, for girls. Marked correlations are significant at p¡0.05.

	AECM	SECM	VECM	AMC	SMC	VMC	ATO	STO	VTO	APHV	SPHV	PHV	AI	PAS
AECM		0.80*	-0.01	0.33*	0.33*	-0.65*	0.04	-0.12	0.08	0.16*	-0.05	-0.12	0.16*	0.01
SECM	0.66*		-0.22*	0.34*	0.69*	-0.69*	-0.04	0.22*	0.25*	-0.03	0.32*	-0.01	0.10	0.32*
VECM	-0.12	-0.19		-0.73*	-0.52*	0.60*	-0.34*	0.04	-0.17*	-0.22*	0.13	0.01	0.12	0.15*
AMC	0.16	0.07	-0.80*		0.71*	-0.50*	0.44*	0.09	0.31*	0.30*	-0.02	-0.28*	-0.07	0.03
SMC	-0.04	0.55*	-0.49*	0.55*		-0.40*	0.17*	0.55*	0.46*	-0.06	0.51*	-0.19*	-0.10	0.49*
VMC	-0.65*	-0.51*	0.78*	-0.66*	-0.29*		-0.16*	0.28*	-0.07	-0.29*	0.16*	-0.14*	-0.16*	0.15*
ATO	-0.10	-0.18	-0.17	0.25*	0.05	-0.06		0.53*	-0.30*	0.80*	0.28*	-0.39*	-0.59*	-0.02
STO	-0.42*	0.08	0.28*	-0.21*	0.40*	0.50*	0.68*		0.02	0.21*	0.79*	-0.36*	-0.58*	0.53*
VTO	0.15	0.01	-0.08	0.35*	0.18	-0.11	-0.26*	-0.08		-0.52*	0.02	0.12*	0.11*	0.11*
APHV	0.16	-0.05	-0.26*	0.24*	-0.10	-0.31*	0.82*	0.31*	-0.48*		0.30*	-0.15*	-0.21*	0.03
SPHV	-0.21*	0.26*	0.25*	-0.26*	0.37*	0.33*	0.42*	0.81*	-0.05	0.32*		0.10*	-0.15*	0.73*
PHV	0.12	0.05	-0.08	-0.12	-0.20	-0.21*	-0.57*	-0.51*	0.05	-0.42*	-0.17*		0.51*	0.13*
AI	0.44*	0.16	-0.18	0.17	-0.13	-0.42*	-0.42*	-0.54*	0.10	-0.13*	-0.24*	0.40*		0.36*
PAS	-0.03	0.30*	0.16	-0.07	0.38*	0.16	-0.08	0.28*	0.12	0.03	0.63*	0.08	0.28*	

The abbreviations of the notations are the same as that of Table 2.

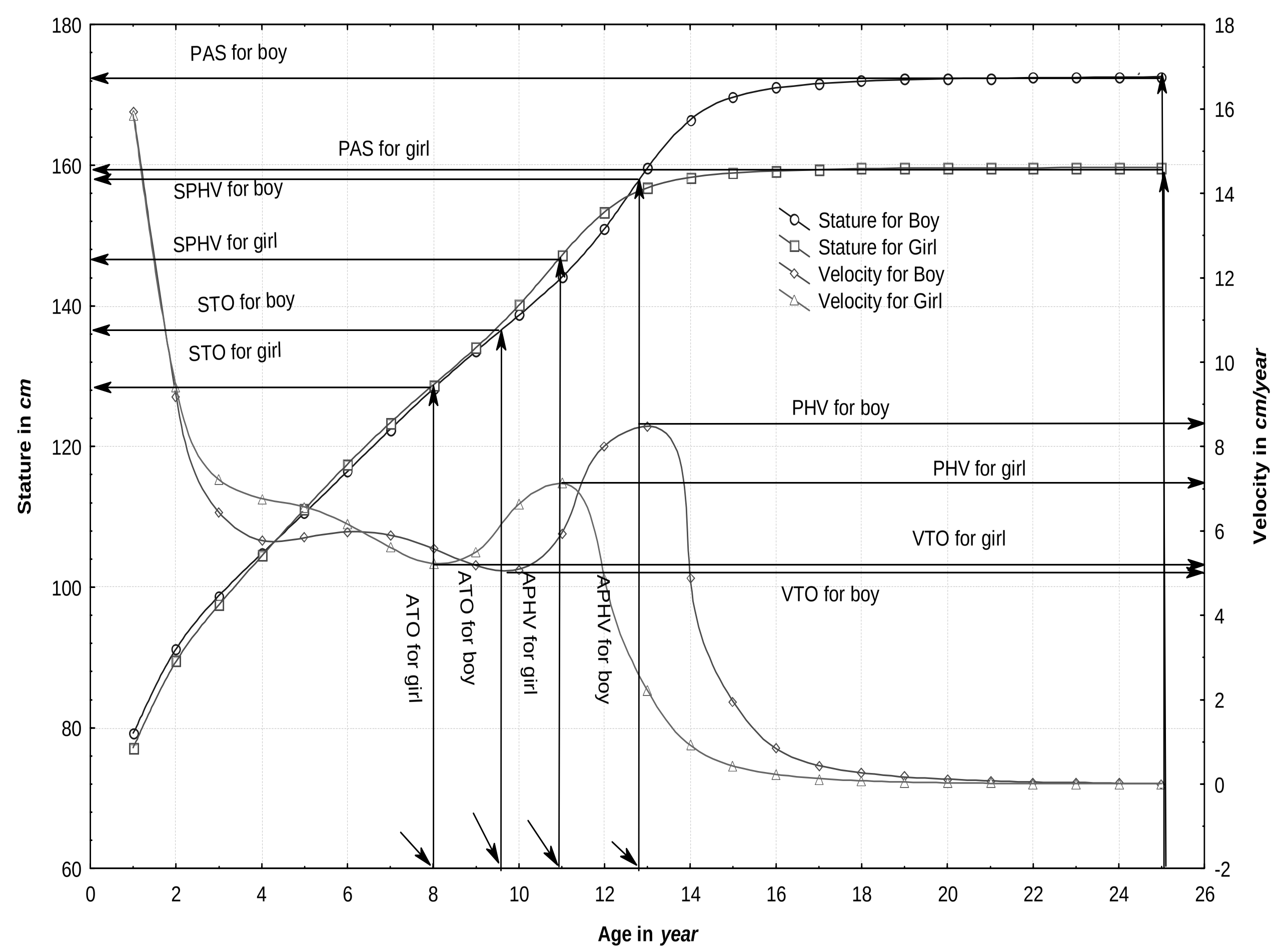

Figure 2 Average predicted stature and velocity of Japanese boys and girls for different ages. Upper two curves and bottom two curves are corresponding to left Y-axis (stature in *cm)* and right Y-axis (velovity in *cm/year*) respectively. Notations are the same as in Table 2. Some of the biological variables, for example, were sketched through hand-drawing and should be considered as the approximate. Biological variables at or onset of mid growth-spurt could not drawn due to the flatness of the average velocity curves for both boys and girls.

4 Discussion

As the BTT model is triphasic, this model tends to generate mid-growth spurt for those individuals who do not have this spurt. Also, if some individuals have more than one mid-growth spurt (Waker and Waker, 2000) then this model tend to smooth out these phases of growth into one long bump in the growth velocity. Figure 1 also support this problem of longer bump.

An attempt was made to compare our findings with those of others who have used longitudinal curve-fitting procedures. Comparative results for age at takeoff, stature at takeoff, and velocity at takeoff are shown in Table 4 for the boys and in Table 5 for the girls. Results for age at PHV, stature at PHV, and PHV are shown in Table 6 for the boys and in Table 7 for the girls.

Table 4 shows that mean age at takeoff (i.e., age at the onset of the pubertal spurt in stature) of Japanese boys is approximately 0.5 years earlier than in Guatemalan boys; one year earlier than in Australian, urban Indian, and American; 1.5 years earlier than in Swiss, French, and Saskatchewan; and 2.5 years earlier than in African, and English boys (Tanner et al., 1976; Largo et al., 1978; Hauspie et al., 1980a; Mirwald et al., 1981; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Bogin et al., 1990; Byard et al., 1993; Ledford and Cole, 1998).

The mean stature at takeoff in Japanese boys (Table 4) is approximately 1.5 cm smaller than in Australian boys, 2.5 cm smaller than in Belgian boys, 3 cm smaller than in Guatemalan boys, 8 cm smaller than in American boys, and Saskatchewan boys, 9 cm smaller than in Swiss boys, but 5 cm larger than in Indian boys (Largo et al., 1978; Hauspie et al., 1980a; Mirwald et al., 1981; Brown and Townsend, 1982; Gasser et al., 1984; Bogin et al., 1990; Byard et al., 1993). These differences in stature are not closely related to the differences in timing.

The velocity at takeoff of Japanese boys (Table 4) is approximately one cm/year larger than that of African and Indian boys (Hauspie et al., 1980a; Billewicz and McGregor, 1982; Bogin et al., 1990). It is about 0.5 cm/year larger than Swiss boys (Largo et al., 1978; Gasser et al., 1984) and Australian boys (Brown and Townsend, 1982; Bogin et al., 1990). The velocity at takeoff is slightly larger in Japanese boys than in Guatemalan, Saskatchewan and United States boys (Mirwald et al., 1981; Bogin et al., 1990, Byard et al., 1993).

The age at takeoff of Japanese girls (Table 5) is approximately one year earlier than in Australian girls, American girls, and French girls; 1.5 years earlier than in Swiss girls, and Indian girls; 2.0 years earlier than in Belgian; and 2.5 years earlier than in African and English girls; (Tanner et al., 1976; Largo et al., 1978; Hauspie et al., 1980a, b; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Bogin et al., 1990; Byard et al., 1993; Ledford and Cole, 1998).

The mean stature at takeoff in Japanese girls (Table 5) is approximately 2.5 cm than in African girls, 4 cm than in Australian girls, 5 cm than in Guatemalan girls, 6 cm than in American girls, 11 cm smaller than in Swiss girls, but 4 cm taller than in Indian girls (Largo et al., 1978; Hauspie et al., 1980a; Billewicz and McGregor, 1982;

Brown and Townsend, 1982; Bogin et al., 1990; Byard et al., 1993). These differences, like as boys, in stature are not closely related to the differences in timing.

Table 4. Average ages at takeoff (in years), stature at takeoff (in cm) and velocity at takeoff (in cm/year) of boys from this and other studies (corresponding SDs are shown in parentheses).

Authors	Ethnic Group	Method	Age at Takeoff	Stature at Takeoff	Velocity at Takeoff
Tanner et al. (1976)	English	Logistic	12.1(0.9)	146.1(6.3)	
Largo et al. (1978)	Swiss	Cubic Spline	11.0(1.2)	143.8(7.7)	4.2(0.6)
Preece and Baines (1978)	English	PB 1	10.7(0.9)	138.9(5.9)	4.5(0.6)
		PB 2	10.9(0.9)	139.7(6.2)	4.5(0.5)
		PB 3	11.2(1.1)	141.0(6.5)	4.7(0.6)
		PB 4	10.5(0.8)	137.7(5.8)	4.0(0.5)
Hauspie et al. (1980a)	India	Curve-fitting	10.5(1.5)	129.7(6.1)	3.9(0.8)
Mirwald et al. (1981)	Saskatchewan	PB 1	11.0(0.9)	142.3(7.1)	4.6(0.7)
Billewicz and McGregor (1982)	Gambian	PB 1	12.2(1.3)	135.7(6.3)	3.7(0.5)
Brown and Townsend (1982)	Australian Aboraginal	PB 1	10.6(1.4)	136.0(8.5)	4.4(0.8)
Gasser et al. (1984a)	Swiss	Kernel	10.9(1.1)	143.4(6.7)	4.3(0.5)
Bogin et al. (1990)	Guatemalan	PB 1	10.1(1.2)	137.6(6.2)	4.6(0.8)
	British		10.8	139.0	4.5
	Belgian		10.0	136.9	4.7
	Urban Indian		10.6	129.5	3.6
	Rural Indian		11.4	119.5	3.9
	Australian		10.8	136.0	4.3
	African		12.2	135.6	3.7
Byard et al. (1993)	American	PB 1	10.6(1.0)	142.7(7.1)	4.8(0.5)
Ledford and Cole (1998)	French	JPPS	11.2(1.1)		
		SSC	11.8(1.1)		
		PB1	10.0(0.9)		
Present Investigation	Japanese	BTT	9.6(1.0)	134.6(6.9)	4.9(0.8)

N.B. The order of references is arranged according to the year published.

The velocity at takeoff in Japanese girls (Table 5) is approximately one cm/year larger than in African girls (Billewicz and McGregor, 1982; Bogin et al., 1990). It is 0.5 cm/year larger than in Indian girls (Hauspie et al., 1980a; Bogin et al., 1990). It was 0.3 cm/year smaller than in Swiss girls (Largo et al., 1978), 0.2 cm/year larger than in Guatemalan and Belgian girls (Bogin et al., 1990), while it is about the same as American and Australian girls (Brown and Townsend, 1982; Byard et al., 1993).

From Table 6, it is found that the age at PHV of Japanese boys reach approximately 3.5 years earlier than African boys (Billewicz and McGregor, 1982) and one year earlier than Venezuelan, Guatemalan, Belgian and United States boys (Gasser et al., 1984; Bogin et al., 1990; Byard et al., 1993; Mercedes et al., 1995). They also reach about 1.5 years earlier than English, Swiss, Indian, French and Swedish boys (Marubini et al., 1972; Largo et al., 1978; Hauspie et al., 1980a; Karlberg, 1989; Bogin et al., 1990; Ledford and Cole, 1998).

The mean stature at peak velocity in Japanese boys (Table 6) approximately is one cm smaller than in African boys, 3 cm smaller than in Australian boys, 5 cm smaller than in English boys, 6 cm smaller than in Guatemalan boys, 7 cm smaller than in Swiss boys, 8 cm smaller than in Saskatchewan boys, and 9 cm smaller than in United States boys (Largo et al., 1978; Mirwald et al., 1981; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Gasser et al., 1984; Bogin et al., 1990; Byard et al., 1993). To the contrary, Japanese boys are 4 cm taller than in Indian boys at peak velocity (Hauspie et al., 1980a; Bogin et al., 1990).

Table 5. Average ages at takeoff (in years), stature at takeoff (in cm) and velocity at takeoff (in cm/year) of girls from this and other studies (corresponding SDs are shown in parentheses).

Authors	Ethnic Group	Method	Age at Takeoff	Stature at Takeoff	Velocity at Takeoff
Tanner et al. (1976)	English	Logistic	10.3(1.0)	137.9(7.0)	
Largo et al. (1978)	Swiss	Cubic Spline	9.6(1.1)	135.8(7.3)	4.8(0.7)
Preece and Baines (1978)	English	PB 1	9.0(0.7)	129.9(6.3)	5.2(0.4)
		PB 2	8.9(0.6)	130.2(6.3)	5.3(0.5)
		PB 3	9.1(0.8)	130.9(6.7)	5.3(0.4)
		PB 4	8.7(0.8)	127.9(6.2)	4.6(0.4)
Hauspie et al. (1980a)	India	Curve-fitting	9.3(1.1)	121.3(6.4)	4.6(0.6)
Hauspie et al. (1980b)	Belgian	Logistic	9.9(1.1)	137.1(6.2)	4.9(1.1)
		Gompertz	9.9(1.1)	136.7(6.2)	4.5(1.3)
		PB 1	8.5(0.9)	129.9(4.2)	5.0(0.7)
		Double logistic	7.8(1.0)	125.6(4.4)	4.6(0.7)
Mirwald et al. (1981)	Saskatchewan	PB 1			
Billewicz and McGregor (1982)	Gambian	PB 1	10.2(1.4)	127.8(6.8)	4.0(0.6)
Brown and Townsend (1982)	Australian Aboraginal	PB 1	8.8(1.5)	129.1(5.2)	5.0(1.2)
Bogin et al. (1990)	Guatemalan	PB 1	9.0(1.0)	129.9(4.8)	4.9(0.7)
		British	8.9	129.8	5.2
		Belgian	8.4	129.4	5.3
		Urban Indian	9.4	121.1	4.6
		Rural Indian			
		Australian	8.9	128.5	5.1
		African	10.3	127.6	4.0
Byard et al. (1993)	American	PB 1	8.8(1.0)	131.0(6.9)	5.2(0.6)
Qin et al. (1996)	Japanese	PB 1	7.3(1.4)	117.4(8.5)	
		Count-Gompertz	8.5(1.7)	123.9(10.0)	
Ledford and Cole (1998)	French	JPPS	8.8(1.4)		
		SSC	9.2(1.2)		
		PB1	8.2(0.7)		
Present Investigation	Japanese	BTT	8.0(1.1)	125.3(6.9)	5.1(0.9)

N.B. The order of references is arranged according to the year published.

The peak velocity of growth in stature of Japanese boys (Table 6) is approximately 0.2 cm/year smaller than that of English, Indian, Swiss and United States boys, 0.5 cm/year smaller than Guatemalan and French boys, and 1.5 cm/year smaller than Australian boys, but 2.0 cm/year larger than African boys (Marubini et al., 1972; Tanner et al., 1976; Largo et al., 1978; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Bogin et al., 1990; Byard et al., 1993; Ledford and Cole, 1998).

The age at PHV of Japanese girls (Table 7) reach approximately 0.5 year earlier than that of Belgian girls, one year earlier than English, Guatemalan, United States, Caracas, Australian, French, and Polish girls, 1.5 years earlier than Swiss, Swedish and Indian girls, and 3.0 years earlier than African girls (Marubini et al., 1972; Bielicki and Welon, 1973; Tanner et al., 1976; Largo et al., 1978; Hauspie et al., 1980a,b; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Karlberg, 1986; Bogin et al., 1990; Byard et al., 1993; Mercedes et al., 1995; Ledford and Cole, 1998).

The mean stature at peak velocity in Japanese girls (Table 7) is approximately 3 cm smaller than in African girls, 6 cm smaller than in English, Guatemalan and Australian girls, 7 cm smaller than in United States girls, and 8 cm smaller than in Swiss girls, (Largo et al., 1978; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Bogin et al., 1990; Byard et al., 1993). To the contrary, also Japanese girls are 4 cm taller than in Indian girls at peak velocity (Hauspie et al., 1980a; Bogin et al., 1990).

Table 6. Average ages at PHV (in years), stature at PHV (in cm) and velocity at PHV (in cm/year) of boys from this and other studies (corresponding SDs are shown in parentheses).

Authors	Ethnic Group	Method	Age at PHV	Stature at PHV	PHV
Marubini et al. (1972)	English	Gompertz	14.1(0.8)		9.1(1.2)
		Logistic	14.2(0.8)		8.8(1.1)
Tanner et al. (1976)	English	Logisic	13.9(0.8)		8.8(1.1)
Largo et al. (1978)	Swiss	Cubic Spline	13.9(0.8)	161.9(6.2)	9.0(1.1)
Preece and Baines (1978)	English	PB 1	14.2(0.9)	159.5(5.5)	8.2(1.2)
		PB 2	14.2(1.0)	159.7(5.6)	8.4(1.4)
		PB 3	14.4(1.0)	160.8(5.6)	8.7(1.0)
		PB 4	13.6(0.8)	155.8(5.5)	8.2(1.3)
Hauspie et al. (1980a)	Indian	Curve-fitting	14.3(1.0)	150.6(5.0)	8.7(1.3)
Hauspie et al. (1980b)	Belgian	Logistic			
		Gompertz			
		PB 1			
		Double logistic			
Mirwald et al. (1981)	Saskatchewan	PB 1	14.3(1.2)	162.5(6.5)	8.7(1.1)
Billewicz and McGregor (1982)	Gambian	PB 1	16.3(1.2)	155.8(5.4)	6.9(1.0)
Brown and Townsend (1982)	Australian Aboriginal	PB 1	14.0(0.8)	157.1(6.3)	10.3(1.2)
Cameron et al. (1982)	English	PB 1	13.9		
Tanner et al. (1982)	Japanese	PB 1	12.8	169.6	
Gasser et al. (1984a)	Swiss	Kernel	13.9(0.9)	161.7(6.7)	8.3(0.8)
Karlberg (1989)	Swedish	ICP	14.2		
Bogin et al. (1990)	Guatemalan	PB 1	13.7(1.1)	160.5(3.8)	9.5(1.8)
	British		14.2	159.6	8.2
	Belgian		13.8	159.5	7.6
	Urban Indian		14.3	150.7	8.8
	Rural Indian		15.6	142.0	7.5
	Australian		14.0	157.2	10.6
	African		16.3	156.1	6.9
Byard et al. (1993)	American	PB 1	13.9(0.9)	163.6(6.2)	8.9(1.1)
Mercedes et al. (1995)	Venezuelan	Cubic Spline	13.5		
Ledford and Cole (1998)	French	JPPS	14.0(1.0)		9.5(1.2)
		SSC	13.9(1.0)		9.7(1.3)
		PB1	13.9(1.2)		8.5(1.3)
Present Investigation	Japanese	BTT	12.7(1.0)	154.5(5.9)	9.0(1.3)

N.B. The order of references is arranged according to the year published.
PHV = Peak Height Velocity

The peak velocity of growth in stature of Japanese girls (Table 7) is approximately 0.5 cm/year smaller than that of English and Australian girls, one cm/year smaller than Italian girls, and about the same with Guatemalan and French girls, but 0.5 cm/year larger than Indian girls, and 1.5 cm/year larger than African girls (Marubini et al., 1971; Marubini et al., 1972; Tanner et al., 1976; Hauspie et al., 1980a; Billewicz and McGregor, 1982; Brown and Townsend, 1982; Bogin et al., 1990; Ledford and Cole, 1998).

Correlation matrix of the parameters of the fitted curves assists understanding of the pattern of growth of individual boys and girls within the study sample (Table 3). Both boys and girls have significant positive correlations between age at takeoff (ATO) and age at peak height velocity (APHV), stature at takeoff (STO) and stature at peak height velocity (SPHV), and SPHV and predicted adult stature (PAS). These relationships imply that the growth of individual children during the adolescent period is consistent with their maturation and size at other phases of growth. Similar findings have been reported for other populations (Hauspie, 1980; Billewicz & McGregor, 1982; Brown & Townsend, 1982; Bogin et al., 1990). The matrix shows that PAS was significantly correlated with statures at early childhood minimum, mid-childhood maximum, onset of the adolescent spurt and at peak height velocity for Japanese boys and girls. In the boys, but not the girls, there were also significant correlations with the velocity of growth at early childhood minimum, mid-childhood maximum, takeoff and peak height velocity. Also, both boys and girls show significant negative correlations between ATO and PHV, APHV and PHV, STO and PHV, and VTO and APHV. This is also in accord with the report by Bogin et al. (1990).

Table 7. Average ages at PHV (in years), stature at PHV (in cm) and velocity at PHV (in cm/year) of girls from this and other studies (corresponding SDs are shown in parentheses).

Authors	Ethnic Group	Method	Age at PHV	Stature at PHV	PHV
Marubini et al. (1971)	Italian	Gompertz	10.2	139.1	8.6
		Logistic	10.6	141.4	8.4
Marubini et al. (1972)	English	Gompertz	11.7(0.9)		8.5(0.7)
		Logistic	11.9(0.9)		8.1(0.6)
Bielicki and Welon (1973)	Polish	Graphical	11.8		
Tanner et al. (1976)	English	Logistic	11.9(0.9)		8.1(0.8)
Largo et al. (1978)	Swiss	Cubic Spline	12.2(1.0)	150.5(5.7)	7.1(1.0)
Preece and Baines (1978)	English	PB 1	11.9(0.7)	148.3(5.1)	7.5(0.8)
		PB 2	11.9(0.8)	148.4(5.1)	7.6(1.0)
		PB 3	12.0(0.9)	149.2(5.2)	7.5(0.8)
		PB 4	11.4(0.9)	145.0(5.2)	7.9(0.7)
Hauspie et al. (1980a)	Indian	Curve-fitting	12.4(1.0)	138.2(5.0)	7.2(1.2)
Hauspie et al. (1980b)	Belgian	Logistic	11.4(1.0)	147.1(5.1)	7.8(1.1)
		Gompertz	11.2(1.0)	145.3(5.2)	8.2(1.1)
		PB 1	11.6(1.0)	148.1(4.1)	7.4(1.0)
		Double logistic	10.9(1.0)	144.1(4.1)	7.7(1.1)
Hoshi and Kouchi (1981)	Japanese	Quardratic Regression	11.1(0.9)		
Billewicz and McGregor (1982)	Gambian	PB 1	13.8(1.3)	144.9(5.4)	6.0(0.9)
Brown and Townsend (1982)	Australian Aboriginal	PB 1	11.9(1.1)	147.9(4.8)	8.4(0.9)
Cameron et al. (1982)	English	PB 1	12.2		
Tanner et al. (1982)	Japanese	PB 1	10.7	156.6	
Gasser et al. (1984a)	Swiss	Kernel			
Karlberg (1989)	Swedish	ICP	12.1		
Bogin et al. (1990)	Guatemalan	PB 1	12.0(1.1)	148.1(4.2)	7.6(1.2)
	British		11.9	148.4	7.5
	Belgian		11.4	147.1	6.6
	Urban Indian		12.4	138.5	7.3
	Rural Indian				
	Australian		12.0	148.2	8.5
	African		13.8	145.1	6.1
Byard et al. (1993)	American	PB 1	11.7(1.0)	149.3(5.6)	7.5(0.9)
Mercedes et al. (1995)	Venezuelan	Cubic Spline	11.7		
Qin et al. (1996)	Japanese	PB 1	10.7(1.1)	139.1(6.1)	
		Count-Gompertz	10.8(1.3)	139.4(7.1)	
		Without curve	10.6(1.6)	138.1(9.0)	
Ledford and Cole (1998)	French	JPPS	11.9(0.9)		7.7(0.9)
		SSC	11.7(1.0)		7.8(1.0)
		PB1	11.6(0.8)		7.6(0.9)
Present Investigation	Japanese	BTT	10.8(1.0)	142.2(4.6)	7.7(1.5)

N.B. The order of references is arranged according to the year published.
PHV = Peak Height Velocity

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Appendix

Estimating population mean and covariance matrix by iteration process

The software AUXAL has the default values of population mean vector and covariance matrix in the prior distribution of the Bayes estimation for the parameters of the BTT model. These default values were predicted based on data from the Fels Longitudinal Study. For the present study, it was necessary to substitute the default values mean vector and covariance matrix that derived from the Japanese population. These were estimated through the following steps:
Step 1. Run data for all sample individuals with BTT model using the default value and estimate the mean vector and covariance matrix of the parameters.
Step 2. Change the default value of mean vector and covariance matrix to the estimated population mean vector and covariance matrix obtained in Step 1, and then repeat Step 1 to estimate the population mean vector and covariance matrix for the second time.
Step 3. Continue the same process until two successive estimated populations mean vectors are closely similar.

In Bayes estimation, estimated population mean is an unbiased estimation of the population mean for large sample. Thus, the value of mean vector and its corresponding covariance matrix from the ith step, is considered as the final estimate of the population mean vector and covariance matrix, if the mean vector of ith step is closer to the mean vector of the (i+1) th step.