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Re-Verification with Regard to Scammon's Growth Curve Proposal of Fujimmon's Growth Curve as a Tantative Idea

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Abstract: The Scammon's growth curve, even during the 80 years since, has been applied to a number of fields. However, one has to wonder if all human characteristics are included in this 4 pattern growth curve classification. Till now, the Scammon's growth curve has yet to be subjected to scientific verification. In this study, this assessment was verified by applying a cross-correlation function in analyzing changes from collapsing one of the curves to examine their similarity. Because of that, cross correlation function can then be applied to the quantified curve by Wavelet Interpolation Method. The data utilized for analysis, cross-sectional growth data from age one to 20 was used for the four attributes classified by the Scammon growth curve. This data was comprised of brain weight (neural type), thymus (lymphoid type), testicle (genital type), and liver (general type). A cross correlation function is used to show the similarity between two waveforms, and the cross correlation function may be evaluated by convolving one function. In this study, a cross correlation function was assumed from the velocity curve values found from differentiation using the wavelet interpolation model (WIM) for Scammon's growth types. There are unanticipated possibilities of similarity between brain weight and thymus, and testicle and liver. What can be newly proposed, therefore, is that growth curve types can be classified as neural, lymphoid, and general body types, with the genital type included in the general body type. The genital type, visceral type, and morphological type are included within the general body type.

Keywords: Similarity, Dissimilarity, Age at MPV (Maximum Peak Velocity), Wavelet Interpolation Model (WIM)

1. Introduction

Fujii [1], Fujii et al [2] objectively verified the four growth patterns by applying the wavelet interpolation model (WIM) to indicators of organ growth distances for a number of internal organs in the four patterns classified with the Scammon growth curve to derive growth velocity curves for those organs. Although objective assessment is difficult using only the present quantitative measurements of organ development due to the need for visual reliance, differences between the four growth patterns were distinguished by assessing the behavior of the development velocity curve to gain a grasp of the adolescent peak. However, the similarity or dissimilarity of the curve cannot be assessed purely from the presence or absence of an adolescent peak. Scientific verification is impossible without quantitative assessment of the similarity or dissimilarity to the curve.

In Animals as Social Beings, Portmann [3] said that, physiologically, humans are born prematurely as they are completely helpless at the time of birth. It takes about 20 years for a human to become an adult, the longest of all the primates. From a human evolutionary point of view, there must be some meaning in being in this "helpless" state at birth. Fujii [4] has previously shown that even large four-legged animals reach an adult weight in about two years, and their weight growth curve differs from the growth curve of humans. In terms of the growth curves of Scammon [5], they show a "neural type" of growth curve; that is, they do not have puberty. Simians show a slight pubertal peak in their body weight growth, although it is not as long as in humans. Among mammals, four-legged animals grow uniformly, with no difference in growth pattern depending on the body area. This means that there is no change in their body proportions. For example, there are no major differences in the body proportion of a four-legged animal at birth and when they are adults. Humans, on the other hand, have very different proportions (change in head and body height ratio) at birth and as adults. Adult humans have a body height to head ratio of 7–8, whereas in newborn babies this ratio is about 4. In the womb there is even a period when it is 3. These changes in the height to head ratio with growth may be unique to humans.

Why are proportion changes seen in humans? A key to this may be in the phenomenon of puberty. In humans, head size approaches that of adults in the first half of growth, as it does in four-legged animals, while the body size continues growing after that. This causes a change in the relative proportions of the body. There is thought to be a deep causal association between this and upright walking on two legs in humans as a result of evolution. For humans, growth of the brain has an important role, and a time such as puberty is needed to protect the brain and facilitate active growth. One may speculate that this period is necessary for development of the brain, and it may be why changes in human body proportion have become a fixture of growth today.

Scammon's [5] growth curves have been convenient to use in demonstrating changes in human body proportion. Takaishi [6] explained that these changes are easy to understand by grasping the relative growth of things that follow the general growth pattern, such as body height and weight, and those that follow the neural growth pattern shown in the growth of the head. Behind this explanation is a history of conveniently demonstrating changes in body proportion with the use of Scammon's growth curves. Moreover, many biological researchers have utilized Scammon's growth curve because of discussing regarding human growth phenomenon. For example, Tanner [7, 8], Malina and Bouchard [9], Kimura [10], Hoshi [11], Takaishi et al [12], Fujii [13] have published Scammon's growth curve in their books. However, even if human growth phenomena can be explained conveniently in this way, this approach will probably not lead to universal findings.

In discussing growth phenomena to date, Scammon's growth curves are often occupy a central position in the arguments given. However, Scammon's growth curves were proposed more than 85 years ago, and the theory was constructed in an age when computers did not exist. Today, when so much more is understood scientifically, it is natural that autor should to try and verify the validity of a theory proposed more than 85 years ago. No report has yet clearly validated this theory. Given the above, in this study the theory proposed by Scammon was first re-examined to investigate the standardization of the human growth system, and a new growth curve model was constructed for the standard human growth pattern. That growth model pattern is proposed as the Fuijimmon growth curve.

2. Methods

2.1. Data Sets

As data showing the four attributes classified from the growth curves of Scammon, the data used were cross-sectional growth data from age 1 year to 20 years for brain weight (as the neural type), thymus gland and tonsils (as the neural type), testicles (as the genital type), and liver and heart (as the general type) shown by Takaishi et al. [12].

2.2. Analytical Techniques

Wavelet interpolation model

The Wavelet Interpolation Model (WIM) is a method to examine growth distance values at adolescent peak. A growth curve is produced by data-data interpolation with a wavelet function and deriving the growth velocity curve obtained by differentiating the described distance curve to approximate the true growth curve from the supplied growth data with the wavelet interpolation model. This distance curve is differentiated to arrive at the growth velocity curve, and the growth distance value of puberty peak is examined. The effectiveness of the WIM lies in its extremely high approximate accuracy in sensitively reading local events. Details on theoretical background and the basis for this effectiveness are omitted here as they have already been set forth in prior studies by Fujii [14-17].

The outline of wavelet interpolation model (WIM) is shown in Figure 1, longitudinal height growth is described by the WIM. The maximum peak velocity (MPV) of height is identified as peak during puberty, and is established as criterion of physical maturation rebel (biological parameter).

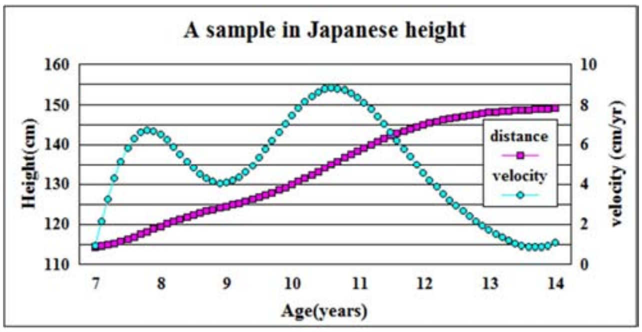

Figure 1. *Height growth described by wavelet interpolation model (WIM).*

2.3. Cross Correlation Function

A cross correlation function is used to show the similarity between two waveforms, and the cross correlation function may be evaluated by convolving one function as shown below. In addition, the degree of time lag can be examined when there are similar regions (Matsuura et al [18], Yamada et al [19]). In this study, a cross correlation function was assumed from the velocity curve values found from differentiation using the WIM for twins' physiques, internal organ types classified in the Scammon growth curve and growth distance values for athletic ability. If the calculated values for the two velocity curves are given as x'(t) and y'(t), then the median value-subtracted transformation x (t) and y (t), is given as x (t)=x'(t)-μ and y (t)=y'(t)-μ. Using the transformations x (t) and y (t), the cross covariance is defined as follows (1), with τ as the time lag assigned to the other data-set and n as the sample size.

$$C_{xy}(\tau)=\overline{x(t)y(t+\tau)}=\lim_{T\to\infty}\frac{1}{T}\int_{-T/2}^{T/2}x(t)y(t+\tau)dt \qquad (1)$$

The cross correlation is the cross covariance Cxy (τ) normalized by the standard deviation of the values for the two velocity curves x'(t) and y'(t), and is given as follows (2):

$$R_{xy}(\tau)=\frac{C_{xy}(\tau)}{C_x(0)C_y(0)N-j}=\frac{\overline{x(t)y(t+\tau)}}{\sqrt{\overline{x^2}}\sqrt{\overline{y^2}}} \qquad (2)$$

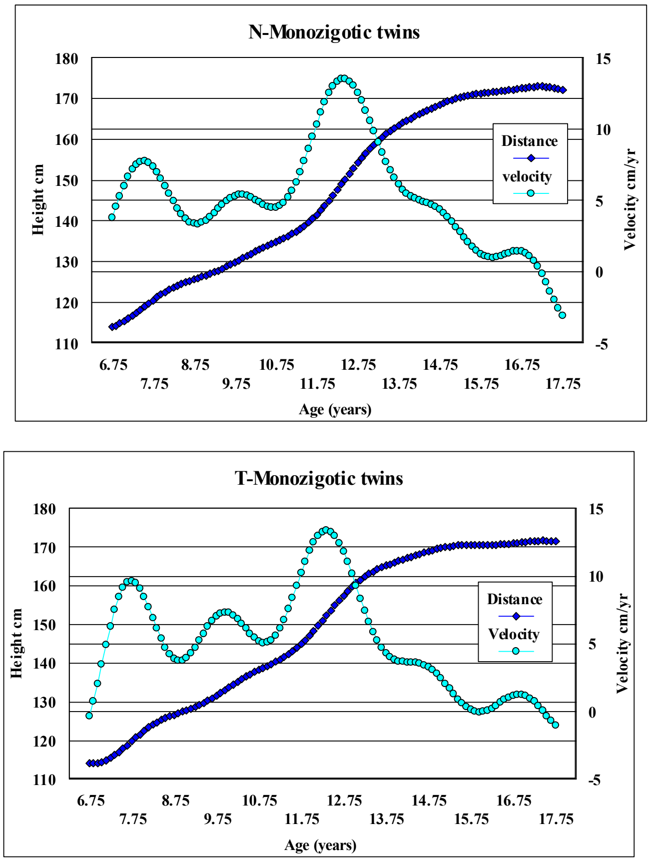

Figure 2. *Height growth distance and velocity curve described by WIM in identical twins.*

Analysis was conducted using the cross correlation function Rxy (τ) calculated as outlined above.

The WIM applied to the height growth of identical twins is shown in Figure 2 and the height of fraternal twins is shown in Figure 3. A glance at the height growth velocity curves on each graph highlights the high similarity between identical twins. Changes in the cross-correlation coefficient found by applying the cross-correlation function to identical and fraternal twin height growth described by WIM and collapsing one (set of) growth distance values and velocity values are shown in Figures 4 and 5. With r = 0.93 for identical twins and r = 0.74 for fraternal twins, similarity in identical twins was found to be very high when examining changes in correlation coefficients shown in both graphs. Similarity among identical twins was also found to be high when weight, sitting height and leg length were analyzed, with high correlation coefficients in all three. That the high similarity between identical twins was objectively verified seems fitting given their monozygotic twins. Therefore, similarity and dissimilarity of the growth curve can be judged by cross correlation function.

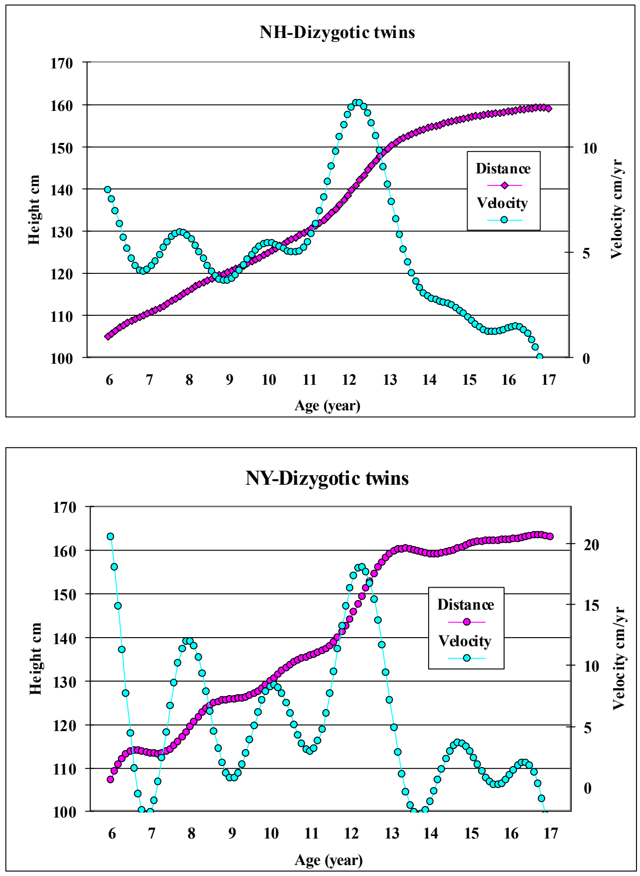

Figure 3. *Height growth distance and velocity curve described by WIM in fraternal twins.*

3. Results

Scammon determined growth types by classifying human growth systems into four basic patterns. As shown in Figure. 6, they are the general type, neural type, lymphoid type, and genital type. As can be seen in Figure. 6, Scammon's graph of growth consists of estimated growth curves drawn freehand, with which it would have been difficult to standardize the growth system. Fujii [20] confirmed that the human growth phenomenon is formed of four major standard growth types as advocated by Scammon, but did not elucidate the evidence that established these four standard growth patterns. Therefore, it is first necessary to investigate whether these four growth curve patterns describe independent curve patterns. An attempt was made to investigate this by applying cross-correlation functions for similarities and differences between the growth curves.

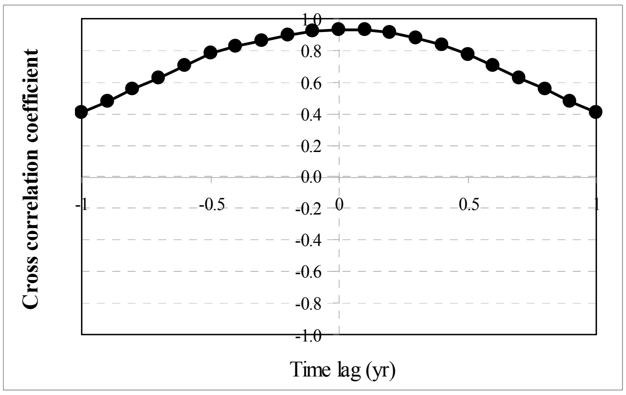

Figure 4. *Cross correlation function in identical twins.*

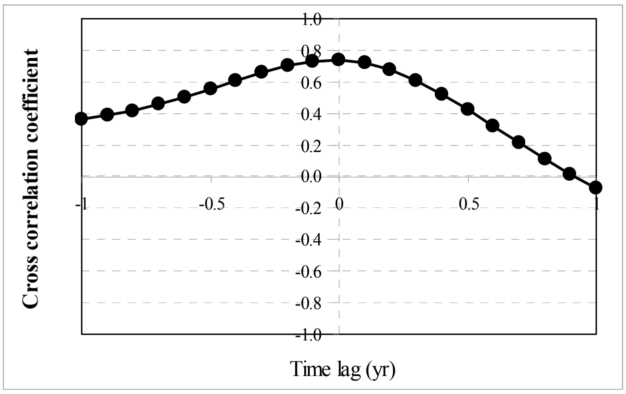

Figure 5. *Cross correlation function in fraternal twins.*

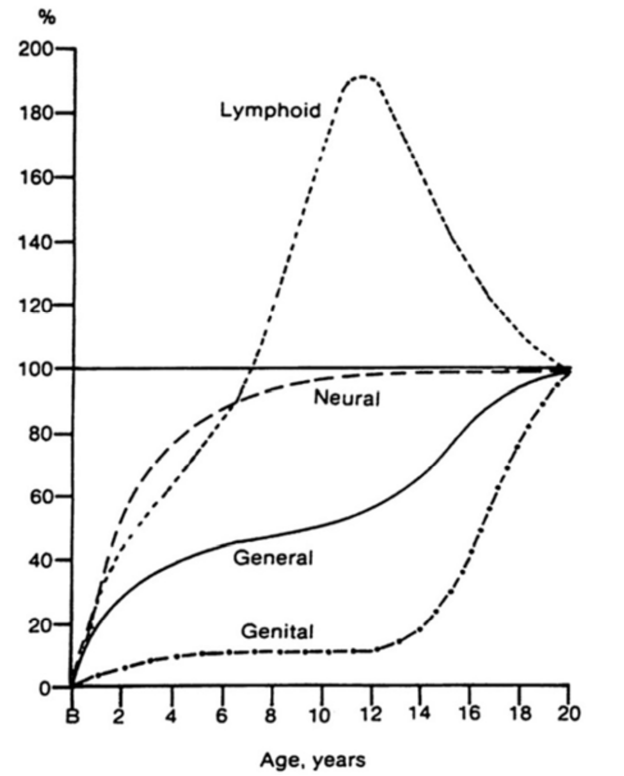

Figure 6. *Four growth patterns in human growth described by Scammon's idea.*

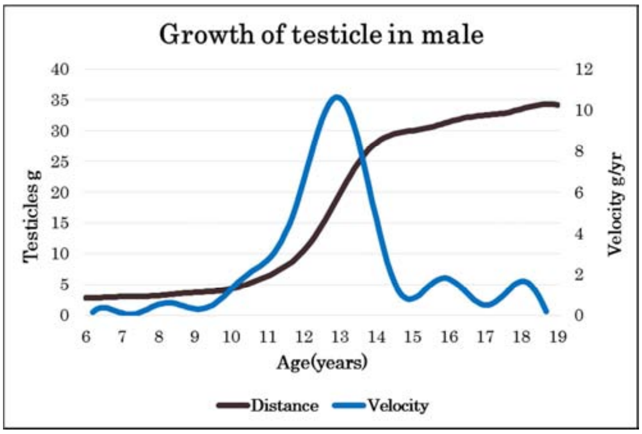

Figure 7. *Growth curve of testicle by wavelet model.*

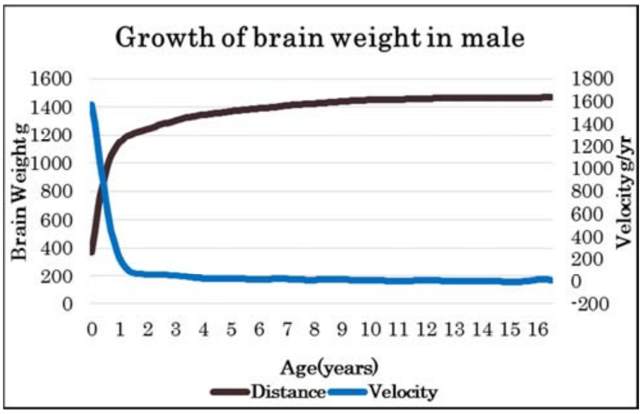

Figure 8. *Growth curve of brain weight by wavelet model.*

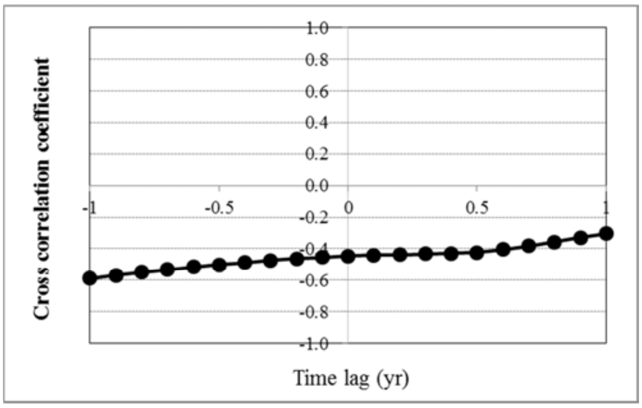

Figure 9. *Cross correlation between testicle and brain weight.*

The growth in testicular weight described by wavelet interpolation is shown in Figure 7, and the growth in brain weight is shown in Figure 8. The results with the application of a cross-correlation function to analyze the similarities and differences between these growth velocity curves (in Figure 9). The results showed an inverse correlation with $r = -0.446$. The differences in the growth in brain weight, which is the neural type, and the testicles, which is the genital type, were obvious. Since it may be that the differences between patterns vary in degree in this way, the respective levels of difference between other physical attributes with this method were derived from cross-correlation functions. The results showed a level of r =

0.743 between brain weight (neural type) and the thymus (lymphoid type), and an inverse correlation of r = −0.639 between brain weight and the liver (general type). Next, the results showed a value of r = −0.70 between the thymus and testicles, r = −0.860 between the thymus and liver, and a fairly high correlation of r = 0.94 between the testicles and liver. Thus, the cross-correlation functions clearly differed between the four patterns and pattern discrimination was shown to be possible. Surprisingly, however, they also indicated the possibility of similarity between brain weight and the thymus and the possibility of very high similarity between the testicles and liver. Therefore, as a result of applying cross correlation functions, 3 standardized type patterns could be distinguished as standardized patterns of growth systems: the neural type, lymphoid type, and general type. The genital type classified by Scammon is then classified in the general type. Thus, new growth system standard type is formed by the classification of a morphology/organ type pattern and a genital type growth pattern within the general type.

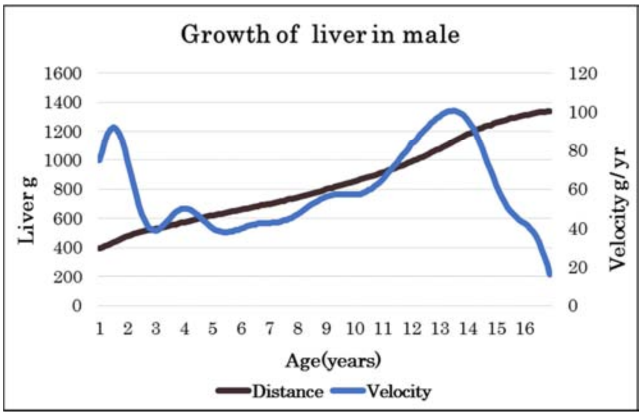

Figure 10. *Growth curve of liver by wavelet model.*

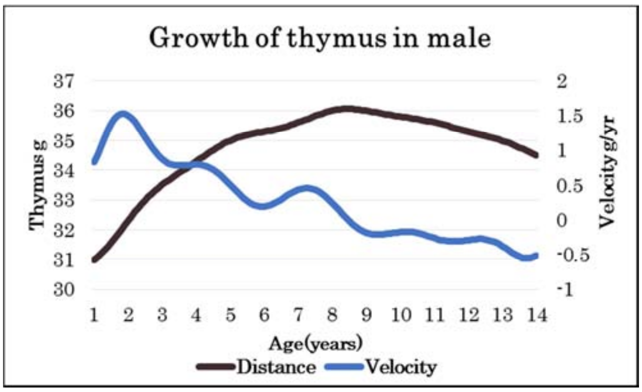

Figure 11. *Growth curve of thymus by wavelet model.*

4. Discussion

Cross correlation functions reveal the degree of interdependence between two time-series waveforms and whether they are similar, with the phase lag times of the two waveforms represented as a Δt function. When a cross correlation function includes time-series waveforms x (t) and y (t+Δt), the correlation coefficient can be found by calculating while increasing Δt. Just like with a correlation constant, the result will be in a range of +1 ≥ r ≥ -1, with a value of 0 signifying no interdependence or similarity between x (t) and y (t). It should be particularly noted that in this study the first derivative fit when the WIM was applied to the growth distance value for each human attribute as x (t).

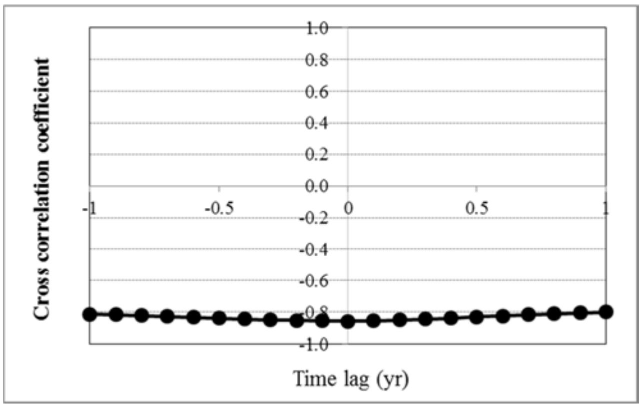

Figure 12. *Cross correlation between liver and thymus.*

Scammon growth curve-based analysis using a range of attributes classified in the four patterns has great potential, this study is content to demonstrate the possibility of classifying by objective methods. While the potential similarity between brain weight (neural type) and thymus (lymphoid type), and testes (genital type) and liver (general type) is demonstrated, differences in coefficients can also be evaluated between the same patterns with high cross correlation coefficients as shown in the similarity between twins. However, there are major differences in coefficients even if there is possible similarity in the relationships between varying patterns. Therefore, for the purposes of this study, it was assumed in coefficients used to assess differences in Scammon growth curve patterns by cross correlation function that pattern dissimilarity was shown when r = 0.3-0.4, with a difference of r = 1 held to be the same pattern. By these criteria, the growth patterns of the thymus, testicle and liver in relation to brain weight were clearly different. However, while the growth patterns of the testicle and liver were also found to differ from that of the thymus, the growth patterns of the testicle and liver demonstrated an extremely high degree of similarity. While clear dissimilarity was found between the neural type, lymphoid type and genital type (general type) growth patterns, similarity was evident between the genital type and general type. While Scammon [5] classified general type as being separate from neural type, lymphoid type and genital type, author may say that, in a fresh development, this study objectively verified the fairly high degree of similarity between genital type and general type.

Author re-examined Scammon's growth curves and considered the general type and genital type, which show the same phenomenon of rapid increase during puberty, to be the same pattern. Author then proposed the Fujimmon growth curves. Fujimmon growth curves classified as neural, lymphoid, and general curves are shown in Figure 13.

Compared with the traditional Scammon growth curves, the growth in the neural type growth reaches a value near the adult value in early childhood. In the lymphoid type, it may be more valid to consider a growth peak up to about 130%, not to 200%, in puberty. The general type is not all that different from the general type in Scammon's growth curves, but the sigmoid shape is not formed to the extent that it is in Scammon's general growth type. This may be the difference between curves drawn freehand and by mathematical functions.

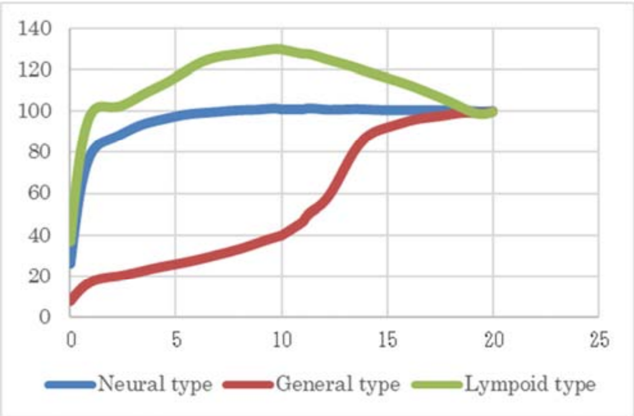

Figure 13. *Newly proposed Fujimmon's growth curve.*

Therefore, the study result that the velocity curves in general type visceral growth and genital type testicular growth can be shown to be very similar is something that seems to have been demonstrated for the first time by Fujii [20]. This proposal for the Fujimmon growth curves as a standardization of the human growth system may make it possible to verify the changes in human proportions formed from three patterns, a neural type, lymphoid type, and general type, from the relative changes in the growth of the head, which is representative of the neural type, and the growth in height, which is representative of the general type.

5. Conclusion

Without yet having been scientifically verified, Scammon's growth curve has been used widely in recent years. There is also a history of advantageous utilization in the field of growth and development research. However, there are major doubts in its application to individuals, and the need for re-verification has been pointed out. In this study, therefore, a wavelet interpolation model and cross correlation function were applied in an analysis of the similarities and differences of growth curves. The wavelet interpolation model was then applied to the growth curves for traits showing four patterns classified as Scammon growth curves: brain weight (neural type), thymus (lymphoid type), testes (genital type), and liver (general body type). Additionally, the cross correlation function was applied to the traits being compared. The cross-correlation coefficients differed between the four patterns of the Scammon growth curves. Pattern discrimination was shown to be possible, but unexpectedly, similarity of the testes and liver was shown. What can be newly proposed, therefore, is that growth curve types can be classified as neural, lymphoid, and general body types, with the genital type included in the general body type. Therefore, as some tentative idea, the Fujimmon growth curves have been proposed as standardization of a new growth system built on Scammon's growth curves.

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