A MODIFIED SOMATOTYPE ASSESSMENT METHODOLOGY

by

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ABSTRACT

Over 50 years ago the idea of a *somatotype* was proposed and described by William Sheldon. With modifications by Parnell in the late 1950's, and by Heath and Carter in the mid 1960's somatotype has continued to be the best single quantifier of total body shape. The process of somatotyping was simplified in 1980 with the publication by Carter of equations for anthropometric somatotype assessment. These equations were claimed to "produce an exact decimalized rating", identical to that produced by the rating forms. No published information has examined this claim.

This thesis examines the relationship between the existing rating form and the published equations, discussing dimensional and conceptual conflicts. New conceptually and historically based equations for calculation of anthropometric somatotype are developed, and a new rating form is proposed that produces the same results as the developed equations.

Summary information shows the differences between the existing rating form and the existing equations and between the existing equations and the proposed equations for a large population (n>18,000) and for sex, age, and activity based subsamples within the population.

For the entire population the most consistency between the existing prediction equation and the newly proposed equation was for ectomorphy with an average difference less than 0.01 units, and with 93.7% of the population producing results within ± 0.1 units

(omitting those with ratings below 0.5 in either system). The least consistent was the prediction of endomorphy where 24.6% of the population differed by more than ± 0.5 units of endomorphy for the two equations. The difference between the existing equation and the new equation for mesomorphy was negligible for populations, but differences occurred for individuals within the population. Mesomorphy ratings agreed within ± 0.1 unit for 75.1% of the population (89.8% of the males and only 49.2% of the females).

The proposed new equations for somatotype assessment are:

$$\text{Endomorphy} = \left[3.269 \times \left(Ln\left(\left(\sum 4 \text{ Skinfolds}\right) \times \frac{170 \text{ cm.}}{\text{Subject Ht. in cm.}}\right)\right)\right] - 8.584$$

$$\text{Mesomorphy} = \frac{170}{\text{height}} \times \Big(.1968\left(\text{arm girth} - \frac{\text{triceps sf}}{10}\right) + .1681\left(\text{calf girth} - \frac{\text{calf sf}}{10}\right)$$

$$+ 0.8973 \text{ (humerus)} + 0.6291 \text{ (femur)} \Big) - 18.84$$

$$\text{Ectomorphy} = 0.7325\left(\frac{\text{Height in cm..}}{\sqrt[3]{\text{Weight in kg.}}}\right) - 28.58 .$$

In all cases, when the calculated result is less than 0.5 a categorical rating of "less than ½" is given.

Dedication

To Maria and Allan, who else?

Quotation

A human being should be able to change a diaper, plan an invasion, butcher a hog, conn a ship, design a building, write a sonnet, balance accounts, build a wall, set a bone, comfort the dying, take orders, give orders, cooperate, act alone, solve equations, analyze a new problem, pitch manure, program a computer, cook a tasty meal, fight efficiently, die gallantly. Specialization is for insects.

Exerpts from the Notebooks of Lazarus Long,
"Time Enough for Love"
Robert A. Heinlein

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Dr. Lindsay Carter. The work would never have been done without your help and criticisms, but your encouragement was most appreciated. As the "keeper of somatotype" for over 25 years I expected some reticence and resistance to my awkward swipes at the area; your immediate response was to open your files and your home to me. "Courteous" and "gentleman" don't do it justice.

Richard and Robin and Craig and ... it won't do, as always, more people to thank than space... you all know you helped a lot. Let's not get mushy about it.

Finally, a few who may not know how much they helped: to Laurie and Shona, who run the place, and to the 303 students who forced me to get a grip on this stuff in the first place.

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I. Background

I.A. Historical Development of Somatotype

For many hundreds of years scientists and philosophers have been attempting to categorize human shape and its relationship to health, intelligence, social stature, criminal behavior, and to a host of other skills and behaviors. Tucker and Lessa (1940a, 1940b) and Carter and Heath (1990, pp. 1-3) summarize much of the constitutional research previous to 1940. For the purpose of this paper the works from Hippocrates - approximately 350 B.C. - through Benke ((1879) cited in Tucker and Lessa , p.268) can all be classified as categorical in nature; they all tended to take the approach that a subject was of one type or of another type, but not a mixture of the two. In 1919 Di Giovanni was one of the first to question this idea by proposing that man was not a "type", but was a blending of types:

> *If the classification of constitutions and of temperaments be based on fictitious scholastic conceptions, the classification is canceled, ... But in the natural morphological characters one studies those complex individual conditions through which every individual is what he is - a variety of the species. (p.3)*
>
> *I do not pretend ... to distinguish human bodies into categories to which must precisely correspond definite morphological combinations. Every attempt at a classification, however severe, would find insuperable difficulties in the law of individual variation. (p.356)*

The preceding quote illustrates the divergence that was occurring about this time. In the mid-1800s Galton, Quetelet, and others began to apply the newly emerging statistical tools involving continuous, Gaussian, distributions to the study of human shape. In the categorical constitution classification methods the subject either "was" or "was not" a type; with the advent and application of continuous statistics a subject could be considered as a number on a continuum. The problem was that, while the categorical methods attempted to classify the entire make-up or constitution of the subject, the statistical evaluation required a single number to work with. Various indexes were proposed over the decades to look at some aspect of physique; for example, Quetelet's (1835) observation that weight was most closely related to $(\text{height})^2$ led to an index of $\frac{\text{weight}}{\text{height}^2}$.

Many more complex examples were also proposed, for example, an index proposed by Wertheimer and Hesketh (1926) attempted to quantify the variation between trunk cavity and limb length: $\frac{\text{leg length} * 10^3}{\text{chest width} * \text{chest depth} * \text{trunk height}} * 100\%$. Jorgensen and Hatlestad (1940) and Tucker and Lessa (1940b) summarize over 40 anthropometric indexes common to the literature from the 1800s through the 1930s related to some aspect of human shape.

The late 1920s and 1930s included innovative conceptual work by Kretschmer (reprinted 1936). Instead of two polar extremes for categories, or separating groups based on cut-off values for simple ratios, his classification scheme involved four basic categories *asthenic*, *athletic*, *pyknic*, and *dysplastic*. Criteria for grouping included anthropometric measurements, descriptive measures of widths and limbs, quality of hair and skin, and others. Again, like Di Giovanni, Kretschmer also seemed to acknowledge that there were intermediate types — one was not necessarily solely in one category. In describing Kretschmer's early work Patterson (1930) states:

> *Although objective measurements are frequently cited, still the differentiation of types remains essentially subjective, involving a synthetic judgment composed of a host of detailed impressions. Indeed, the criteria are so numerous and so unstandardized that it is very doubtful whether or not two independent investigators, equally desirous of faithfully applying Kretschmer's scheme, would classify the same individuals into the same physical categories. ... As the matter stands, Kretschmer's outline is definitely limited in application to material similar to that from which it was derived ... (pp. 158-9)*

By the end of the 1930s the state of constitutional assessment was in evolution. Many ratios and indexes existed to look at some aspect of constitution, but they missed the broad nature of human form available in categorical methods. There was development towards classification of constitution, but it was recognized that it would be ideal to somehow combine the best of categorical and index systems:

> *Another method of morphological classification, ... based its categories on extreme types ... . The method is satisfactory within its obvious limits: it has applicability only for extreme types. Moreover, the groups so formed are not equally pure... .*
>
> *There is still another method of classification, that of the physical*

anthropologist. In combining the two above methods it has proven more satisfactory than either. ... A variant on this technique is to gather data on as large a group as is pertinent to the study, segregate those individuals which tend to cluster about certain types, and then determine if such types correlate with whatever category one may be investigating.

Temporarily such methods may have great value. But when valid systems of morphological classification and norms shall have been worked out for the **entire population** *it would seem the more logical procedure to compare given groups with such norms, rather than employ inter-group comparisons.*

Tucker and Lessa (1940b), p. 417.

It is also about this time that some scientists began to recognize and accept that the assessment of human shape and form was complex and demanding enough to be a specialization; Hooton (1939), while writing about the anthropology of crime, bluntly drew attention to the point:

Knowing that he is a human animal solely by virtue of physical human inheritance ... man has nevertheless neglected almost completely the study of human heredity. ... [W]ith unbelievable stupidity he has refused to admit the self-evident truth that the nature of his own behavior varies principally with the hereditary endowment of his own organism. Faced for centuries with the most blatantly obvious structural-functional relations ... the medical profession has obstinately turned away and occupied itself exclusively with diseases,

> *microörganisms, pharmacology, hygiene, immunology, and everything except man himself. ... The many medical specialties must relinquish their fatal habit of wearing blinders which prevent them from seeing anything except their own specific problems of pathology. ...*
>
> *... I am afraid that they will even have to utilize the services of the physical anthropologist, because he is the only human biologist who has bothered with the morphology and anatomy of man as an evolving animal rather than as a potential patient. He is at present also almost the only specialist who is accustomed to the scientific statistical analysis of intricate masses of data pertaining to great series of human beings.*
>
> *Crime and Man, Hooton (1939), pp. 394-5.*

With the turn of the decade such a "physical anthropologist" appeared, a with a rating scheme broad enough to encompass all of humankind. In *Varieties of Human Physique* (1940) William Sheldon - a self-professed "constitutional psychiatrist" - first proposed his ideas for a three component rating scheme for the assessment of human shape; this self-professed constitutional psychologist was the first to propose the idea of the *somatotype*. Sheldon's somatotype was composed of endomorphy - relative predominance of soft roundness throughout the various regions of the body, mesomorphy - predominance of muscle, bone and connective tissue, and ectomorphy - relative predominance of linearity and fragility (p.5). The somatotype was an assessment of the body shape, regardless of its size, and a person's somatotype was assumed to be unchanging for life, despite outward changes in physique:

There is evidence for the hypothesis that the somatotype can be accurately measured at age 6, and that it can be approximately predicted almost from birth, but both suppositions remain to be tested. Similarly it seems probable that the physical constitution at the morphological level is rather rigidly determined before birth, and that it cannot be perceptibly changed during the course of a lifetime.

Sheldon, (1940), p.216.

In this ground-breaking book Sheldon tended at times to vacillate between scientific description and anecdote. Much more printed space was given - less than a page - to describing the technique for photographing the subjects ("... Corona type of portrait camera ... either film pack or cut film may be used ... by using a long focal length ... subject stands on a pedestal so placed that the backs of the subject's heels ... light gray background is most satisfactory ..." p.30) than to the subjects themselves ("... 4000 undergraduate male students ... collected at several midwestern and eastern universities ... racial element was disregarded ..." p 31). That three components were satisfactory and sufficient to describe physique - a fundamental aspect of defining what "somatotyping" is - Sheldon spends less than a paragraph:

To those who may wonder why three *extremes were chosen, it should be pointed out that in a large random sample it is precisely three extreme types which stand out. Repeated combing of the population for what might reasonably be called a fourth basic type of extreme variation simply yielded nothing at all. We were not committed to find three first-order variants - and only three. It is, indeed, fair to state that we rather* *expected to find more than three. We were initially reluctant to accept the conclusion that only three fundamentally different extremes can be isolated.*

Sheldon, (1940), p.31.

No proof is offered. Sheldon never published raw data, summary results, or methodologies detailed enough to allow replication or validation for any of the claims made in this or in his later works. The reader was, and is still, left to accept the claims on face validity or not at all.

At that time Sheldon's somatotyping methodology primarily involved comparison of photographs of the subject to check-lists of criteria, comparison to some photographs of "known" somatotypes, and comparison of the subject's $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ ratio to tables of possible somatotypes. This information was combined with information derived more systematically by taking measurements from the photographs and using ratios to narrow down the possible somatotype (Sheldon,1940). Additional details on Sheldon's somatotyping methodology are to be found in section A.I.

From its publication *Varieties of Human Physique* was criticized on both methodological and conceptual grounds (Meredith, 1940; Lasker, 1947; Hunt, 1949), but it was also becoming accepted; by 1949 the situation in physique analysis was summarized by Tanner (1949):

There have been several more or less recent systems of classification which provide, or claim to provide, this more accurate assessment [physique assessment beyond habitus apoplecticus, or athletic type]. The method devised by W.H. Sheldon is much the most flexible, accurate, and comprehensive. Indeed, it has only one rival, which may ultimately overtake it but at present is far less practically useful - the factor analysis method. Sheldon's system renders Kretschmer's classification obsolete, ...

Factor analysis, the extraction of relationships from correlation matrixes, was still popular as a potential way of utilizing the plethora of physique ratios in attempts to capture "physique" in the most statistically-significant numerical form. In an attempt to apply factor analysis to Sheldon's somatotype Adcock (1948) commented:

The striking feature about Sheldon's scheme is its tripolar nature. This is a rather unusual state of affairs since we should expect that any two traits which correlated negatively would have opposite signs for their correlation with a third. Obviously such a result can come about only if at least two of the traits concerned involve at least two factors each ... All this analysis has been concerned with a modified matrix and not our original correlations at all. Are we not wasting our time playing with a solution that cannot fit the original data unless we can justify our modification of the data?

That scientists of the era were having difficulty finding statistical significance and interrelations between components of somatotype, and were having difficulty fitting this new tool to their current favorite statistic was not a failing of somatotyping. It was a failure on the part of the experimenters to comprehend the nature of a somatotype; a rating of "3½" in mesomorphy had, and still has, a much different meaning for a subject's body shape composition and potential psychological evaluation depending upon the values of the other two somatotype components. This was beyond the comprehension of the statistics, and apparently therefore of the scientists themselves.

Human biologists were quick to realize the potential for somatotype as a method of physique assessment, but were stymied by the methodology. Experimenters were limited to collaborating with Sheldon's group for somatotype assessment (for example Perbix, 1954), or to making their own attempt at interpreting Sheldon's scheme. An example of the latter, from Garn and Gertler, 1951): "The somatotype studies followed the methods of Sheldon ('40) as closely as possible, although no standards were available for this age group ... the height-weight ratio was not used as fixed criterion ... and less attention was paid to exclusively abdominal fat deposits ..."

Tanner (1951) describes the situation at that time succinctly:

> *... Sheldon's system fundamentally rests on anthroposcopy - i.e., looking at the person. Admittedly he later measured his pictures and thus produced a set of tables by which he claimed it was possible to somatotype quite objectively young men between the ages of 16 and 20 in a normal stage of nutrition and health ... Though ten years have elapsed since the publication of these tables there has been not a single report, so far as I know, of any attempt by other laboratories to use this anthropometric technique. Perhaps this is because the technique is*

certainly arduous and time-consuming; but it may also be that investigators have met unexpected difficulties. Certainly we have; for several years in my laboratory we have been trying to use this metric technique and have encountered considerable trouble.

First, Sheldon gives insufficient details of the photographic technique he adopted for it to be repeated exactly. ... Personal communication dispelled these difficulties, but we then found others ...

... I say this not in criticism of somatotyping, which I believe to be the greatest single advance yet made for the study of human physique, but to indicate that in Sheldon's system measurement is a secondary consideration. He has now made this very clear himself ...

This is echoed by Hunt (1952):

The classification of body build is still one of the most controversial problems in constitutional research ... The somatotype, as first described by Sheldon, Stevens, and Tucker ('40) is still the focus of this controversy. ... In my opinion, the skill necessary to derive such fundamental ratings [from photographs, fixed for life] *is still impossible to acquire. For example ...*

In 1954, Sheldon (with Dupertuis and McDermott) published his *Atlas of Men*. This volume including photographs of 1175 men selected to represent the entire available spectrum of physique types and criteria for photographing and measuring subjects. The Atlas also contained updated height-weight tables for males from 18 to 63 years old, in five year increments. It lacked, however, any methodological information for somatotyping, containing only hints and vague statements to help the somatotyper scattered throughout its text. Presumably the vague, incomplete, instructions contained in *Varieties of Human Physique* (Sheldon, 1940) were deemed adequate; this despite numerous claims in the preface that "the principal purpose of the Atlas is to make available a standard file of somatotype variations, together with the criteria actually employed in somatotyping ...". Sadly, this work dropped the technique of using measurements from the photographs to assist, clarify, or objectify the assessment of somatotype; the metrification of somatotype was soundly renounced by Sheldon (pp. 7-9).

In the *Atlas* Sheldon also discussed - in passing - the effect of sex, age, and nutrition on somatotype assessment; he attempted to make it possible for other interested scientists to make use of his systematized rating scheme for assessing human shape. This work represented a clarification, not a change, in his fundamental position on the nature of somatotype.

Somatotype, as defined by Sheldon, had the following basic characteristics:

- It was composed of the three components, endomorphy, mesomorphy, and ectomorphy.
- The somatotype was a rating of shape, not of size.
- A subject's physique was composed of all three components in equal or unequal parts. A person was not "pure mesomorph" for example, but could have much more mesomorphy than s/he had the other two components.

- A subject's rating for each component went from 1 to 7 in whole units or, more often, was rated from 1 to 7 in ½ unit intervals.

- The sum of the three components was to be between 9 and 12.

- The somatotype scales were arbitrarily defined by the series of photographs Sheldon and his group used to create them. For example, the difference between a 4 and a 4½ in mesomorphy had no defined relationship to the difference between a 6 and a 6½ in mesomorphy; the scale was wholly described by the nature of the original sample.

- When assessed correctly, a subject's somatotype did not change over time or with nutritional status. If these changes occurred they were due to rater error, not due to change in somatotype. This invariant nature is mentioned by Sheldon at a conference in 1951 where he discusses the difference between a *morphophenotype* - the current expression of form - and a *morphogenotype* - "the original hereditary and continuing genetic influence which cannot change". Sheldon does not claim that somatotype and the morphogenotype are the same, only that the somatotype "is the makeshift causeway by which we attempt to progress from phenotype to genotype ..."

To this time, little had been done to look at inter-measurer reliability, since the few scientists claiming to be assessing somatotype in accordance with Sheldon's photographic methods were all working within the same general laboratory group. When Tanner (1954) published a paper looking at the inter-measurer and intra-measurer reliability of somatotypers he contented himself with looking at three observers: himself, Barbara Honeyman, and C.W. Dupertuis, all classifiable as members of "Sheldon's group"; when Tanner and Weiner (1954) wanted to look at the reliability of measurements from photographs Sheldon himself did the measurement. As Parnell (1958) put it:

> *"Why has Sheldon's method of somatotyping, with its great appeal and prospect of usefulness, not come into daily use?" Apart from the theoretical objections ... there are other reasons ... Foremost among these is the subjective nature of photographic somatotyping. ... No scientist could be sure that he was doing what Sheldon did without requesting personal supervision of his work by the master. ... As I have said elsewhere, agreement between photoscopic somatotypists implies that they have learnt to sing in harmony, but their song does not thereby become a science, it remains an art. (p. 6)*

The mid-1950s found a number of researchers, while acknowledging the interesting aspects of Sheldonian somatotype, still working on physique or constitution assessment systems of their own. Factor analysis (for example Howell,1951) where he devised his own factors or (1952) where he used Sheldon's components) and ratios or numeric indicators (for example Hammond, 1953) continued to be proposed. Some investigators were looking at the relationship between various anthropometric quantities and somatotype components (for example Brozek and Keys, 1952; Bullen, 1953), while others were comparing photogrammetry (measurements from photographs) to anthropometry (measurements of the subject directly) — for example Tanner and Weiner (1954).

In 1954 Parnell produced a paper, *Somatotyping by Physical Anthropometry*, outlining a technique for using standard deviation tables of anthropometric measurements to determine relative strength of somatotype components within a subject, and then using Sheldon's height-weight tables to select the most likely somatotype (additional information on the technique is in section A.III). Effectively, this was the first application of anthropometry for the prediction of somatotype. In 154 men between 16 and 20 years of age Parnell reports that in 90% of the cases the ratings were the same as the Sheldonian photometric method to within a half a somatotype unit, essentially the same as inter-observer agreement using photoscopic assessment.

In his 1958 book, *Behavior and Physique,* Parnell outlines the first system of somatotyping that was completely independent of Sheldon's work (the 1954 tables required the rater to resort to Sheldon's tables for a final estimation), and that relied entirely on anthropometry. Parnell summarized his perceived advantages of somatotyping by physical anthropometry (p.7): ...

(a) provide somatotype procedure with the backing of objective anthropometry.

(b) extend objective phenotyping to women, to older persons and also to children, thus promoting the start of family studies.

(c) report a preliminary phenotype or somatotype estimate (depending on the age and circumstances) at the time of the clinical interview which may be completed, together with a written report, in fifteen minutes.

(d) provide useful information about healthy populations without resort to photography. ...

(e) Re-interpret data in terms of new components or factors as the science develops: for this the combined physical anthropometric and photographic data are more comprehensive.

Endomorphy was estimated by the sum of three skinfolds; mesomorphy was estimated from arm girth, calf girth, elbow width, and knee width, with a correction for adiposity and for age; and ectomorphy was estimated from $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$. The calculation was performed by circling appropriate values on a table and directly estimating the somatotype from the table. The technique is described in more detail starting in section A.IV.

This M.4 deviation table was developed to be as close to Sheldon's somatotype as possible for a phenotypic system, with an emphasis on remaining consistent especially for healthy young males (Parnell, 1958, pp. 19-20). In this work Parnell tries to point out that he is estimating something related to, yet different from Sheldon's somatotype due to the phenotypic nature of his rating. He originally begins by describing the system as a "F M L rating" - for "Fat, Muscularity, and Linearity" (p.19), yet much of the remainder of the text refers to endomorphy, mesomorphy, and ectomorphy derivation, as does the M.4 table itself. In that the M.4 method effectively had adjustments in all three components to account for increased fatness and decreased muscularity with aging and tried to use a typical weight, based on weight at ages 18 and 23 taking into account recent weight loss or gain, it is clear that Parnell was trying to estimate something very close to Sheldon's idea of a somatotype - something that was relatively fixed for the individual despite changes in shape due to aging or health.

Where Parnell had used a systematic methodology to construct his tables, attempting to maintain conceptual consistency with his predecessors, others were less diligent. In 1962

Damon, et. al. published a series of equations for the prediction of somatotype components from anthropometry. These equations were determined by statistical analysis of 49 anthropometric measures and derived values to predict somatotype components. While this may well represent the first reported equations for somatotype estimation, no attempt is made to distinguish 'reasonable' variables from those with secondary or sample-specific predictability. Despite using more variables than Parnell's M.4 table, the equations predicted Sheldonian somatotype poorer than the M.4 tables. It is of interest that, while the paper by Damon, et. al.(1962) contains Parnell's works in the references, and while it makes passing reference to a result by Parnell linking somatotype to a clinical psychology measure, no mention is made to the M.4 system of anthropometric somatotype derivation.

From its inception Sheldon's view of somatotype had been scientifically attacked (Meredith, 1940; Lasker, 1947; Hunt, 1949; Bodel, 1950; Hunt and Barton, 1959), primarily on the grounds that - while Sheldon claimed a somatotype was "fixed" and recognizable - there was a growing body of evidence that body shape changed unpredictably over time with many subjects, and secondarily that many of Sheldon's "rules" seemed arbitrary and based on personal biases rather than experimental evidence.

Heath (1963) continued this tradition of pointing out problems in Sheldon's method of somatotyping, but she did something different - she also suggested changes. Heath had the advantage of having worked in Sheldon's lab, presumably doing much of the rating of the thousands of photographs given to Sheldon for rating — in the preface to the *Atlas of*

Men (1954) Sheldon wrote "Barbara Honeyman [Heath], Dorothy Paschal and Madge Deaver, being women, have naturally done most of the hard work of the project in recent years." Heath's modifications were as follows (modified from Heath ,1963, p.228):

Table 1: Changes in Somatotype Proposed by Heath (1963)

Sheldon	Heath's Modification
7 point scale. Ratings no lower than 1 and no higher than 7.	The rating scale is open at both ends, beginning (theoretically) at zero and having no (theoretical) end point.
The sum of somatotype components should be between 9 and 12.	No arbitrary limit of the sum of components.
Sheldon's height-weight ratio for age 18, showing possible somatotypes for each ratio.	Modified to preserve a linear relationship of somatotype components over the range of height-weight ratios. In theory, this would allow extrapolation beyond the table range.
Sheldon produced height-weight tables for male subjects in five-year increments.	The same table was to be used for all ages and both sexes.

These four specific modifications are expressions of more fundamental premises:

- The somatotyping technique should be as internally consistent as possible.
- The somatotype is a description of current shape, and not a morphogenotype estimate.
- Internal consistency dictates that the same rating technique and scale should be used for all ages and sexes.
- The original "vocabulary" of somatotyping should be preserved as much as possible.

This paper describes no new techniques for assessing somatotype, and might be described as only a "modernization" of Sheldon's original idea to bring it better in line with current scientific opinion of what somatotyping should be.

In 1966 Heath and Carter produced a detailed comparison of Heath's 1963 method and Parnell's 1958 M.4 method for determining somatotype. While this paper is a valid work on its own, the primary value is two-fold: (i) to indirectly suggest that neither photoscopic nor anthropometric assessment of somatotype is intrinsically better, rather that they can be combined to give a very reproducible quantification, and (ii) to provide supportive data for their 1967 publication. This paper by Heath and Carter (1967) melded photoscopic and anthropometric somatotype estimation into a single technique; the actual methodology for using this new Heath-Carter somatotype is in section A.V. The major changes to Parnell's M.4 table were to eliminate any adjustment for age, and to better adapt it for use by both sexes over a wider potential range of somatotype values.

The 1967 Heath-Carter somatotype form was developed using as much data as was currently available to the authors. Samples representing extreme physiques - where photoscopic ratings as well as anthropometry were available - were used as much as possible. In some cases this resulted in a compromise, while over 800 subjects are cited as being used for the development of the techniques this does not tell the whole story. For example only 501 subjects had enough information to be used in the estimation of endomorphy, and effectively all of the subjects with photoscopic ratings over 7.5 - over

20% of the entire sample group - came from a study of 102 obese females where only height, weight, triceps and subscapular skinfolds were measured (all other anthropometry was missing and was estimated). That the authors chose to use a wide range of physique types, even though some anthropometry was missing, is to be commended rather than condemned when one considers the alternative of using only the widely available, but hardly representative, "young, fit, university" samples that tend to permeate the scientific literature.

Others were contributing to somatotype methodology during the same time period. Petersen (1967) published an *Atlas for Somatotyping Children*; while it contained a large number of photographs with their somatotypes, as in Sheldon's atlas, it had no significant discussion of the methodology for assessing the somatotype of children or the specific problems related to somatotyping children. Preston and Singh (1972) developed an ingenious device for photo-electrically estimating somatotype from the light transferred through an amputated, size-adjusted, slide of the subject. The authors claim that this was a much simpler method of determining somatotype than other existing methods. Interestingly, while Heath and Carter's 1967 paper is one of the three references for this work, no mention is ever made of their (far simpler) rating form.

Sheldon's four major works, *The Varieties of Human Physique* - Sheldon, et. al (1940), *The Varieties of Temperament* - Sheldon et. al (1942), *Varieties of Delinquent Youth* - Sheldon, et. al (1949), and *Atlas of Men* - Sheldon, et. al (1954) continued to be cited regularly in the scientific literature during this period. Sheldon himself appears to have published nothing in refereed journals during the 1960's, using the occasional symposium as the only method of disseminating his views. For example, in a paper presented at a symposium in 1965 Sheldon discussed the development of somatotype components from basic tissue layers (with no scientific support), brushed off objections to somatotyping with platitudes and (presumably) hyperbole ("since I had never encountered a two-dimensional man it seemed reasonable that a scientific classification of men had better rest its case on at least three primary structural dimensions"), and - most significantly - mentioned a new "Trunk-index" method of somatotyping.

This Trunk-index method of somatotyping involved, in part, measuring the area of the upper (thoracic) trunk versus the lower (abdominal) trunk from photographs with a planimeter. That this new method had no published relationship to any older somatotype method, that it now included "size" in the rating - violating the always present definition that a somatotype was to be "shape", not "size" related, that its development was defined only in poetic rather than verifiable terms, and that Sheldon continued to avoid publishing his results and methodologies in open journals likely all contributed to the lack of adoption of this new method. It is likely that the presence of a clearly described, well documented, consistent, and historically grounded method - the Heath-Carter somatotype - also lead to the lack of acceptance of this innovative and unsubstantiated trunk-index.

The Heath-Carter somatotype was quickly accepted in a number of disciplines. In the more than 400 papers utilizing somatotype published during the 1960's and 1970's "only"

28% of the papers from the 1960's used the Heath-Carter somatotype, yet by the 1970's 70% of the papers using somatotype used the Heath-Carter technique (Deutsch and Ross, 1978).

In 1973 an adjustment to the Heath-Carter somatotype calculation form was proposed by Hebbelinck, Duquet, and Ross in a paper discussing the application of somatotyping children. While height is accounted for in the calculation of both mesomorphy and ectomorphy - nominally removing "size" from the assessment of "shape" - endomorphy was being calculated using a sum of three skinfolds. Larger people have larger skinfolds than smaller people of the same shape (see section 1.B for a discussion of geometric scaling), yet both should receive the same endomorphy rating for body shape. The proposed adjustment involved multiplying the subject's sum of skinfolds by $\left(\frac{170.18\text{ cm}}{\text{subject height}}\right)$, effectively reducing the value for larger subjects and increasing the value for smaller subjects before comparing them to the table. This correction was endorsed by Heath and Carter becoming a recommended inclusion in the calculation of the Heath-Carter somatotype since its suggestion.

In 1977 Ross, Brown, Yu, and Faulkner published a paper in which they state that "a computer program was used to derive somatotypes, plot sample distributions and calculate somatotype dispersions indices", however they give no information regarding the program's methodology. The only information is in an acknowledgment:

... The SOMA computer program used in the analysis was assembled by Mr. Reo Audette, Simon Fraser University Computer Centre from contributed programs designed by Mr. B.D. Wilson, formerly SFU currently at State University of Iowa; Dr. J.E. Lindsay Carter and Mr. S.P. Aubry, San Diego State University; and Dr. D.A. Bailey and Mr. C. Weese, University of Saskatchewan....

From the number of contributing sources to the program it is clear that many researchers were working on somatotype calculation; it is unfortunate that none bothered to publish their algorithms.

In 1980 equations were first published by Carter allowing direct prediction of Heath-Carter somatotype from the anthropometric variables without the use of look-up tables. The equations were published as a chapter addendum by Carter in his 1980 laboratory manual (Carter, 1980), but the addendum carries the trailer "J.E.L. Carter, Dec., 1978". No information is given in this or later works describing the derivation methodology for the equations, though it is reasonable to assume that they are in some way related to the program referred to by Ross, et. al. since Dr. Carter was one of the contributors. These equations by Carter have remained unchanged since their initial presentation and have been accepted as producing equivalent results to those obtained from the tables. This acceptance has never been tested, although its acceptance is clearly demonstrated in that many studies using Heath-Carter somatotype published in the 1980's and 1990's cite Carter's manual for calculation methodology, yet do not specify if they are using the table or the equations to calculate the somatotypes.

Currently, to use somatotyping in a scientific study means to use Heath-Carter somatotyping - either the table method or the equations. While it is possible to find papers which still claim to use Sheldon's 1954 method, Parnell's 1958 method, or other less accepted methods to calculate somatotype (Sheldon's 1969 Trunk Index, and Tucker's 1982 Perceived Somatotype Scale), Heath-Carter somatotype is the de facto standard for modern somatotype determination.

While a number of papers have been published comparing various methods of somatotype analysis - Parnell versus Sheldon, Sheldon versus Heath-Carter, et cetera - no comparative analysis has been done comparing the Heath-Carter form method to the Heath-Carter equations. This comparison will be one of the purposes of this thesis.

I.B. Kinanthropometric Concepts: Size, Shape, and Dimensional Scaling

In order to discuss potential problems with the existing equations for determining somatotype, and to provide a basis for evaluating any proposed changes, it is necessary to discuss what is generally meant by shape as it relates to changing size. Shape can generally be considered to be related to the ratio of measurements or dimensions. For example, when a person is viewed from a distance they still appear to have the same shape as they do when they are closer; all of the visual dimensions have diminished in proportionally. That a photograph can accurately represent the shape of a person in an image that is only centimeters tall allows it to be used for somatotype rating in the first place. A Barbie doll and Michelangelo's David both seem visually humanoid despite being about 25 centimeters and 5.4 meters tall respectively - a result of dimensional scaling to maintain shape.

When we say that two objects, or two people, "have the same shape" we are really saying that they are geometrically similar. A big cube is geometrically the same as a small cube because it maintains the same dimensional ratios - all of the sides of a given cube are the same length - so a big cube and a small cube appear to have the same shape, despite differing in size. The geometrical similarity system as it applies to human anthropometry is a "what if" statement: "what if, as individuals changed their size, they maintained their same shape and relative body composition?" The premise behind this model is like a big slide projector, as you turn the zoom knob everything gets bigger and smaller in the same ratio (a picture of a person gets twice as wide if it gets twice as tall...).

Before being able to discuss somatotype-related concerns it is necessary to cover the mathematics of geometric scaling. Geometry is interested (in part) in showing the inter-relationships between the measurements of various two and three-dimensional objects, for example, a sphere:

Circumference (simple):	$2\pi * r$	(where r is the radius of the sphere)
Surface Area:	$4\pi * r^2$	
Volume:	$\frac{4}{3}\pi * r^3$	

a cube:

Circumference (simple):	$4 * L$	(where L is the length of a side)
Surface Area:	$6 * L^2$	
Volume:	L^3	

A big cube is related to a small cube in a very specific way; if the ratio of <u>any</u> of their linear measurements is $\left(\frac{L_{BIG}}{L_{SMALL}}\right)$ then the ratio of <u>any</u> of their area measurements is $\left(\frac{L_{BIG}}{L_{SMALL}}\right)^2$ and the ratio of their volumes is $\left(\frac{L_{BIG}}{L_{SMALL}}\right)^3$. The same relationships hold for a big sphere compared to a small sphere. The same relationships hold for any three-dimensional objects, where there is no difference is shape, only in size.

With the geometrical similarity system it is customary to express all quantities in terms of a primary quantity of length [L]. The circumference of a sphere or cube, an arm girth, a skinfold measurement ... all are linear measurements, and all are expressed as $[L]^1$. The surface area, or cross-sectional area of a sphere or cube, a human body's surface area, a cross-section of a limb ... all are measurements related to area, and all are expressed as $[L]^2$. The volume of a sphere or cube, a lung volume, ... all are volume measurements, and all are expressed as $[L]^3$. It is important to note one other assumption of geometrical similarity: both shape and composition (density) are constant. Since density is constant, mass is directly proportional to volume, and therefore has the dimension $[L]^3$.

This relationship between the size of an object and various other measures has been accepted and discussed for centuries. Galileo's "cube-square law" is often invoked when comparing structures - animal or otherwise - that are different sized. Simply put, if one accepts that the strength of an object is related to its cross-sectional area (the strength of a bridge pillar to resist breaking, the force a muscle can exert,...) $[L]^2$, and that the load being supported or moved is the object's mass, $[L]^3$, then the strength per unit mass ratio becomes $\frac{[L]^2}{[L]^3}$ or $\frac{1}{[L]^1}$ or $[L]^{-1}$. A bigger person being compared to a smaller person geometrically is stronger - $[L]^2$, but is weaker *for their size* - $[L]^{-1}$. If we make a model of a bridge that is $\frac{1}{20}$ the size of the actual bridge, all of the linear dimensions will be $\frac{1}{20}$ the size of the real bridge, the strength of the supports will be $\left(\frac{1}{20}\right)^2$, but the mass of the structure will be $\left(\frac{1}{20}\right)^3$ of the real bridge. The model will be stronger (per unit mass) by a factor of 20 compared to the full-sized bridge, demonstrating scaling proportional to $[L]^{-1}$.

A complete discussion, and further clarification, is available in the definitive source for dimensionality - Darcy Thompson's *On Growth and Form* (1963)

This *dimensionality* is implicit in an equation, for example the strength per unit mass ratio, $\frac{[L]^2}{[L]^3}$, as an equation has the dimension $\frac{1}{[L]^1}$ or $[L]^{-1}$; within the geometric similarity system, the strength to mass ratio of any object decreases with the increasing size of the object. Quetelet's $\frac{\text{weight}}{\text{height}^2}$ ratio also has the dimensionality of $\frac{[L]^3}{[L]^2}$ or $[L]^1$, as does the Body Mass Index (BMI) - the modern invocation of Quetelet's ratio. In a geometric system any result other than $[L]^0$ implies that the result changes with changing size of the subject, yet the BMI has been selected precisely because it best removes size from the comparison of weight. This potential contradiction lies in the acceptance or rejection of geometric scaling as the method of size adjustment. Big people, as a group, tend to not look exactly the same as smaller people; bigger people tend to be more "stretched out", having less weight for their height. The BMI tries to account for what is "normal" by having a sample-specific, non-geometric, exponent for height, where geometry would dictate an exponent of "3" for height. That geometry doesn't match the "real world" is no more a failing of the geometric system than it is a failing of humans to differentiate "correctly" along geometric lines, some systems fit geometric similarity better than others.

Somatotype, from its developmental roots, has been geometric in nature. A photograph - a tiny, geometric, representation of the actual person - is being used to represent the actual person. The $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ ratio - $[L]^0$ in geometric dimension - has been used from Sheldon's inception of somatotyping to initially limit the potential somatotypes of a subject. The same height-weight ratio has always been used to calculate ectomorphy, continuing to the present Heath-Carter somatotype system. The height correction to the Heath-Carter determination of endomorphy; all of these examples highlight the implicitly geometric nature of somatotype. If one accepts that somatotype as a concept is geometric in nature then it follows that the methods for calculating somatotype should also be geometric.

I.C. Dimensionality of Somatotype

The basic presupposition that somatotype is a rating of shape independent of size, and that somatotype is geometrically based lead one to the conclusion that somatotype determination should be "$[L]^0$", or dimensionally independent of size in its assessment.

Heath-Carter table - Endomorphy

The original Heath-Carter method of looking up a sum of skinfolds in a table implied that endomorphy is proportional to the sum of skinfolds, or endomorphy $\propto [L]^1$.

That the relationship between the sum-of-skinfolds and the predicted endomorphy is not linear - a doubling in skinfold thickness does not necessarily result in a doubling in endomorphy - clouds the issue somewhat, but if we had two subjects geometrically the same shape but differing in size, the larger person would have larger skinfolds and would be given a larger rating for endomorphy.

The modification to Heath-Carter endomorphy calculation proposed by Hebbelinck, et. al (1973), and adopted by Carter (1980), where the sum of skinfolds is multiplied by $\frac{170.18}{\text{subject's height}}$, is another matter.

Endomorphy $\propto (\Sigma \text{ skinfolds})(\frac{170.18}{\text{subject's height}})$ has the dimensionality of endomorphy $\propto [L]^1 * \frac{[L]^0}{[L]^1}$, or endomorphy $\propto [L]^0$. This shows that the current method of calculating Heath-Carter endomorphy is truly geometrically size-dissociated.

Heath-Carter equation - Endomorphy

The current equations for the calculation of endomorphy have:

endomorphy = -0.7182 + 0.1451(X) - 0.00068(X)^2 + 0.0000014(X)^3

where X = sum of (triceps, subscapular, suprailliac skinfolds)

or X = [sum of (triceps, subscapular, supraspinale skinfolds)] * $\frac{170.18}{\text{subject's height}}$

for height-corrected endomorphy (the modification by Hebbelinck, Duquet, and Ross, 1973).

In exactly the same manner as for the tabular determination of endomorphy, with the equation form endomorphy $\propto$ (Σ skinfolds)($\frac{170.18}{\text{subject's height}}$) has the dimensionality of endomorphy $\propto [L]^1 * \frac{[L]^0}{[L]^1}$, or endomorphy $\propto [L]^0$.

Parnell M.4 table - Mesomorphy

It is not simple to discuss the dimensionality of Parnell's mesomorphy determination table. The columns in Parnell's 1958 M.4 deviation table for mesomorphy were truly geometrically based, and thus might, to a first approximation, dimensionally adjust for size. That different parts of the table are used depending upon the height of the subject, blurs the pure geometry of the system; this is best illustrated with an example. Imagine a person 55 inches tall with a humerus width of 5.78 mm. Looking at the M.4 table (Figure 11) this represents exactly three columns of deviation to the right for the bone measurement from the height column. If the same person is now geometrically scaled to 74.5 inches tall their humerus measurement would be 5.78 mm * $\frac{74.5 \text{ inches}}{55 \text{ inches}}$ = 7.83 mm. This geometrically derived humerus measurement represents four columns of deviation from the new height, not the three columns that should have occurred if true size-dissociation was present.

It is not simple to define an equation that relates the quantities involved, so it is not simple to define the dimensionality of the table. Suffice it to say that the dimensionality is not $[L]^0$, but may be close to it.

Heath-Carter table - Mesomorphy

The preceding discussion of Parnell's M.4 mesomorphy table is also applicable to the Heath-Carter mesomorphy table. That Heath and Carter shifted all of the height values one column to the left complicates the assessment of its geometric dimensionality. In Parnell's table each column of values was geometrically identical to all of the other columns - for example, all of the values in the column headed by 70 inches of height were $\left(\frac{70}{58}\right)$ the size of the values in the column headed by 58 inches of height. In the Heath-Carter mesomorphy table all of the values in the column headed by 70 inches of height were $\left(\frac{70\text{-}1.5}{58\text{-}1.5}\right)$ the size of the values in the column headed by 58 inches. That the ratio in heights is not the same as the ratio in the other measurements is a clear indication that correct geometric scaling is not maintained.

To follow the same example used in the preceding discussion of Parnell's table, if we take a subject 55 inches tall with a humerus width of 5.64 mm (different from the value used in the preceding example, but with the same number of columns deviation from the height column) this produces a deviation of exactly three columns from the height column. If this person is then geometrically scaled to 74.5 inches tall their humerus measurement would be 5.68 mm * $\frac{74.5 \text{ inches}}{55 \text{ inches}}$ = 7.64 mm. This represents almost four columns of deviation from the height column. This is not the geometrically expected value of three columns, neither is it exactly the same as that resulting from Parnell's table; there is additional confounding factor introduced by the shifting of the height values one column to the left. Again, it is difficult to determine exactly what the dimensionality of the Heath-Carter mesomorphy table is, but it is potentially also close to, but not equal to, $[L]^0$.

Heath-Carter equation - Mesomorphy

Substituting dimensional notation into the Heath-Carter mesomorphy calculation: mesomorphy = 0.858(humerus) + 0.601(femur) + 0.188(corrected arm girth) + 0.161(corrected calf girth) - 0.131(height) + 4.5 gives: mesomorphy $\propto$ 0.858 $[L]^1$ + 0.601 $[L]^1$ + 0.188 $[L]^1$ + 0.161 $[L]^1$ - 0.131 $[L]^1$ + 4.5 $[L]^0$ or mesomorphy $\propto$ 1.68 $[L]^1$. That the variables in the equation are all size related ($[L]^1$ rather than $[L]^0$) leads to the conclusion that resulting equation must also be $[L]^1$.

Heath-Carter table - Ectomorphy

To determine ectomorphy with the original Heath-Carter table, the user was required to calculate and look up the $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ ratio.

If ectomorphy $\propto \frac{\text{height}}{\sqrt[3]{\text{weight}}}$ then

$$\text{ectomorphy} \propto \frac{[L]^1}{\sqrt[3]{[L]^3}} \text{ or}$$

$$\text{ectomorphy} \propto \frac{[L]^1}{[L]^1}, \text{ or}$$

$$\text{ectomorphy} \propto [L]^0.$$

Heath-Carter equation - Ectomorphy

To determine a subject's ectomorphy with the Heath-Carter equations one must first calculate the subjects height-weight ratio - (height)/($\sqrt[3]{\text{weight}}$) - and then use this value in an equation. As shown in the preceding section related to the Heath-Carter table determination of ectomorphy, this height-weight ratio geometrically dissociates size from the determination of ectomorphy.

II. Methodology

Subjects

When developing or modifying a tool that will be used universally across the human species there is no such thing as a "representative population" with which to build a simple mathematical model. For analysis purposes four existing data sets were combined into a single set, with the original group retained as a coding variable. Because both size and shape differences are important factors to examine, the following data groups have been chosen for use within this thesis.

Children

Children, being much shorter than adults, are likely to have the biggest discrepancies associated with their data where the difference is substantially related to size; this observation led to the first modification of the Heath-Carter somatotype by Hebbelinck, et. al. (1973), described in section I.A. Data from the Coquitlam Growth Study will be included, comprising over 900 boys and girls from six to sixteen years old. This data set has been described in Ross, et. al. (1980b).

Bodybuilders

Bodybuilders represent the maximum "pure mesomorphy" obtainable within a population. By including data from the 1981 Cairo International Body building Championships (described in Borms, et al.,1984) it will be possible to observe the effect of the different methodologies under the most extreme of mesomorphic conditions.

Olympic Athletes

Data from the 1976 Montreal Olympic Games (described in Carter, 1982) is included to increase the proportion of athletes in the test population. In addition, the Montreal Olympic Games Anthropological Project (MOGAP) data included somatotype photographs of all subjects. A subset of this data is used in the recommended learning process for photoscopic somatotype assessment by Carter and Heath (1990).

National Sample

The YMCA Lifestyles Fitness Survey included over 18,000 Canadian males and females, from 7 to 69 years old measured since 1976 (described in Bailey, Carter, and Mirwald, 1982).While the data does not address any special sampling considerations it can be considered a large, "typical" population.

Data Exclusion

Subjects missing any single variable of the ten variables necessary for Heath-Carter anthropometric somatotype assessment (height; weight; triceps, subscapular, supraspinale, and medial calf skinfolds; flexed arm and calf girth; and humerus and femur bone breadths) were eliminated from this study. It is recognized that the elimination of subjects can pose problems in traditional studies, however in this study (i) the elimination of approximately 50 subjects out of over 20,000 subjects was felt to be inconsequential, and (ii) the purpose of this study is not to describe or analyze this population. The data is not being considered statistically representative of anything more than "a large, varied, group of subjects"; elimination of subjects with missing data in no way violates this sample. Subjects were eliminated from the YMCA Lifestyles and the Coquitlam Growth study by this criterion.

In the YMCA Lifestyles data set there were subjects with what was felt to be "impossible" data. Whether this is a result of poor measurement or data entry/screening mistakes is immaterial, and some criteria for removing obvious data errors was necessary. A subject was deleted if:

- Any single skinfold was recorded as less than 2.0 mm.
- Any single skinfold represented more than 70% of the sum-of-4-skinfolds.
- Any single skinfold represented less than 5% of the sum-of-4-skinfolds.
- The humerus width was greater than the femur width.

This resulted in an original population of 20,785 subjects for analysis. To answer any criticisms regarding the use of the same population to develop and test the new system, a randomly selected hold-out of approximately 10% of the population was then set aside. This gave a population of 18,677 for general use and a hold-out population of 2108 subjects.

Both populations were about 64% male. For the females the average age was 32.7 years (s.d. 12.7 yr.), the average weight was 59.2 kilograms (s.d. 10.1 kg.) and the average height was 164.4 centimeters (s.d. 7.8 cm.). For the males the average age was 37.1 years (s.d. 12.2 yr.), the average weight was 78.2 kilograms (s.d. 12.8 kg.) and the average height was 178.2 centimeters (s.d. 8.5 cm.).

Working Assumptions:

For this thesis:

- The existing Heath-Carter somatotype rating form was considered the closest approximation of a subject's true somatotype, unless there was a compelling conceptual reason to do otherwise.
- Existing errors in typesetting and mathematical rounding were not considered intentional parts of somatotype methodology.

Goals / Rationale

1: To test the claim that the Heath-Carter somatotype equations and the Heath-Carter somatotype rating form produce identical results.

The claim originally put forward by Dr. Carter in his 1980 laboratory manual, that the equations for calculation of somatotype produce the same result as the somatotype rating form, has never been demonstrated. There are no papers published testing this claim, and no published information explaining how the equations were developed.

The theoretical discussions of the dimensionality of the somatotype components (section I.C.) show that this claim was at least open to question:

- The existing endomorphy equation was not dimensionally the same as the height-dissociated endomorphy of the rating form.
- The existing mesomorphy equation did not dissociate the subject's size from its rating of shape the way that it conceptually should.

2: To develop theoretically and dimensionally sound equations that closely mimic the existing somatotype form.

Even if the existing equations produced similar results to the somatotype rating form, they could be considered conceptually weak: the endomorphy equation was a cubic fit of a sum of skinfolds, the mesomorphy equation was linear, and there were two different equations to use for ectomorphy. While considering the existing Heath-Carter rating form the best estimate of anthropometric somatotype, Parnell's rating form, and conceptual considerations were also used when developing new equations.

Recognizing that the equations are likely to be used much more frequently than the rating form, the conceptual validity and consistency of any newly developed equations was considered as important as the actual constants they contain.

3: To develop a new somatotype rating form that produce identical results as the newly developed equations .

With the widespread acceptance and availability of calculators and computers there is little reason to expect the trend of using equations rather than lookup tables for the prediction of anthropometric somatotype to reverse. The lookup table currently has two primary functions: (i) to help the conceptual teaching of somatotype, and (ii) to aid in the resolution of discrepancies between photoscopic and anthropometric somatotype assessment (Carter, personal communication, 1994). Both of these functions are valid, and are likely to continue to exist. A new rating form should produce the identical result as the new equations, but it should also do it in a manner that is consistent with the functions of the form — to conceptually separate and clarify the flow of the anthropometry through to a rating.

Equation Development

Variables

Equation development was limited to the same variables used in the existing Heath-Carter form and equations: height; weight; triceps, subscapular, suprailliac, and medial calf skinfolds; calf and flexed arm girths; and humerus and femur breadths.

Population Independence

Population-specific constants were (when possible) avoided:

- By creating the form of the equation theoretically and historically.

- By determining constants theoretically or based on constants and relationships in the existing Heath-Carter somatotype form, or based on other somatotype-relevant historical works.
- Then, finally, by fitting any remaining constants using uniformly distributed data.

Analysis

At least three relevant comparisons could be made for each of the three somatotype components:

1. Existing rating table to existing equation.
2. Existing equation to new equation.
3. Existing table to new equation.

If the existing rating tables were found to be in close agreement with the existing equations comparisons (2) and (3) could be considered fulfilled by a single comparison.

Historically - described in Carter and Heath (1990), pp. 46-55 - there have been three analysis techniques used by researchers comparing somatotype methods on a component-by-component basis within a population:

1. Regression analysis (usually Pearson).
2. Paired t-test of the difference of the means.
3. Descriptive information, usually the percentage of the population for which the two techniques agree within ± 0.5 somatotype unit and the percentage of the population agreeing within ± 1.0 somatotype unit.

For this thesis, regression analysis, technique (i), was not used; interpreting various near-perfect correlations gives no new insight to the problems being examined here, and the difficulty in interpreting correlation coefficients produced in equations lacking a constant term is bypassed.

T-tests, technique (ii), were not used for pairwise comparisons; with over 18,000 subjects any difference, no matter how trivial, would be statistically significant. As an example, the subjects' weight was recorded in kilograms. If we were interested in using their weight measured in pounds we could multiply by 2.2, by 2.205, or by 2.204623; all are correct conversions between kilograms and pounds to different numbers of significant digits. T-tests showed that each of these "weights" was significantly different from the others for the sample population, in all cases $p < 0.0001$. When differences in the fifth significant figure of a constant produce significant t-test differences it is obvious that all methodologies will also be significantly different.

T-tests were used for comparing the means of independent populations, specifically when it was necessary to check for differences between the main test population and the hold-out population.

Technique (iii) was used with the addition of narrower categories - the percent of the population where techniques agreed within ± 0.1, ± 0.25, as well as ± 0.5 and ± 1.0 were determined.

The technical error of measurement was used to look at the difference between techniques, as recommended by Mueller and Martorell (1988). Population statistics were calculated with Systat for Windows version 5.03. Graphing was done with Systat for Windows version 5.03 and with Microsoft Excel for Windows versions 4 and 5. Nonlinear curve fitting was performed redundantly with Systat and with the "Solver" add-in of Microsoft Excel, confirming the model constants.

Kolmogorov-Smirnov tests were performed to check for consistency in somatotype component distributions between the main population and the hold-out sample using Systat for Windows and SPSS running under UNIX.

III. Geometric Adjustment of Data

Striving for Consistency

As discussed in the section I.C, the existing Heath-Carter rating tables and rating equations are mixed both in their method for handling size-dissociation and in their success in doing so. As a first fundamental step in developing a model somatotype assessment system, the approach to geometrically account for size should be consistent within and between rating tables and equations.

The geometrically simplest method of adjusting for the height of a subject is to express each measurement (with the exception of body weight) as a fraction of the subject's height:

$$\text{Measurement}_{\text{adjusted}} = \frac{\text{Measurement}}{\text{Height}}$$

and for weight:

$$\text{Weight}_{\text{adjusted}} = \frac{\text{Weight}}{(\text{Height})^3}.$$

While being simple and conceptually correct, this method removes much of the intuitive "feel" from the data. Is "0.20" large for an adjusted arm girth? Is "0.000015 kg/cm.^{3} " a large adjusted body weight? ...

A method that is equally valid and that produces much more intuitive results is to choose an arbitrary height and consistently adjust all subjects geometrically to that height as the first step of any analysis. For all measurements except weight the adjustment would be:

$$\text{Measurement}_{\text{adjusted}} = \text{Measurement} \times \frac{\text{Arbitrary Height}}{\text{Subject Height}}$$

and for weight:

$$\text{Weight}_{\text{adjusted}} = \text{Weight} \times \left(\frac{\text{Arbitrary Height}}{\text{Subject Height}} \right)^3 .$$

This is the method proposed by Hebbelinck, et. al. (1973) for the adjustment of the sum-of-skinfolds prediction of endomorphy with the Heath-Carter rating, as well as in the Ross-Wilson phantom (Ross and Wilson, 1974) and the O-Scale physique assessment system (Ward, 1988). In all these cases the scaling height was chosen to be 5' 7" (170.18 cm.).

Height Adjustment to 170 cm.

In the geometric adjustment of the sum of skinfolds to a height of 170.18 cm. (5' 7") , originally proposed by Hebbelinck, Duquet, and Ross (1973) this height was chosen "because 5' 7" was the middle of the Heath-Carter mesomorphy rating table, and it produced a correction in the right direction..." (Ross, personal communication, 1992). Ross was also instrumental in choosing this height as the reference height in the other methods previously mentioned.

5' 7" is *not* the "middle" of the Heath-Carter mesomorphy rating form; Parnell's original work (1954) was built around an average height of 70 inches (5' 10"), and when Heath and Carter moved the height column to account for the systematic rating differences the "middle" column became related to a height of 71.5 inches (5' 11½"). Ignoring rounding errors in the existing Heath-Carter mesomorphy table, *any* column could be considered the "middle" methodologically - used for the derivation of all the other column values - depending upon the sample population being evaluated and upon the experimenter's bias or whim, but the column spacings lead back to Parnell's 70 inch column as being the mathematical "middle".

In Parnell's (1954) sample population - used to construct the original rating form - the average height is reported as being 70 inches (5' 10"). The population was entirely male. No information is given concerning the average height of the populations used by Heath and Carter (1967). The average height of the population used in this work is 173 cm.

(68.2"), with the average for the males and females being 178 cm. (70.1") and 164 cm. (64.7") respectively.

Conceptually, there is no reason to choose one height to adjust to over another as the mathematics of geometric adjustment would produce identical results for the resulting somatotype. Practically, a stature of 170 centimeters has many advantages:

1. 170 centimeters is very close to the historically significant 5' 7" (170.18 cm.). Those who wish to height adjust to 5' 7" instead of the recommended 170 cm. would introduce only 0.1% error into their adjusted linear measurements and 0.3% for weight if they compare against the tables produced for 170 cm. height adjustment. This level of measurement scaling error, even being systematic, is unlikely to introduce meaningful rating differences for individual subjects.

2. It is a nice, round, *metric* number.

3. 170 cm. is probably the average height of North American adults, to the nearest decimeter. Putting aside scientific geocentricity, somatotype was originally derived from a United States sub-sample, and there is the continuous tie to North American populations in the development of the techniques.

4. Originally, somatotype ratings were from "one" to "seven" in "whole units". "1", "7", "0". A nice historic touch.

The last two advantages are perhaps frivolous, but the first two advantages support a case for using 170 cm. as the reference height. It will, of course, be possible for interested scientists to modify any new equations and rating forms to a reference height of their own choosing without effecting the predicted somatotype.

IV. Endomorphy

Theoretical Form of the Equation

The only published equation for the calculation of Heath-Carter somatotype is:

Endomorphy = $-0.7182 + 0.1451(X) - 0.00068 (X)^2 + 0.0000014 (X)^3$

where X = triceps + subscapular + supraspinale skinfolds

and X = (triceps + subscapular + supraspinale skinfolds) * $\frac{170.18 \text{ cm}}{\text{subject's height in cm}}$ for height-corrected endomorphy (Carter, 1980).

Predicting Endomorphy with a cubic equation has no conceptual basis, and it ignores the fact that polynomial fitted equations are often "unstable" beyond the range over which they are fit. Figure 6 shows this predicting equation with the sum-of-skinfolds extended to large values. At the large skinfolds, especially above about 200 mm., we see the incongruous result that the graph is "turning up" - it takes smaller and smaller changes in skinfolds to produce a change in endomorphy; clearly this was not the implication of the original work (described starting in section I.A, and shown as the open circles in Figure 2).

The Logarithmic Nature of Skinfolds

There is, of course, no way to "prove" that Endomorphy is related to any mathematical function of skinfolds. There are however significant indicators that a logarithmic relationship between skinfolds and endomorphy is "in the right direction":

1. Parnell, in the discussion of the development of his rating form from anthropometry (Parnell, 1958, p. 111) shows he believed that the logarithmic adjustment of the sum-of-skinfolds was reasonable for predicting endomorphy:

   Not all the measurements with which we are concerned are distributed normally. ... The total of the three fat measurements in young men averages about 33 mm. with a standard deviation of roughly 12 mm. The range from -3 S.D. to +3 S.D. about the mean would be from -3 mm. to + 69 mm. if fat were naturally distributed. Such a scale is obviously useless, for negative values do not occur and values of 100 mm. or more are quite common. Fortunately, plotting the distribution against a log scale of fat produces a curve which is much closer in appearance to that of a natural distribution.

   ...

2. Heath and Carter "eyeballed" a curve through their data, but this curve is remarkably consistent with the assumption of a logarithmic relationship, but with a change in slope at about endomorphy "3" (see Figure 2).

3. An equation where Endomorphy is proportional to the logarithm of skinfolds has the right shape over all possible ranges, avoiding the absurd "up turn" of the existing polynomial fit (shown in Figure 6).

Calculating equations for the lines shown in Figure 1, Parnell's 1958 rating form (reproduced as Figure 13) produces the equations:

$$\text{Endomorphy} \cong [2.62 * \text{Ln(Sum3SF)}] - X$$

Where X depends on the age group, ranging from 5.6 for 16-24 year olds to 6.7 for 45-54 year olds.

Examining the upper end of the Heath-Carter graph (Figure 2), where it is visibly linear for endomorphy versus the logarithm of the skinfolds we get:

$$\text{Endomorphy} \cong [4.8 * \text{Ln(Sum3SF)}] - 6.9$$

There is a much bigger slope implicit in the Heath-Carter data than in Parnell's. This makes sense, considering that most of the high-adiposity subjects - and all of the subjects with endomorphy ratings over about 7.5 - in the Heath-Carter model were female while Parnell was dealing entirely with males. The 3 skinfolds measured (two from the trunk and one from the arm) would tend to underestimate female adiposity/endomorphy unless a much larger scaling factor was used. It is also worth remembering that the skinfold data was incomplete for much of the Heath-Carter sample, refer to section I.A, for detail.

<u>Four Skinfolds Instead of Three</u>

Since 1967 anthropometrists have been collecting four skinfolds - triceps, subscapular, supraspinale, and calf - to determine anthropometric somatotype via Heath-Carter methodologies. Parnell's original work used only three skinfolds (calf skinfold was not required), and Heath and Carter continued to use only the three skinfolds in their prediction of endomorphy, effectively "wasting" information available from the calf skinfold.

Three facts support the inclusion of the extra site in the determination of endomorphy:

- The original three skinfold sites are all on the upper body and two are on the trunk. This may have been sufficient for Parnell whose subjects were all male, but it ignores the critical fat patterning differences between males and females, especially the females lower body as an adipose deposition zone.
- The measurement of skinfolds is a technically challenging task. The more skinfolds combined into the predicting quantity the more stable and precise it can be expected to be.
- Historically, Sheldon's photoscopic assessment of endomorphy involved breaking the body into five regions, rating the regions independently, and combining the results to produce a total body rating. The regions were upper trunk, lower trunk, arms, legs, and head-neck. The four skinfolds - with the inclusion of the calf - sample the first four of these five regions.

Since the calf skinfold has been collected for over twenty years by anyone doing anthropometric somatotype, there is no compelling reason *not* to include it in an endomorphy assessment technique.

Theoretical Solution

If one accepts that endomorphy is related to the logarithm of skinfolds and that four skinfolds will be used instead of three there is no sample-independent method to directly determine the relationship between predicted endomorphy and the sum-of-four-skinfolds. A population specific solution is shown in the next section, *Statistical Solution*.

To minimize the sample-specificity a two-step approach can be used:

1. Determine the best logarithmic relationship between Heath-Carter table endomorphy and the sum of *three* skinfolds using only information from the rating form, then

2. Determine the best relationship between the sum-of-three skinfolds and the sum-of-four-skinfolds.

The Relationship Between Endomorphy and the Sum-of-Three Skinfolds

The four simplest models relating endomorphy and the natural logarithm (log to the base-*e*) of the sum-of-three skinfolds (Ln(Sum3SF)) are:

1. Endomorphy = A * Ln(Sum3SF)

2. Endomorphy = [A * Ln(Sum3SF)] - B

3. Endomorphy = A * Ln (Sum3SF - B)

4. Endomorphy = [A * Ln (Sum3SF - B)] - C

In words these could be expressed as:

1. Perceived fatness (endomorphy) is directly related to the logarithm of the skinfold thickness, adjusted by a multiplier to account for the range of human variability and the measuring scale used.

2. Perceived fatness (endomorphy) is related to the logarithm of the skinfold thickness, adjusted by a multiplier to account for the range of human variability and the

measuring scale used, and 'zeroed' to a minimum possible result.

3. The "zeroing" for minimum possible fatness occurs before the scaling.

4. A "zeroing" occurs both before and after the scaling.

There is also the consideration of *what* sum-of-3-skinfolds (Sum3SF) to use to build the model. Since the assumed "gold standard" is the rating form, it is possible to put aside population-dependent problems by using a uniform sum-of-three-skinfolds over an appropriate range. The existing endomorphy table encompasses a range from 7 mm. to 204 mm - endomorphy ratings from ½ through 12 - but there is no evidence to show that this was much more than a convenience dictated by the size of the rating form.

Alternately, Sheldon and Parnell decreed that endomorphy only existed between 1 and 7 in whole units, or between 1 and 7 in one-half units. The range of sum-of-three-skinfolds corresponding to endomorphy ratings of 1 through 7 are 11 mm. through 81.2 mm. on the Heath-Carter rating form. Keeping in mind the vagueness of very small somatotype ratings (discussed in section VIII) and that all of Heath and Carter's subjects with endomorphy ratings of 7½ or over were female and lacked at least one of the predicting skinfolds, the use of the more limited range is supported.

For this reason a range of skinfolds from 11 mm. to 81.2 mm was used to develop the relationship; only 405 of the sample population of over 18,000 (2.16%) were outside of this range using raw skinfolds, and only 418 (2.2%) were excluded using height adjusted skinfolds.

Since the model is assuming a linear relationship between endomorphy and the natural logarithm of the sum-of-three-skinfolds [Ln(Sum3SF)] the distribution should be uniform over the range Ln(11 mm.) to Ln(81.2 mm.); using a uniform distribution over the range of 11 mm. to 81.2 mm. would result in a skewed distribution of the predicting variable. Table 2 shows the results of nonlinear curve fitting for 300 points over this skinfold range for the four predicting models.

Table 2: Least squares regression constants for four models predicting endomorphy from the logarithm of the sum of 3 skinfolds

Model	A	B	C	r^2	corrected r^2
1. Endomorphy = A * Ln(Sum3SF)	1.066			.884	.518
2. Endomorphy = [A * Ln(Sum3SF)] - B	3.269	7.701		.993	.972
3. Endomorphy = A * Ln (Sum3SF - B)	1.285	10.338		.953	.806
4. Endomorphy = [A * Ln (Sum3SF - B)] - C	7.728	-41.337	29.873	.999	.994

While the fourth model fit best as judged by the corrected r^2 value, it produced the illogical result of *adding* a certain amount of fatness before taking the logarithm.

Equation 2 was the next best fitting equation, predicting almost as well as equation 4, and had theoretically reasonable constants. It was also of the form produced from the work by Parnell and by Heath and Carter (described above). For all of these reasons it was considered the best, sample-independent relationship between endomorphy and the sum-of-three-skinfolds:

$$\text{Endomorphy} = [3.269 * \text{Ln}(\text{Sum3SF})] - 7.701$$

This relationship is shown in context with the work of Parnell and Heath and Carter in Figure 3 and Figure 4.

The Relationship Between the Sum-of-Three and the Sum-of-Four Skinfolds

Simple linear regression, using all 18,677 subjects produces the following equation:

Sum 4 Skinfolds = 1.205 (Sum 3 Skinfolds) + 3.214 mm (S.E.E.=4.8 mm)

For the males alone (n=11,887):

Sum 4 Skinfolds = 1.162 (Sum 3 Skinfolds) + 2.882 mm (S.E.E.=3.3 mm)

and for the females alone (n=6,790):

Sum 4 Skinfolds = 1.202 (Sum 3 Skinfolds) + 6.877 mm (S.E.E.=4.9 mm)

It is hard to conceptually justify the constant added in each equation even though all are statistically significant ($p < 0.0001$). In the extreme, if we had a subject where the sum-of-three skinfolds was "zero" we still would be faced with some sample-specific thickness for the predicted sum-of-four skinfolds. Eliminating the constant, regression using all 18,677 subjects produces the following equation:

Sum 4 Skinfolds = 1.273 (Sum 3 Skinfolds) (S.E.E.=4.9 mm)

For the males:

$$\text{Sum 4 Skinfolds} = 1.226\,(\text{Sum 3 Skinfolds}) \qquad (\text{S.E.E.}=3.5\text{ mm})$$

and for the females:

$$\text{Sum 4 Skinfolds} = 1.338\,(\text{Sum 3 Skinfolds}) \qquad (\text{S.E.E.}=5.4\text{ mm})$$

Considering the simpler form of the conversion after removing the additional constant, and the very similar standard error of estimates with and without the constant, it is a reasonable step to use the simpler models.

The dissimilar results for males and females (1.226 and 1.338 respectively) brings into question the result of 1.273 for the combined group, considering the higher fraction of males in the sample. While it would be possible to use a weighting factor to account for this factor there are additional problems to consider.

Table 3 shows the ratio of $\left(\frac{\text{Sum 4 Skinfolds}}{\text{Sum 3 Skinfolds}}\right)$ for the sample population, broken down by "fatness categories" (represented by ranges of sum-of-3 skinfolds) for males, females, and the total population. The most obvious trends are that this ratio gets smaller as the total fatness increases, and that ratio is larger for females than for males at all levels of fatness.

Table 3 :The ratio of Sum-of-4 skinfolds to Sum-of-3 skinfolds by population sub-samples

"Fatness"	Ratio of (Sum4SF/Sum3SF)			
	Male & Female		Male Only	Female Only
	% male			
All	64	1.294 (n=18677)	1.247 (n=11887)	1.375 (n=6790)
Ln(3SF) < 2.5	67	1.443 (n=12)	1.312 (n=8)	1.704 (n=4)
2.5 < Ln(3SF) < 3	87	1.338 (n=939)	1.320 (n=819)	1.461 (n=120)
3 < Ln(3SF) < 3.5	70	1.325 (n=5305)	1.2757 (n=3688)	1.439 (n=1617)
3.5 < Ln(3SF) < 4	61	1.286 (n=8987)	1.231 (n=5522)	1.375 (n=3465)
4 < Ln(3SF) < 4.5	55	1.251 (n=3245)	1.206 (n=1774)	1.304 (n=1471)
4.5 < Ln(3SF) < 5	40	1.246 (n=187)	1.205 (n=76)	1.275 (n=111)
5 < Ln(3SF)	0	1.130 (n=2)	(n=0)	1.130 (n=2)

Again, it would be possible to build a complicated weighting factor to account for the changing ratio with increasing sum-of-three skinfolds, but what about the changing fat patterning with aging? And what about ethnic fat pattern differences? And, what about secular trends in fat patterning? ... In this problem, as in most, there is no intelligent way to control for all possible "nuisance" factors.

Table 4 extracts summary information from Table 3, eliminating subjects where ln(sum 3 skinfolds) is less than 2.5 or greater than 5.0; only 14 subjects (0.075% of the population) are excluded by this trimming. If an "grand average" is calculated for the ratio of

$\left(\frac{\text{Sum 4 Skinfolds}}{\text{Sum 3 Skinfolds}}\right)$ it comes out equal to 1.309. The sample ratio (average of sample male and female ratios) was 1.311.

Table 4: Summary Information and Calculations for the Sum-of-Skinfolds Ratio

"Fatness"	Ratio of (Sum4SF/Sum3SF)		
	Male Only	Female Only	Average
All	1.2471	1.3748	1.3110
Ln(3SF) <2.5	1.3121	1.7036	excluded
2.5 < Ln(3SF) < 3	1.3202	1.4612	1.3907
3 < Ln(3SF) < 3.5	1.2757	1.4387	1.3572
3.5 < Ln(3SF) < 4	1.2308	1.3748	1.3028
4 < Ln(3SF) < 4.5	1.2058	1.3044	1.2551
4.5 < Ln(3SF) < 5	1.2045	1.2750	1.2398
Ln(3SF) < 5	no data	1.1302	excluded
		Average:	1.3091

While it is impossible to consider this result "sample independent", a recommended conversion of:

$$\text{Sum-of-4-skinfolds} = 1.31 \times \text{Sum-of-3-skinfolds}$$

is at least somewhat sample dissociated. This is of course not recommended as a conversion for any individual or for any specific population, rather it is an attempt to blend results in the context of modifying a universal, skinfold-based endomorphy assessment system.

Combining the Results

Combining the results from the previous sections:

$$\text{Endomorphy} = [3.269 * \text{Ln}(\text{Sum3SF})] - 7.701$$

and $$\text{Sum-of-4-skinfolds} = 1.31 \times \text{Sum-of-3-skinfolds}$$

and geometric height adjustment to 170 centimeters

gives (after simplification):

$$\text{Endomorphy} = \left[3.269 * \left(Ln\left(\left(\sum 4 \text{ Skinfolds}\right) \times \frac{170 \text{ cm.}}{\text{Subject Ht. in cm.}}\right)\right)\right] - 8.584$$

While it would be possible to mathematically remove the "170 cm." from within the logarithm, keeping the equation in this form will allow those who wish to use the equation without height-adjusting the skinfolds to do so. While there is no conceptual reason to do this the demand still exists for non-size-adjusted endomorphy estimation (Carter, personal communication, 1994).

Statistical Solution

Accepting that the relationship should be of the form:

$$\text{Endomorphy} = A \times Ln\left(\left(\sum 4\ \text{Skinfolds}\right) \times \frac{170\ \text{cm.}}{\text{Subject Ht in cm.}}\right) + B\ ,$$

the following results are obtained by standard regression analysis. In both cases n=18,677 and all predicted constants are significant ($p<0.0001$).

Table 5: Statistical Prediction of Heath-Carter Endomorphy from the Sum of 4 Skinfolds, Height Adjusted to 170 cm.

Where: $\text{Endomorphy} = A \times Ln\left(\left(\sum 4\ \text{Skinfolds}\right) \times \frac{170\ \text{cm.}}{\text{Subject Ht in cm.}}\right) + B$

Predicted Variable	A	B	r^2	S.E.E.
Height adjusted Heath-Carter Endomorphy, determined from Rating Form	3.771	-10.645	0.921	0.410
Height adjusted Heath-Carter Endomorphy, determined from Equation	3.768	-10.668	0.922	0.405

Because the endomorphy determined from the rating form is effectively rounded to the nearest ½ unit, where it is calculated precisely with the equation, it is not surprising that the equations are very slightly different or that the equation predicting the rating-form endomorphy has a slightly poorer correlation coefficient and standard error of estimate (S.E.E.).

Recommended New Equation

Figure 5 shows the statistically derived equation and the "developed" equation for the prediction of endomorphy from the sum of four skinfolds. If the Heath-Carter rating form was to be considered the "gold standard", and no other criteria were considered, the statistical equation would have to be the favored choice. Because of the small, unusual, population used by Heath and Carter and the consideration of the missing skinfold data in their sample, combined with the desire to remove sample-specific variables as much as possible, it is the recommendation of this thesis that the more conceptual "developed" equation be adopted as the recommended predicting equation:

$$\text{Endomorphy} = \left[3.269 * \left(Ln\left(\left(\sum 4\ \text{Skinfolds}\right) \times \frac{170\ \text{cm.}}{\text{Subject Ht. in cm.}}\right)\right)\right] - 8.584$$

where the four skinfolds are the triceps, subscapular, supraspinale, and calf. As discussed in section VIII, results below 0.5 are given a rating of "less than ½".

V. Mesomorphy

The Current Equation

By examining the existing Heath Carter rating form (Figure 15 and Figure 17), understanding the development of Parnell's M4 mesomorphy rating table (in Figure 13), and the modifications made by Heath and Carter in 1967 it is obvious that an equation to mimic the existing rating form would be:

$$\frac{(D_{\text{arm girth}} - D_{\text{height}}) + (D_{\text{calf girth}} - D_{\text{height}}) + (D_{\text{humerus}} - D_{\text{height}}) + (D_{\text{femur}} - D_{\text{height}})}{8} + 4$$

where $D_{\text{arm girth}}$, D_{height}, ... are columns of deviation for each of the anthropometric measurements from any arbitrarily chosen column on the mesomorphy rating table.

More specifically, the calculations of each of these columns, using Parnell's historic "center" of the form as the reference column (the column with height = 181.6 cm., humerus = 6.80 cm., femur = 9.70 cm., adjusted arm girth = 31.0 cm. and adjusted calf girth = 36.3 cm.):

$$D_{\text{arm girth}} = \frac{\left(\left(\text{arm girth} - \left(\frac{\text{triceps skinfold}}{10}\right)\right) - 31.0\right)}{31.0 \times \frac{1.5}{70}}$$

$$D_{\text{calf girth}} = \frac{\left(\left(\text{calf girth} - \left(\frac{\text{calf skinfold}}{10}\right)\right) - 36.3\right)}{36.3 \times \frac{1.5}{70}}$$

$$D_{\text{humerus}} = \frac{(\text{humerus} - 6.80)}{6.80 \times \frac{1.5}{70}}$$

$$D_{\text{femur}} = \frac{(\text{femur} - 9.70)}{9.70 \times \frac{1.5}{70}}$$

$$D_{\text{height}} = \frac{(\text{height} - (71.5 \times 2.54))}{(70.0 \times 2.54) \times \frac{1.5}{70}} = \frac{(\text{height} - 181.61)}{177.80 \times \frac{1.5}{70}}$$

The above equations have not been simplified, to allow the explanation of their derivation. Because these numbers were the center column that Parnell used to develop his form (noting that the height for Parnell's center column was 70 inches), and because the columns were spaced 1.5 inches of height apart , the denominator of each deviation equation becomes clear. Two points to note in the height deviation calculation: the number subtracted in the numerator is 71.5 inches, not 70.0 inches - a result of the shift in the height column by Heath and Carter (1967), and the conversion to height measured in centimeters is included.

By substituting the deviations into the original equation and performing the necessary simplifications the resulting equation is:

$$\text{Mesomorphy} = .1882\left(\text{arm girth} - \frac{\text{triceps sf}}{10}\right) + .1607\left(\text{calf girth} - \frac{\text{calf sf}}{10}\right)$$

$$+ 0.8578\ (\text{humerus}) + 0.6014\ (\text{femur}) - 0.1312\ (\text{height}) + 4.50$$

This is exactly the equation recommended by Carter (1980). The derivation of this equation has never before been discussed or demonstrated in a published work.

Theoretical Solution

Taking Parnell's 1958 M4 deviation table as the basis of mesomorphy, it could be expressed in words as:

> a person 70 inches tall (177.8 cm.), with a humerus width of 6.8 cm., a femur width of 9.7 cm., an arm girth of 31.0 cm., and a calf girth of 36.3 cm. deserves a mesomorphy rating of 4 before considering the effect of adipose thickness. For every 2.14% (1.5/70 = 2.14%) one of their four indicating measurements deviates from these values, $\frac{1}{8}$ of a unit of mesomorphy is added to or subtracted from this rating.

Heath and Carter's 1967 modification could be expressed as:

> a person with these measurements actually deserves a rating of 4½, not 4, the adjustment for adipose thickness should only be made to the girth measurements, and the adjustment should be made to the anthropometry before assessing initial mesomorphy.

To insure true size dissociation, and keeping with the ideas presented in section III, the start of an ideal equation could be described as:

> Parnell's basic anthropometric 'model' should be scaled to 170 cm. and should represent a mesomorphy rating of 4½, as suggested by Heath and Carter.

A decision of how to deal with the $\frac{1\frac{1}{2}}{70}$ 'steps' is necessary. It is possible to argue that the recommendation to height adjust to 170 cm. is doing nothing more than using a different column for reference purposes; using the column headed by 170 cm. - if such a column existed - rather than the currently assumed column headed by 71.5 inches (181.6 cm.). If this argument was accepted then the steps, corresponding to each $\frac{1}{8}$ mesomorphy unit would remain the same as it currently is: $6.8\ (\frac{1\frac{1}{2}}{70}) = 0.146$ cm. for humerus, et cetera.

Another argument could be to keep the steps the same 2.14% of the chosen reference value. For example, geometrically adjusting the original 70 inch (177.8 cm.) tall, 6.8 cm. humerus width "subject" to 170 cm. tall would produce a 6.50 cm. humerus width. 2.14% of this value would result in a step size of 1.39 cm. for humerus. In all four measurement this would result in step sizes 4.6% $(1 - \left(\frac{170}{177.8}\right))$ smaller than the previous suggestion. This would result in a systematic difference from the previous suggestion, producing smaller mesomorphy estimates than the previous suggestion for subjects with mesomorphy less than 4 and producing larger results than the previous suggestion for those with mesomorphy greater than 4.

To decide between these two approaches requires a decision between the following two statements: (i) the existing mesomorphy rating form is the closest representation of mesomorphy from anthropometry and (ii) Parnell's methodology, resulting in the rating form, modified by Heath and Carter, is the closest representation of mesomorphy from anthropometry. To help decide, consider what would happen if the arbitrary height to adjust the subject to was chosen to be 1 cm., rather than 170 cm. The step size would still be 0.146 cm. for humerus in the first case, resulting in a step size of over 26%, while the second suggestion ensures a step size of 2.14% regardless of the height chosen for the geometric size adjustment. This argues strongly for the second approach.

Building an equation of the same general form as the equation above, but using the new ideas presented would result in:

$$\frac{\left(D_{\text{H.A. arm girth}}\right)+\left(D_{\text{H.A. calf girth}}\right)+\left(D_{\text{H.A. humerus}}\right)+\left(D_{\text{H.A. femur}}\right)}{8}+4.5$$

where $D_{\text{H.A. arm girth}}$, $D_{\text{H.A. calf girth}}$, ... are columns (or steps) of deviation for each of the height-adjusted anthropometric measurements from the height-adjusted reference values. Because of the consistent height adjustment of the data, there is no need for any height-deviation in the equation. The number 4.5 must be added, rather than 4, because the height adjustment was to Parnell's original values; Heath and Carter's 1967 shifting of the height row to account for a systematic ½ unit difference must be included.

Table 6: Constants for Calculation of Mesomorphy, Scaled to 170 cm. height

Parnell's reference values for the 70 inch (177.8 cm.) height column, the same values geometrically adjusted to a height of 170 cm., and the theoretical step size for each $\frac{1}{8}$ mesomorphy unit, calculated as 2.14 % of the height adjusted value.

	Parnell's Reference Values	Values Adjusted to 170 cm. Height	Step Size
Height (cm.)	177.8	170.0	not required
Humerus Width (cm.)	6.80	6.501	0.1393
Femur Width (cm.)	9.70	9.274	0.1987
Skinfold adjusted Arm Girth (cm.)	31.0	29.64	0.6351
Skinfold adjusted Calf Girth (cm.)	36.3	34.71	0.7437

The calculations for each of these height-adjusted deviations are:

$$D_{\text{H.A. arm girth}} = \frac{\left(\left(\text{arm girth} - \left(\frac{\text{triceps skinfold}}{10}\right)\right) \times \text{H.A.F.}\right) - 29.64}{0.6351}$$

$$D_{\text{H.A. calf girth}} = \frac{\left(\left(\text{calf girth} - \left(\frac{\text{calf skinfold}}{10}\right)\right) \times \text{H.A.F.}\right) - 34.71}{0.7437}$$

$$D_{\text{H.A. humerus}} = \frac{((\text{humerus width} \times \text{H.A.F.}) - 6.501)}{0.1393}$$

$$D_{H.A\ femur} = \frac{((\text{femur width} \times \text{H.A.F.}) - 9.274)}{0.1987}$$

where "H.A.F." is the height-adjustment factor, equal to $\frac{170 \text{ cm.}}{\text{subject's height in cm.}}$.

By substituting the deviations and performing the necessary simplifications the resulting equation is:

$$\text{Mesomorphy} = \left\{ .1968\left(\text{arm girth} - \frac{\text{triceps sf}}{10}\right) + .1681\left(\text{calf girth} - \frac{\text{calf sf}}{10}\right)\right.$$

$$\left. + 0.8973 \text{ (humerus)} + 0.6291 \text{ (femur)} \right\} \times \frac{170}{\text{height}} - 18.84$$

Recommended New Equation

The recommended equation for the prediction of mesomorphy is:

$$\text{Mesomorphy} = \left\{ .1968\left(\text{arm girth} - \frac{\text{triceps sf}}{10}\right) + .1681\left(\text{calf girth} - \frac{\text{calf sf}}{10}\right)\right.$$

$$\left. + 0.8973 \text{ (humerus)} + 0.6291 \text{ (femur)} \right\} \times \frac{170}{\text{height}} - 18.84$$

As discussed in section VIII, results below 0.5 are to be given a rating of "less than ½".

VI. Ectomorphy

Theoretical Form of the Equation

In the initial proposal of the Heath-Carter somatotype system (1967, p. 68) the authors state:

> *...the use of a regression equation to predict the third component value from the [height-weight ratio] suggested itself. ... For the 121 somatotypes the correlation was r = 0.97, and the regression equation for predicting Y from X is :*
>
> $$Y = 2.42\ X - 28.58\ ...$$

Their "X", or height weight ratio, was equal to $\frac{\text{Height in inches}}{\sqrt[3]{\text{Weight in pounds}}}$. Converting to metric results in the equation:

$$\text{Ectomorphy} = 0.7325\left(\frac{\text{Height in cm..}}{\sqrt[3]{\text{Weight in kg.}}}\right) - 28.58\ .$$

This is the same equation currently recommended for height-weight ratios over 40.75, with the constant rounded to 0.732.

Why there has to be a different equation for height-weight ratios below 40.75 (corresponding to a predicted ectomorphy of 1.26) is never explained or justified. In the 1967 paper Heath and Carter discuss the handling of ectomorphy ratings of one and of one-half as being somewhat special; because of the large differences between very ponderous and very, very, ponderous subjects they recommend that a rating of one-half be reserved for the very, very, extreme and a rating of one be given otherwise:

> *[i]f the L-scale ['linearity scale' - ectomorphy] is* one-half, *but the subject shows slight tendencies towards linearity or elongation of the limbs or their segments, a rating of* one *should be assigned.*

It is possible that the use of a special equation for height-weight ratios below 40.75 is an attempt to "open up" the ratings below one unit to allow more differentiation between the very ponderous and the very, very, ponderous, but no such justification is ever given. If indeed this is the reason for the extra equation it tends to be a major divergence from the interpretation of somatotype - while somatotype is valid only to the nearest one-half unit for ratings above "1", it suddenly becomes valid to a much finer degree below "1".

It is worth mentioning that, even though ectomorphy has *always* been anthropometricly defined by height-adjusted body weight - the height-weight ratio - it is impossible to "see" body weight in a photograph. It has bothered every major contributor to somatotype methodology since Sheldon, but none have been able to arrive at a better predictor.

Recommended New Equation

To suggest anything other than height-adjusted body weight as the indicator of ectomorphy would be historically unjustifiable. The original equation is as valid now as it was when it was originally proposed by Heath and Carter in 1967, but there exists no good justification to treat cases below a height-weight ratio of 40.75 specially. The recommended equation for the anthropometric prediction of ectomorphy is:

$$\text{Ectomorphy} = 0.7325\left(\frac{\text{Height in cm..}}{\sqrt[3]{\text{Weight in kg.}}}\right) - 28.58\ .$$

As discussed in section VIII, results below 0.5 are to be given a rating of "less than ½".

VII. The Rating Form

Conceptual Considerations

Historically somatotype has been defined by a rating form, with equations being a later extension of the technique. This thesis proposes equations as the primary definition for anthropometric somatotype, and develops a rating forms only as a convenient visual tool for the expression of the equations. The primary concern in developing a rating form for the determination of somatotype was that it must accurately produce the same answer as the predicting equations, to the limit of its precision. Historically this precision has been "to the nearest ½ somatotype unit", and there is no reason to strive for greater precision with a new rating form.

As much as possible, all data on the form was to be treated consistently and systematically. The steps required for the new form were to be:

- Measured anthropometric values are recorded.
- A height-adjustment factor is calculated.
- This adjustment factor is applied to all the measurements.
- Derived values - the sum of skinfolds and the skinfold adjusted girths - are calculated.
- The necessary values are found on the relevant somatotype derivation section, leading to an unambiguous rating.

While there is little conceptual reason to do so, some scientists may wish to calculate endomorphy without applying a height adjustment to the sum of skinfolds (Carter, personal communication, 1994). This is conceptually incorrect, but is justifiable for comparison to historic results that precede the introduction of the height-adjustment to the sum of skinfolds. Keeping with the concept of treating all measurements consistently, the new form should allow scientists to calculate mesomorphy and ectomorphy without height-adjustment, in addition to non-height-adjusted endomorphy.

All of the previous rating forms were developed before the near-universal availability of pocket calculators. This lead to simple on-form calculations and the requirement of having look-up tables for any nontrivial calculations. This constraint is largely eliminated, however all calculations should be limited to those available on the most basic of calculators - four-function math and a single memory (useful, but not necessary, for the height-adjustment factor).

The height-weight ratio (HWR) is now an anachronism. There are only two reasonable justifications for its use:

- It has been a part of somatotype methodology since Sheldon.
- It "goes in the same direction" as ectomorphy - larger HWRs correspond to larger ectomorphy ratings.

An alternative to the HWR is the use of height-adjusted body weight as mentioned by

Ross, et. al (1980a). Height-adjusted body weight has a number of advantages:

- Height-adjusted body weight is consistent with the idea of treating all anthropometric measurements consistently, where the HWR was an unusual, special, treatment.
- Using height-adjusted body weight allows those who wish to calculate non-height-adjusted somatotype to do so. With the HWR the calculation is neither simple nor obvious.
- Mathematically, height-adjusted body weight = $\left(\frac{170}{\text{HWR}}\right)^3$. It is simple to convert between the two if the need appears.
- Height-adjusted body weight can be calculated with the most basic of calculators. The HWR requires the ability to calculate cube-roots.
- The HWR was changed when the Heath-Carter table was converted from measuring height in inches to measuring height in centimeters. While a reasonable range of HWRs was originally about "12 through 16", it became about "38 through 51". Neither of these rating scales have any sense of what is "reasonable" to less experienced raters. Body weight, even when height-adjusted, maintains a much closer tie to the original measurement. It should be easier for a rater to determine if a value is "unreasonable" (either a measurement or calculation error) with the use of height-adjusted body weight.

The use of height-adjusted body weight instead of the height-weight ratio for the ectomorphy rating form is adopted grudgingly. It produces a slightly better tool for the calculation of ectomorphy, for the reasons mentioned above, but it is at the sacrifice of a component of somatotyping that has been part of the methodology since its inception.

Practical Changes

Many of the following considerations are somewhat personal in nature, any rating form that would allow the user to arrive at a correct answer would fulfill the requirements. Over the last two decades most scientists have moved towards the use of equations for the determination of somatotype the rating form has become primarily a teaching tool. Many of the proposed practical changes are made in this light.

The Heath-Carter rating form was a "one size fits all" tool. In order to accommodate very large ratings (up to 12 in endomorphy and 9 in mesomorphy and in ectomorphy) the form needed to contain large ranges of numbers. Recognizing that the primary use for the new rating form will be for teaching somatotype lead to more basic form, one that would work for most of the "typical" population while dropping the unnecessary extra information necessary for rating extreme physiques. This basic form covers endomorphy and ectomorphy ratings up to 7, and mesomorphy deviations corresponding to ratings of about 8, depending upon the subject's dysplasia. An expanded rating form, covering ratings up to approximately 12 in all somatotype components and printed on 8½ x 14 "legal sized" paper would be a reasonable future development.

The reduction of the scope of the rating form, combined with the height adjustment of the anthropometry before using the tables, allowed smaller steps between columns in the mesomorphy table than in the Heath-Carter and Parnell tables. This resulted in each column of deviation being equivalent to $\frac{1}{10}$ unit of mesomorphy rather than the previous

$\frac{1}{8}$ unit, reducing the need to interpolate between columns and the somewhat complex calculations arising from the interpolation.

The standard Heath-Carter rating form leaves very little space for the calculations required if a user wishes to perform them by hand or to have a written record. The calculation of columns of deviation for mesomorphy and the skinfold adjustment of girths have been given more space than on the existing rating form.

Subject information on the existing Heath-Carter rating form had defined areas for the subject's name, occupation, age, sex, ethnic group, and subject number, as well as space for a project description, the measurement date, and the measurer. There was no room available for the inclusion of additional information. Certain basic information has been retained; the subject's name, sex, and date of birth and the date measured are all likely to be information relevant to any analysis. Open space has been left for the inclusion of additional information as required, not limiting the user to predetermined information.

The change to height-adjusting all anthropometry before using it required expanding the anthropometry section of the rating form. A clear distinction between "measured" and "height adjusted" information was maintained, as was a separation between measured and derived anthropometry. An elegant feature of the Heath-Carter rating form, where the anthropometric contributors each component were directly beside their look-up rows, has been lost by these changes. In exchange, the anthropometry section was reorganized for easier and more consistent recording of measurements and calculation of height-adjusted and derived information.

The Heath-Carter rating form had a large section on the bottom for recording the anthropometric and anthropometric-plus-photoscopic ratings. The photoscopic portion was eliminated and the subject's somatotype rating moved to the top of the form.

For those wishing for the simplest tool to arrive at the correct answer, Figure 18 uses lookup tables to calculate somatotype ratings identical to those produced by the equations recommended in previous chapters. This rating form was kept as simple as possible, even removing the midpoints of the Heath-Carter endomorphy and ectomorphy lookup tables.

The purpose of the midpoints was to allow the rater a better idea of how close the subject was to the edge of the rating category, effectively producing a "high", "middle", and "low" rating for each category of endomorphy and ectomorphy (Carter, personal communication, 1994). Figure 19 expands on this idea by using number-lines - non-linear scales similar to the calculation scale on slide rulers - for the determination of ectomorphy and endomorphy. The major scales allow the user to find the height-adjusted sum-of-skinfolds or height-adjusted weight and to directly see both the somatotype rating and where in the rating it is - near a boundary or central. The inclusion of exact cut-off value between rating categories allows the same precise rating as the look-up table. These number-lines break up the visual monotony of a form filled with tables of numbers while giving an improved feel for subject's position within the rating category.

The change to height-adjusted body weight instead of height-weight ratio for the prediction of ectomorphy posed a minor style problem. Because predicted ectomorphy decreases as body weight increases there were two possible choices for the ectomorphy section of the form: (i) have body weight increase from left to right like all other anthropometry, resulting in ectomorphy decreasing from left to right, or (ii) have ectomorphy increase from left to right, consistent with the other sections of the form, resulting in body weight decreasing from left to right. A style choice, based on the idea that somatotype was the focus of the rating form lead to the adoption of the second choice in both Figure 18 and Figure 19.

VIII. Reporting Somatotype

Precision of Results

Until 1980 somatotype ratings were recorded in ½ units. With the publication of equations for estimating somatotypes in 1980 it became possible to generate ratings to long streams of decimal places. Drs. Carter and Heath have always been conservative in their recommendations of somatotype: " [t]he component ratings should be rounded to the nearest tenth of a unit, or nearest one-half unit depending on their subsequent use." (Carter and Heath, 1990, p.375). It is unfortunate that this recommendation is so vague on this area of 'subsequent use'; it is extremely common to see somatotypes recorded to the nearest one-tenth, even in teaching laboratories and fitness clubs where this precision is definitely not warranted.

It is difficult to assess the variability in the measurement of somatotype. Little is published related to the actual precision of anthropometric measurements themselves, and assumptions of randomness in errors in anthropometry are questionable. For the following discussions results are taken from Carr (1994) where the measurements were made on 165 subjects. The subjects tended to be athletes, relatively lean, and young-to-middle aged. All repeat measurements were made by the same, well trained, anthropometrist on landmarked subjects, and all 'r' values within the range recommended for measurement reliability in Carter and Heath (1990) , p.371. All 'r' scores, except femur width were at the upper limit of the recommended reliability; as such these results are *very* conservative errors; the errors are certain to be higher in most 'real-world' applications.

For endomorphy: The percent technical-error-of-measurement (%TEM) ranged from 6.2% to 10.7% for the four skinfolds used in estimating endomorphy, averaging about 7.5%. If we assume that the errors are independent the sum of errors should be about $\frac{7.5\%}{\sqrt{4}}$, or about ± 3¾ %. The same calculation for the three skinfolds comes out to $\frac{8.0\%}{3}$, or about ± 4½ %.

Each increase or decrease in the sum-of-4-skinfolds of 3¾ % increases or decreases the endomorphy estimated by the new equation by about $\frac{1}{8}$ unit of endomorphy. In this case, with highly reliable measurers, it would be fair to report an individual's predicted endomorphy as "X ± ¼ units" about 19 times in 20 based on single anthropometric measurements. Reporting of endomorphy to the nearest 0.1 is clearly inappropriate for individual assessment, even under these very optimistic assumptions of measurement reliability.

For mesomorphy: The percent technical-error-of-measurement (%TEM) for flexed arm girth and calf girth were about ½ % and ¼ % respectively. For humerus breadth it was about 1½ % and for femur width it was slightly less than 2¼ %.

As previously discussed, the implicit assumption of both the Heath-Carter and the new mesomorphy rating tables is that a deviation of about 2.2% in any of these measurements corresponds to a change of one column, or $\frac{1}{8}$ unit of mesomorphy. Expressing the %TEM as columns of deviation give about .2 columns for arm girth, about .1 columns for calf girth, about ¾ columns for humerus, and about 1 column for femur breadth. Using the same $\frac{\sum \%TEM}{\sqrt{n}}$ equation gives an approximate error of a little more than one column, or $\frac{1}{8}$ unit for mesomorphy. With highly reliable measurers, it would be fair to report an individual's predicted mesomorphy as "X ± ¼ units" about 19 times in 20 based on single anthropometric measurements, similar to endomorphy.

For ectomorphy: Body weight is the primary anthropometric indicator of ectomorphy. While body weight can be measured very accurately, it tends to vary considerably over the day, presumably without altering the subject's true ectomorphy significantly. If one takes a within-day variation of ½ kg in weight as being extremely common - weight before versus after eating a large meal, as an example - and that athletes commonly sweat or drink a liter of water (1 kg), this gives some working assumptions.

For even moderately high endomorphy ratings - say above "5" - each ½ unit category spans only about 2 kg of height-adjusted body weight. A reliability of 1 kg. would correspond to ± ¼ units. For smaller endomorphy ratings this is not such a problem, where each ½ unit category can span 3 to 3½ kg. Still, there is ± $\frac{1}{6}$ unit for a 1 kg weight change, and one would expect the amount weight changes to increase as the subject gets heavier. It would not be at all conservative to report an individual's predicted ectomorphy as "X ± ¼ units" about 19 times in 20.

The reasonably conservative calculations above show that an individual's predicted somatotype should certainly be reported no more precisely than to the nearest ¼ unit. No consideration is made for the likelihood of systematic errors, the error in the measurement of height which would produce a systematic error through the height-adjustment of all the anthropometry, or the error in skinfolds in the skinfold-adjustment of the girths in the mesomorphy estimation. This, combined with no historical precedent for reporting somatotype in ¼ units, make the recommendation of reporting somatotype to the nearest ½ unit reasonable, and not particularly conservative.

In large studies where the individuals data is to be treated only as part of a population there is no reason not to record the individual somatotypes to one or more decimal digits. When performing statistical summaries it is necessary to keep in mind the potential error in the individual measurements. In cases where the experimenter can not, or will not, carry the error calculations through the only reasonable recommendation would be to treat summary statistics that agree within ± 0.5 units as not significantly different. This caution, or the careful analysis of the contribution of the individual's potential error to the population estimates, is especially important in studies where the experimenters are using extremely tiny sample sizes such as 10 or 15 subjects.

Somatotype Below ½ Unit

Until the development of the Heath-Carter somatotype equations the lowest rating possible for an individual in any component was ½ unit. Particularly in ectomorphy, this rating of ½ failed to differentiate between physiques that were obviously different, leading to the development of a different equation for ectopenic individuals (individuals low in ectomorphy) than the equation used for other subjects. This was a strong break with the traditional reporting of somatotypes, effectively saying "somatotypes are only precise to the nearest ½ unit *except* for small values, where differences are valid to 0.1 units". For this extremely unconventional change no support has ever been published. Figures 26, 27, and 28 show the devastating effect the change has on population distributions, making ectomorphy distributions unlike those of the other somatotype components.

With no evidence to support it, and strong graphical evidence against it, it is clear that the recommendation to treat small somatotypes ratings as "special cases" is not justified. The simplest case would be to maintain the rating of "½" as the lowest possible rating, but this too has problems. The idea of the ½ unit somatotype categories is that they would gather together individuals who were very similar in that somatotype component. Subjects who are dramatically dissimilar anthropometrically and photoscopically could all end up in the category "½" if this remained the only available category.

A change to the scaling of somatotype, such as shifting the scale to make more room at the low end, or to open the scale to ratings of "zero" and negative numbers is historically unacceptable. Worse yet would be to create some new type of ectomorphy - perhaps something like $\frac{1}{\text{old ectomorphy}}$, or (20 - old ectomorphy) - that would solve the mathematical problem and lose all relevance to historic somatotype.

A new recommendation would be to adopt the possible category of "less than ½ unit". This would allow the ½ unit rating to truly represent those who deserve it, and would give a category for those where somatotype is not able to produce a meaningful rating. It would have the negative result that for some subjects the system would produce an ordinal, rather than continuous numerical, rating. It is better to admit that a tool is sometime inappropriate than to continue to try and use it where it is obviously not appropriate; only a very stubborn - or very ignorant - worker insists on trying to drive screws with a hammer.

Setting the boundary for this "less than ½ unit" category is not entirely obvious. The "3" category, for example, spans ratings from 2.75 through 3.25, since these ratings round to "3", to the nearest ½ unit. Being consistent, the "½" category should span ratings from 0.25 through 0.75. This would be mathematically correct, but would lead to the contradictory condition where a mathematically derived rating of 0.26 in one component would be given a rating of "½", yet a rating of 0.24 would receive a rating of "less than ½", conflicting with the logical meaning of "less than one-half". A more conservative suggestion is to give all mathematical ratings below 0.5 a rating of "less than ½". This produces a narrowing range of measurements corresponding to ratings of "½" than one might expect, but it is consistent with the idea behind the new rating.

IX. Differences In Methodologies

Heath-Carter Rating Form and Heath-Carter Equations

As previously stated, despite the 1980 claim that the equations "produce an exact decimalized rating based on the measurements provided" (Carter, 1980, p.5-22b) there has never been published work demonstrating this fact.

Figure 7 shows the difference over a wide range of skinfolds between the Heath-Carter endomorphy table and equation. While the agreement is not perfect, the difference is no more than 0.33 units; differences of up to 0.25 units are accountable by the rounding of the table to the nearest ½ unit, so this is a real difference of only 0.08 units - trivial. Figure 6 shows that, beyond 200 mm of skinfolds (about endomorphy ratings of 12), the problem will become more severe as the cubic equation nears and passes its inflection point. This shows that, while not exact, the existing equation is reasonably close - errors less than 0.1 unit - over the most common range of skinfolds, but will produce greater and greater errors for subjects with skinfolds increasing beyond about 185 mm (Heath-Carter endomorphy 11½).

This thesis has derived the existing equation from the existing form, supporting the claim for mesomorphy that the two produce identical results.

Figure 8 shows the difference between the Heath-Carter ectomorphy table and equation units ascribable to the rating table rounding to the nearest ½ unit, the only serious difference appears for height-weight ratios below about 40, where the difference approaches ½ unit. This is likely a result of the Heath-Carter rating form giving all height-weight ratios (HWR) below 39.65 a rating of ½ unit, where the constants in the equation change at HWR less than 40.75 and try and produce meaningful ratings in the very low ectomorphy ratings.

Heath-Carter Equations and New Equations

Hold-out Sample

Even though no completely sample-specific constants have been used in the development of the new somatotype equations, it may be of concern that the same population used to develop the equations is being used to test them. A series of t-tests and Kolmogorov-Smirnov tests were performed comparing endomorphy, mesomorphy, and ectomorphy predicted with the new equations between the major test population (n = 18,677) and the hold-out sample (n=2,108)., and between sex and sample-group subsamples within each population. The results, summarized in Table 7 and Table 8, show no significant difference between the sample means or distributions of the main population and the hold-out sample, or between any tested sub-sample of the populations.

Table 7: T-Tests between the Main and Hold-out Samples for Predicted Somatotype Components

T statistics (T), degrees of freedom (DF), and significance (p) for independent t-tests with pooled variance between the main test population and the hold-out sample for each of three somatotype components, as predicted with the newly developed equations. Values are also given for males and females separately and for each of the four sub-populations separately.

Sample	T	DF	p
Endomorphy			
All	0.539	20783	0.59
Females	0.209	7566	0.83
Males	0.310	13215	0.76
YMCA Lifestyle	0.783	19352	0.43
Bodybuilders	0.150	64	0.88
COGRO	0.695	906	0.49
MOGAP	0.015	455	0.99
Mesomorphy			
All	0.278	20783	0.78
Females	0.317	7566	0.75
Males	0.154	13215	0.88
YMCA Lifestyle	0.489	19352	0.62
Bodybuilders	0.584	64	0.56
COGRO	0.936	906	0.35
MOGAP	0.411	455	0.68
Ectomorphy			
All	0.250	20783	0.80
Females	0.572	7566	0.57
Males	0.071	13215	0.94
YMCA Lifestyle	0.261	19352	0.79
Bodybuilders	0.336	64	0.74
COGRO	0.466	906	0.64
MOGAP	0.551	455	0.58

Table 8: K-S tests between the Main and Hold-out Samples for Predicted Somatotype Components

Kolmogorov-Smirnov tests between the main test population and the hold-out sample for each of three somatotype components as predicted with the newly developed equations. Values are also given for males and females separately and for each of the four sub-populations separately.

Sample	p
Endomorphy	
All	0.50
Females	0.88
Males	0.84
YMCA Lifestyle	0.36
Bodybuilders	0.74
COGRO	0.47
MOGAP	0.49
Mesomorphy	
All	0.85
Females	0.35
Males	0.85
YMCA Lifestyle	0.86
Bodybuilders	0.95
COGRO	0.77
MOGAP	0.44
Ectomorphy	
All	0.98
Females	0.58
Males	0.75
YMCA Lifestyle	0.95
Bodybuilders	0.87
COGRO	0.48
MOGAP	0.68

Differences: Endomorphy

Figures 20, 21 and 22 show the distributions for predicted endomorphy for the new equation and for the existing Heath-Carter equation for the entire sample population (n=18,677), the females only (n=6,790), and the males only (n=11,887) respectively. Table 9 summarizes the agreement between the old Heath-Carter equation and the new equation for the entire population, and for males and females individually. Table 10 summarizes the technical error of measurement (T.E.M.) between the two equations, and Table 11 summarizes the population statistics.

Table 9: Agreement Between Old and New Endomorphy Equations

Summary of endomorphy rating differences between the Heath-Carter equation and the new equation. Below the double line in the table the percentages are calculated using the number of subjects for whom *both* rating systems produced a rating of ≥ ½ unit.

Agreement	Males	Females	Males & Females
Either Rating Below ½ unit	0.1%	0.0%	0.1%
Within ± $\frac{1}{10}$ units	27.0%	10.3%	20.9%
Within ± ¼ units	58.1%	27.1%	46.8%
Within ± ½ units	85.8%	57.0%	75.4%
Within ± 1 units	98.8%	93.3%	96.8%
Greater than ± 1 units	1.2%	6.7%	3.2%

Table 10: T.E.M. for Endomorphy

Technical Error of Measurement (T.E.M.) between the Heath-Carter equation and the new equation for the prediction of endomorphy. Subjects were excluded from the calculation if either system rated them "less than ½ unit". There were no females in the bodybuilder sample.

Sample	T.E.M. Males	T.E.M. Females	T.E.M. Males & Females
All	0.25	0.41	0.32
YMCA Lifestyle	0.24	0.41	0.31
Body builders	0.17	*	0.17
COGRO	0.39	0.41	0.40
MOGAP	0.19	0.45	0.30

Table 11: Distribution Summary Statistics for Endomorphy

Summary statistics for the distributions shown in Figures 20, 21, and 22 for endomorphy calculated with the Heath-Carter (H-C) equation and with the new equation. Positive skewness indicates a right skewed distribution and negative skewness indicates a left skewed distribution. Positive kurtosis indicates a flattened" distribution and negative kurtosis indicates a "peaky" distribution.

	Males		Females		Males & Females	
	H-C	New	H-C	New	H-C	New
Total n	11,887	11,887	6790	6790	18,677	18,677
Rating "< ½" n	0	14	0	3	0	17
Mean	3.76	3.81	4.55	4.81	4.05	4.18
Standard Deviation	1.38	1.18	1.45	1.07	1.45	1.24
Maximum	9.9	8.3	11.0	8.8	11.0	8.8
Skewness	0.47	-0.05	0.56	0.06	0.50	-0.08
Kurtosis	-0.02	-0.21	0.17	0.00	0.14	-0.11

Summary Discussion

If one was working only with the sum of 3 skinfolds, and looking at Figure 3 and Figure 4, one would expect that the new equation would produce slightly smaller endomorphy estimates than the existing Heath-Carter equation for sum-of-3-skinfolds below about 15 mm, slightly larger ratings between sum-of-3-skinfolds between about 15 mm. and about 50 mm., and progressively smaller ratings as the sum-of-3-skinfolds increases above about 50 mm. This expected result is shown in Figure 29 for a random sub-sample of the population. That there is variability around this expected "U-shape" is due to the variability between the $\frac{\text{sum of 3 skinfolds}}{\text{sum of 4 skinfolds}}$ ratio within individuals. That the spread is most pronounced in the middle - between about 20 mm. and 80 mm. of sum-of-3-skinfolds - makes sense considering this is where there is the most overlap between males and females; the $\frac{\text{sum of 3 skinfolds}}{\text{sum of 4 skinfolds}}$ differences between the sexes is demonstrated in Table 3.

As summarized in Table 11, the new equation produces much less skewed results than the Heath-Carter equation for males, females, and the combined population. While the maximum endomorphy ratings are reduced from 11 to 8.8 for females and from 9.9 to 8.3 for males using the new equations, the population averages all increase slightly.

With less than one half of the sample population showing agreement within ± ¼ rating unit and the strikingly different distributions resulting, there is a definite, real, difference between Heath-Carter endomorphy and the new endomorphy.

Differences: Mesomorphy

Figures 23, 24 and 25 show the distributions for predicted mesomorphy for the new equation and for the existing Heath-Carter equation for the entire sample population (n=18,677), the females only (n=6,790), and the males only (n=11,887) respectively. Table 12 summarizes the agreement between the old Heath-Carter equation and the new equation for the entire population, and for males and females individually. Table 13 summarizes the technical error of measurement (T.E.M.) between the two equations, and Table 14 summarizes the population statistics.

Table 12: Agreement Between Old and New Mesomorphy Equations

Summary of mesomorphy rating differences between the Heath-Carter equation and the new equation. Below the double line in the table the percentages are calculated using the number of subjects for whom *both* rating systems produced a rating of ≥ ½ unit.

Agreement	Males	Females	Males & Females
Either Rating Below ½ unit	0.0%	0.4%	0.15%
Within ± $\frac{1}{10}$ units	89.8%	49.2%	75.1%
Within ± ¼ units	98.8%	93.4%	96.8%
Within ± ½ units	99.8%	99.6%	99.7%
Within ± 1 units	100.0%	99.9%	100.0%
Greater than ± 1 units	0.0%	0.1%	0.0%

Table 13: T.E.M. for Mesomorphy

Technical Error of Measurement (T.E.M.) between the Heath-Carter equation and the new equation for the prediction of mesomorphy. Subjects were excluded from the calculation if either system rated them "less than ½ unit". There were no females in the bodybuilder sample.

Sample	T.E.M. Males	Females	Males & Females
All	0.06	0.11	0.08
YMCA Lifestyle	0.05	0.10	0.08
Body builders	0.14	*	0.14
COGRO	0.12	0.14	0.13
MOGAP	0.07	0.06	0.06

Table 14: Distribution Summary Statistics for Mesomorphy

Summary statistics for the distributions shown in Figures 23, 24, and 25 for mesomorphy calculated with the Heath-Carter (H-C) equation and with the new equation. Positive skewness indicates a right skewed distribution and negative skewness indicates a left skewed distribution. Positive kurtosis indicates a flattened" distribution and negative kurtosis indicates a "peaky" distribution.

	Males		Females		Males & Females	
	H-C	New	H-C	New	H-C	New
Total n	11,887	11,887	6790	6790	18,677	18,677
Rating "< ½" n	2	2	14	26	16	28
Mean	5.05	5.02	3.88	3.81	4.62	4.58
Standard Deviation	1.28	1.29	1.28	1.38	1.40	1.45
Maximum	13.8	14.2	12.5	14.2	13.8	14.2
Skewness	0.28	0.40	0.69	0.84	0.29	0.34
Kurtosis	0.86	1.09	1.68	2.13	0.53	0.73

Summary Discussion

All of the figures and tables indicate that there is very little difference between the existing Heath-Carter mesomorphy equation and the new equation. There seems to be an average difference of about 0.03 to 0.05 units across a broad sample of populations, with the Heath-Carter equations producing the larger results. T-tests show that for all combinations of sex and sample group the difference between means - though very small - is statistically significant ($p < 0.001$), except for males from the COGRO sample where the mean difference of 0.006 was not significant ($p = 0.94$). Section II has discussed the implication of very tiny systematic differences on t-tests for large samples; it is probably fair to say that the two methods produce, practically, the same result for most populations.

Individual results, however, are another matter. The new equation truly dissociates size from the rating of mesomorphy using the Parnell column with height equal to 70 inches (177.8 cm.) as the reference for a somatotype rating of 4½; the same assumptions as those for the Heath-Carter equation and rating table. As discussed in section I.C the existing Heath-Carter rating form, and therefore equation, does not actually dissociate size from the mesomorphy rating.

The changing column widths as a percentage of the subject's height as one moves away from the 177.8 cm. in the Heath-Carter mesomorphy estimate implies that the difference between the old and new equations should increase as the subject height moves farther from this height. Figure 30 shows exactly this. Similarly, the more the subject's mesomorphy rating deviates from a rating of 4½ - the more columns of average deviation in their measurements - the more the two rating methods should differ. Figure 31 shows this effect.

For subjects near 177.8 cm. tall, or those with mesomorphy ratings near 4½, it would be fair to assume that the new equation is equivalent to the existing Heath-Carter equation. Where height and mesomorphy both differ from these values this equivalence is no longer guaranteed. This can be seen clearly in the higher T.E.M. for bodybuilders with extremely high mesomorphy and in the COGRO sample where many of the children were relatively short.

However, with three quarters of the sample population showing agreement within ± .1 rating unit, and over 95% of the population showing agreement within ± ¼ unit, it would be fair to claim that the new mesomorphy equation is practically equivalent to the existing Heath-Carter equation for most non-extreme populations.

Differences: Ectomorphy

Figures 26, 27 and 28 show the distributions for predicted ectomorphy for the new equation and for the existing Heath-Carter equation for the entire sample population (n=18,677), the females only (n=6,790), and the males only (n=11,887) respectively. Table 15 summarizes the agreement between the old Heath-Carter equation and the new equation for the entire population, and for males and females individually. Table 16 summarizes the technical error of measurement (T.E.M.) between the two equations, and Table 17 summarizes the population statistics.

Table 15: Agreement Between Old and New Ectomorphy Equations

Summary of mesomorphy rating differences between the Heath-Carter equation and the new equation. Below the double line in the table the percentages are calculated using the number of subjects for whom *both* rating systems produced a rating of ≥ ½ unit.

Agreement	Males	Females	Males & Females
Either Rating Below ½ unit	11.1%	9.3%	10.4%
Within ± $\frac{1}{10}$ units	92.5%	95.8%	93.7%
Within ± ¼ units	100.0%	100.0%	100.0%
Within ± ½ units	100.0%	100.0%	100.0%
Within ± 1 units	100.0%	100.0%	100.0%
Greater than ± 1 units	0.0%	0.0%	0.0%

Table 16: T.E.M. for Ectomorphy

Technical Error of Measurement (T.E.M.) between the Heath-Carter equation and the new equation for the prediction of ectomorphy. Subjects were excluded from the calculation if either system rated them "less than ½ unit". There were no females in the bodybuilder sample.

Sample	T.E.M. Males	Females	Males & Females
All	0.04	0.03	0.04
YMCA Lifestyle	0.04	0.03	0.04
Body builders	0.07	*	0.07
COGRO	0.02	0.02	0.02
MOGAP	0.02	0.02	0.02

Table 17: Distribution Summary Statistics for Ectomorphy

Summary statistics for the distributions shown in Figures 26, 27, and 28 for ectomorphy calculated with the Heath-Carter (H-C) equation and with the new equation. Because of the obvious, severe truncation at the lower end of the distributions neither skewness nor kurtosis are included.

	Males		Females		Males & Females	
	H-C	New	H-C	New	H-C	New
Total n	11,887	11,887	6790	6790	18,677	18,677
Rating "< ½" n	809	1319	441	629	1250	1948
Mean	2.31	2.39	2.65	2.72	2.43	2.51
Standard Deviation	1.12	1.11	1.12	1.10	1.13	1.12
Maximum	8.9	8.9	13.9	13.9	13.9	13.9
Skewness	-	-	-	-	-	-
Kurtosis	-	-	-	-	-	-

Summary Discussion

For height-weight ratios above 40.75 - corresponding to height-adjusted body weights below 72.6 kg, and Heath-Carter ectomorphy ratings above 1.25 - the old and new equations are identical, except all constants are given to four significant digits in the new equation rather than three. There are very slight differences shown between the two methodologies, but they are purely a result of the number of digits in the calculation and the effects of rounding to the nearest ½ somatotype unit before comparing.

The Heath-Carter recommendation of using a different equation - and especially the nature of the relationship - for (rounded) ratings of 1 and below has never being well justified. This extra equation results in questionable population distributions; Figure 28, the male distribution, is particularly bizarre. That all of the other somatotype components, for all the other populations and subpopulations, produce moderately smooth, unimodal, curves indicates that the bimodal "hump" inflicted on the endomorphy data by the extra equation is unnatural, and probably unjustifiable.

That both the Heath-Carter equation(s) and the new equation for rating ectomorphy relegate a large part of the population (over 11% for males using the new equation) to the rating of "less than ½" is unfortunate for those wishing to use somatotype to differentiate between the ponderous and the extremely ponderous. It is, however, much better to recognize the limitation of the tool than to try and modify it to perform a task it is not suited for. Modifications such as opening the scale to ratings of zero and below, defining ectomorphy to be "ponderosity" rather that "linearity", or treating arbitrarily small ratings mathematically different, would all solve the small problem at hand, but would fundamentally destroy some aspect of the tool as a whole.

X: Conclusions

This thesis had three goals:

1: To test the claim that the Heath-Carter somatotype equations and the Heath-Carter somatotype rating form produce identical results.

2: To develop theoretically and dimensionally sound equations that closely mimic the existing somatotype form.

3: To develop a new somatotype rating form that produce identical results to the newly developed equations .

Summary statistics and theoretical analysis have been included to show that, for most subjects, any difference between the Heath-Carter rating form and the Heath-Carter equations are trivial and are inconsequential. For subjects with very large skinfolds however, the existing equation is shown to produce inappropriately large results as a result of the unjustified use of a cubic equation.

The first goal was predicated on the assumption that the existing rating table for mesomorphy and the existing equation for mesomorphy were dimensionally different, and therefore would produce different results for subjects depending upon their size.

Within this thesis the existing Heath-Carter mesomorphy equation was shown to truly produce "an exact decimalized rating", exactly equivalent to the rating form; a proof never before published. While not overly stressed in this work, the chain of logic: (i) the Heath-

Carter equation does not dimensionally remove size from the assessment of mesomorphy, (ii) the existing equation truly mimics the Heath-Carter mesomorphy table, and (iii) the Heath-Carter mesomorphy table is only a subtle modification of Parnell's M.4 rating table leads to the interesting conclusion that there has *never* been a truly size-dissociating anthropometric assessment of mesomorphy.

The second goal, to produce equations that were theoretically and dimensionally sound, was achieved. For ectomorphy, the equation that Heath and Carter recommended for most subjects was adopted for all subjects. Heath and Carter never clearly justified the use of multiple equations for the prediction of ectomorphy, and this thesis has graphically shown the illogical effect of their use of multiple equations.

A new equation, based entirely on the constants implicit in both the Heath-Carter mesomorphy rating form and Parnell's M.4 rating form was developed. This equation truly dissociates size from the assessment of mesomorphy for the first time, and has been show to produce only trivial differences from the Heath-Carter mesomorphy assessment within a number of populations.

Endomorphy assessment resulted in the most dramatic departure from the existing methodology. From the start, the idea of a cubic equation was discarded in favor of a logarithmic-based equation, an idea borrowed from Parnell that made more intuitive sense. During the development of the new equation a logarithmic-based equation with near perfect agreement to the existing table was developed, yet it was discarded in favor of a simpler, more theoretically sound equation. To expand the existing equation to include the medial calf skinfold as a fourth representative skinfold required the calculation of sample-specific constants from a very large (n > 18,000) population; this was done in a way chosen to minimize any sample distribution effect.

It is felt that the new equation for the prediction of endomorphy is both historically relevant and conceptually sound, even though it produced significantly different results than the existing Heath-Carter equation for both individuals and for sample populations.

The equations recommended for the prediction of somatotype from anthropometry are:

$$\text{Endomorphy} = \left[3.269 \times \left(Ln\left(\left(\sum 4 \text{ Skinfolds}\right) \times \frac{170 \text{ cm.}}{\text{Subject Ht. in cm.}} \right) \right) \right] - 8.584$$

$$\text{Mesomorphy} = \Big(.1968\left(\text{arm girth} - \frac{\text{triceps sf}}{10}\right) + .1681\left(\text{calf girth} - \frac{\text{calf sf}}{10}\right)$$

$$+ 0.8973\ (\text{humerus}) + 0.6291\ (\text{femur}) \Big) \times \frac{170}{\text{height}} - 18.84$$

$$\text{Ectomorphy} = 0.7325\left(\frac{\text{Height in cm..}}{\sqrt[3]{\text{Weight in kg.}}} \right) - 28.58\ .$$

The third goal, to produce a new rating form that produced identical results to the new equations, was also achieved. The mesomorphy section retained the idea, used since Parnell's M.4 form, of calculating mesomorphy from columns of deviation for the four predicting anthropometric values. In the new form the values were height-adjusted before determining the deviations, thereby removing size from the prediction.

The endomorphy and ectomorphy sections were represented as both lookup tables (similar to the existing Heath-Carter form) and as graphic "number lines" in two different versions of the rating form. The results were of course the same, but the "number lines" had certain visual and analytical appeal. The form was put forward more as a vehicle for promoting change and flexibility and was not being suggested as a final tool. Anyone using the new equations, and the techniques and information used to derive them discussed in the thesis, could produce a form of their own design that would be just as effective.

A fourth development, not perceived at the time the goals for this thesis were originally formulated, was required to complete this work. It was necessary to create and justify an additional rating category for somatotype components. To date all somatotype component ratings had been numeric. This work builds a case for the use of a "below 1/2" rating to be used for ratings that are mathematically less than 0.5. That this recommendation produced the first non-numeric somatotype rating caused it to be approached with apprehension, yet it dramatically simplified and unified the tool by removing the need to invent special scales for arbitrarily small rating or to enforce different precision above and below arbitrary values.

Many of the contributions of this work stand as significant in themselves: the first demonstration of differences between the existing rating form and the existing equations;

the first publication of the derivation of the existing mesomorphy equation from the rating form; and the development of the first mesomorphy equation and table that truly and completely separate size from the assessment of shape.

The most important contribution is, however, felt to be the reopening of the equations to examination, especially the endomorphy equation. It is obvious that other experimenters, starting with the same general assumptions and datasets, could have arrived at significantly different endomorphy equations. There is no "inherent truth" to somatotype, nothing that can be dissected and weighed, ultrasounded, CAT scanned, or measured to determine whose equation was "best". Somatotype has always been historically determined by the carefully considered opinion of a few - Sheldon, Heath, Carter, and perhaps Parnell - and this definition of "best" has changed over the decades. This current work needs to be pondered and discussed, not rushed into acceptance.

Future work needs to focus first on the idea of photoscopic somatotype. To quote Parnell, "... agreement between photoscopic somatotypists implies that they have learnt to sing in harmony, but their song does not thereby become a science, it remains an art." Until Carter and Heath published their book in 1990 - fully a half a century after the original development of somatotype - there was *never* a written description of how one should go about rating a photograph. It still has never been demonstrated in print that it is possible to learn to do so from the written instructions. Undoubtedly Heath, Carter, and perhaps others, can rate consistently and reliably; this doesn't make photoscopic somatotyping a science, only - to paraphrase Parnell - a small choir.

If photoscopic somatotyping proves to be an objective scientific tool it can be used to support or refute many of the recommended changes in this thesis. If future studies show that photoscopic somatotyping is too subjective to be considered as a valid scientific tool it would open up questions as to Heath and Carter's work, especially the nature of the extension to the endomorphy scale where the photoscopic rating of a relatively small number of females, all with missing skinfold measurements, have defined the nature of endomorphy for the last quarter of a century.

XI: Figures

Figure 1: Parnell's Prediction of Endomorphy from the Sum of 3 Skinfolds

Parnell's values for the sum of 3 skinfolds used to predict endomorphy from the tables reproduced as Figure 10 and Figure 13, showing the relationship between the natural logarithm of this sum of 3 skinfolds and the predicted endomorphy.

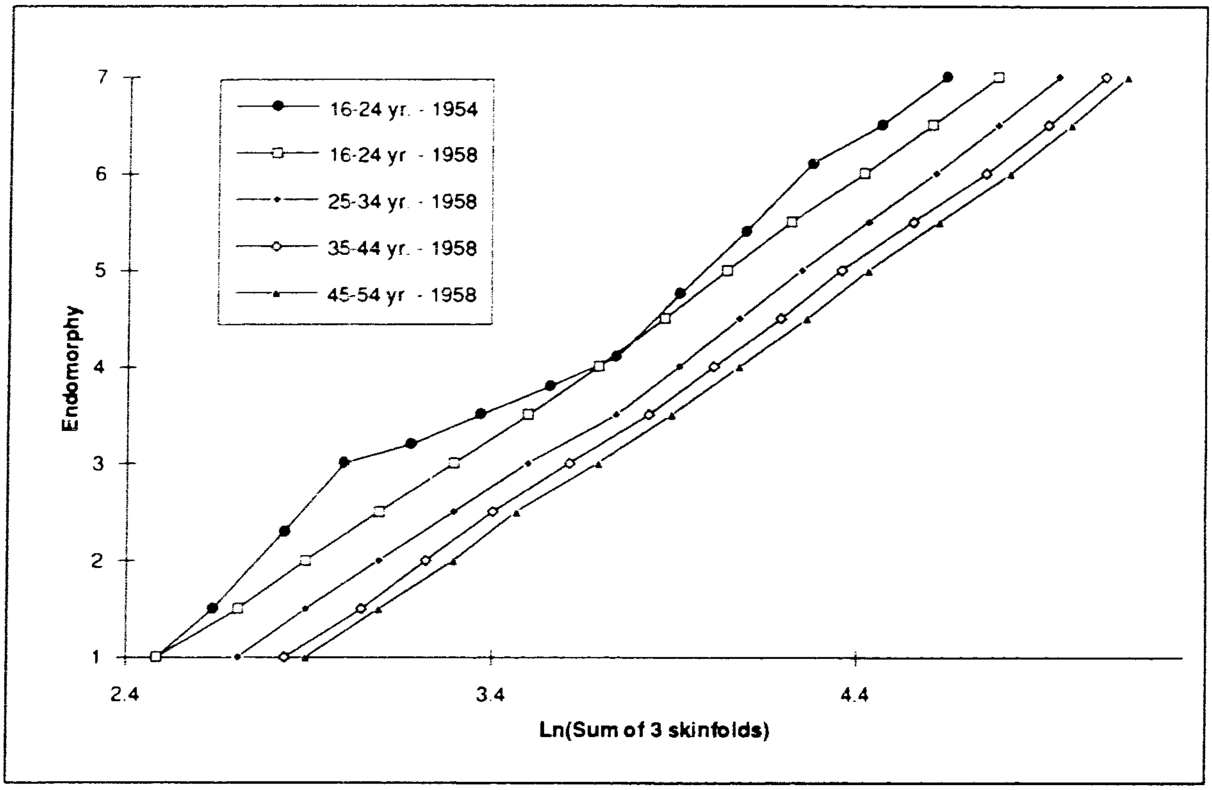


Figure 2: Heath and Carter's Prediction of Endomorphy from the Sum of 3 Skinfolds

The relationship between the sum of three skinfolds (Sum3SF), the natural logarithm of the sum of three skinfolds (Ln(Sum3SF)) and the endomorphy rating predicted from the Heath-Carter somatotype rating form. The solid line represents a stylized reproduction of Fig. 3 from Heath & Carter (1967), "A Modified Somatotype Method".

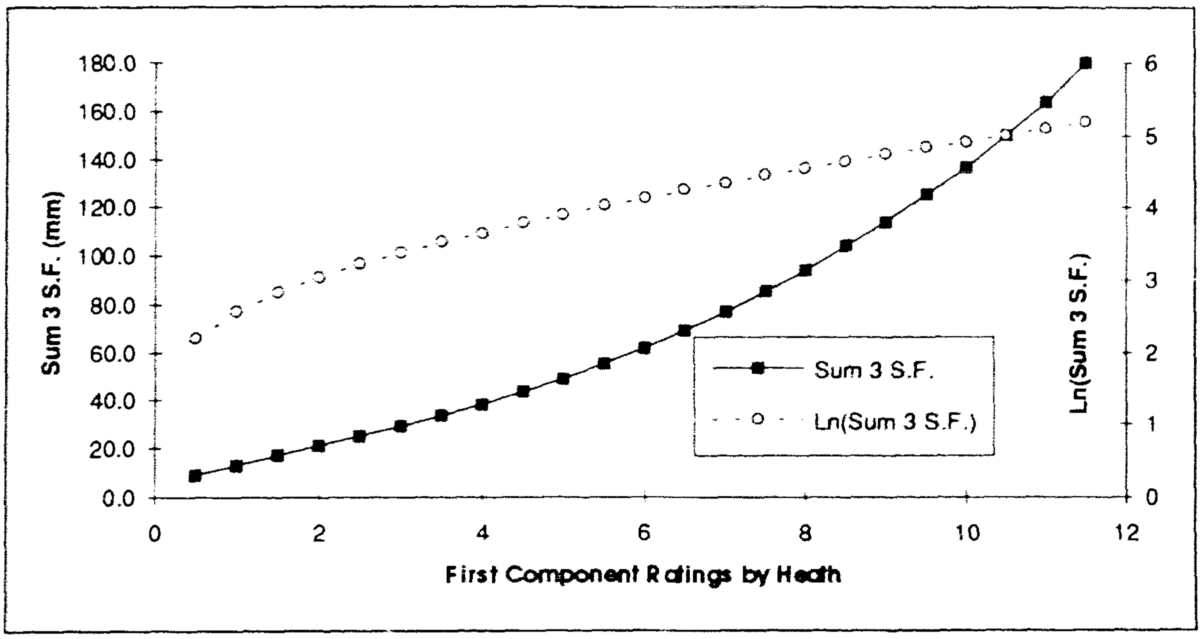


Figure 3: Prediction of Endomorphy From the Logarithm of the Sum-of-Three Skinfolds for Historical and Newly Proposed Methodologies

Information from Figure 1 and Figure 2, combined with the intermediate equation developed in section IV, showing the proposed new equation in the context of previous systems.

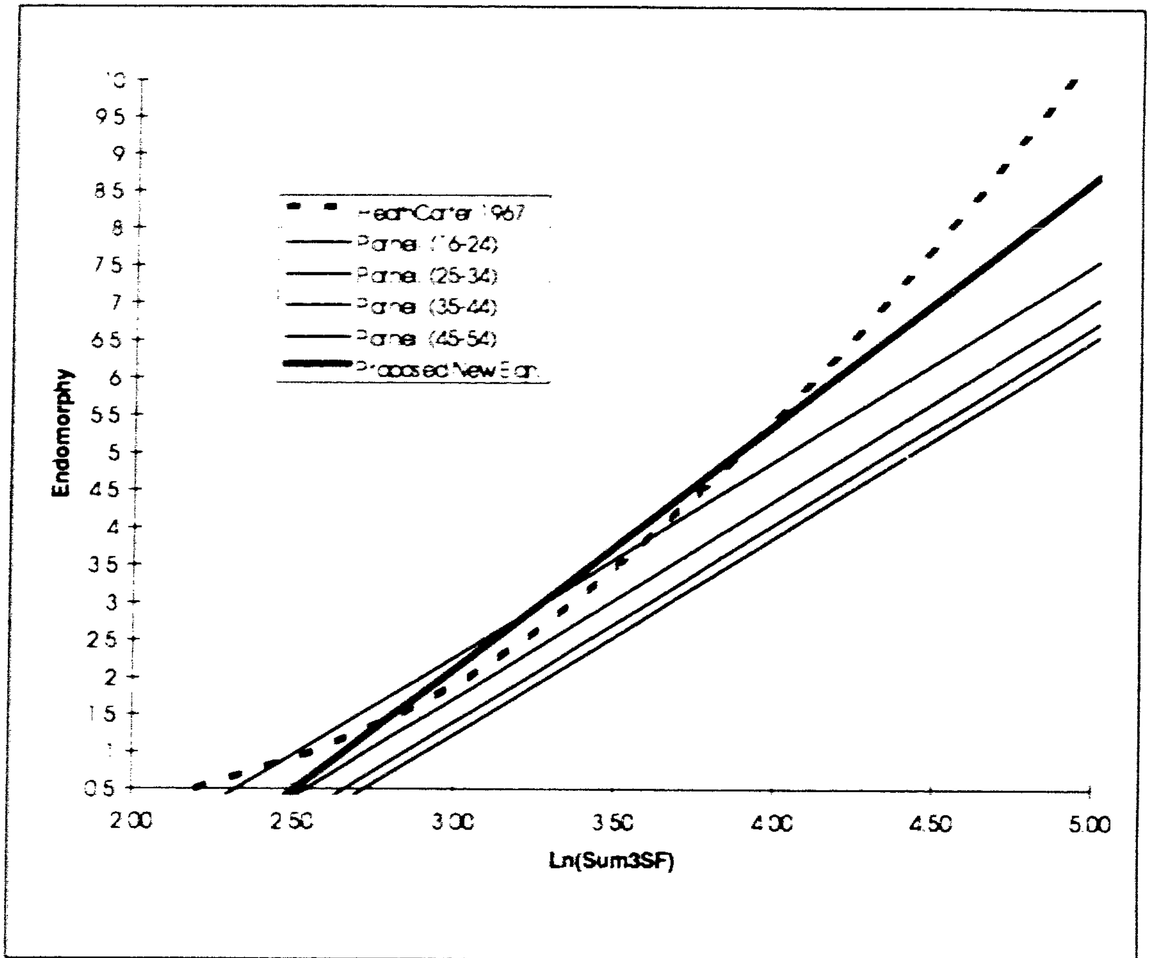


Figure 4: Prediction of Endomorphy From the Sum-of-Three Skinfolds for Historical and Newly Proposed Methodologies

Figure 3, with the skinfold axis (X-axis) expressed as absolute skinfold thickness (in mm.).

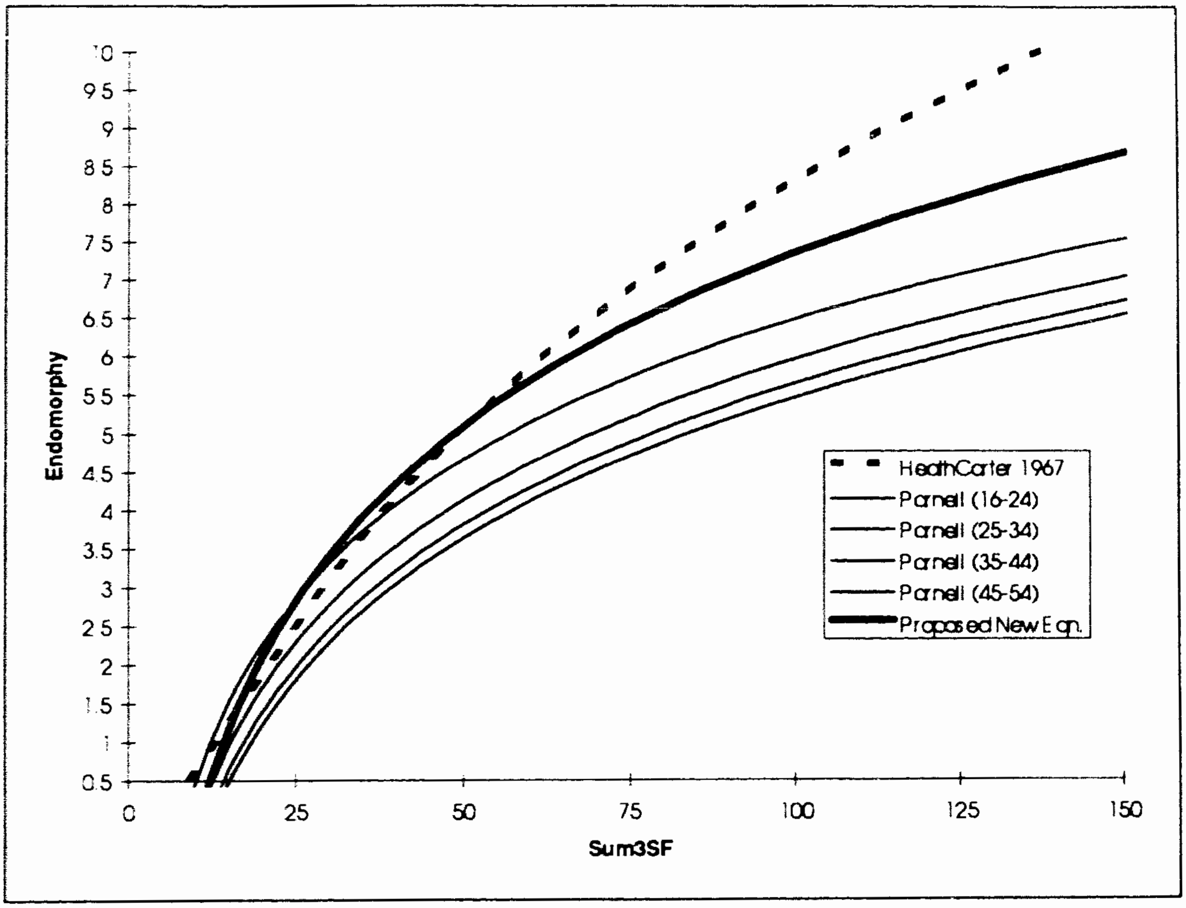


Figure 5: Two New Equations for Predicting Endomorphy from the Sum of Four Skinfolds

Solid Line: Equation Developed in section IV:

$$\text{Endomorphy} = \left[3.269 * (Ln)\left(\text{Ht. Adjusted} \sum 4 \text{ Skinfolds}\right)\right] - 8.584$$

Dotted Line: Sample-specific fit from section IV:

$$\text{Endomorphy} = \left[3.768 * (Ln)\left(\text{Ht. Adjusted} \sum 4 \text{ Skinfolds}\right)\right] - 10.668$$

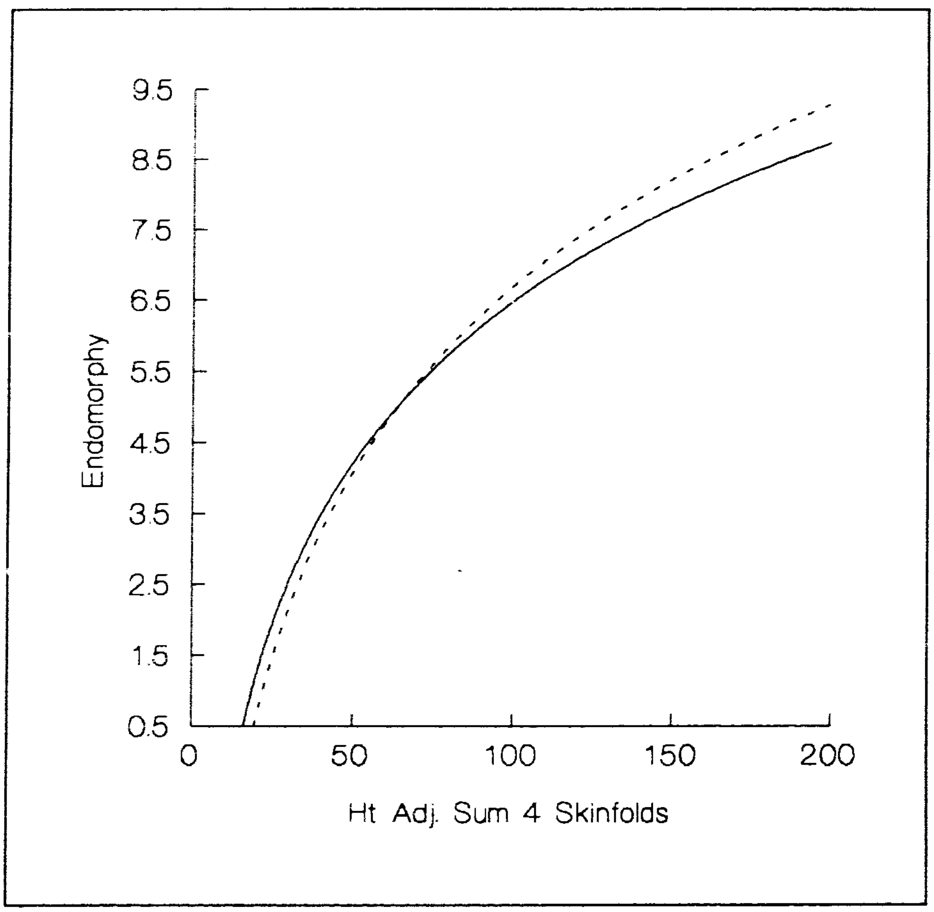


Figure 6: The Existing Heath-Carter Endomorphy Equation

The existing Heath-Carter equation for the prediction of Endomorphy over a large range of skinfolds. Endomorphy = $-0.7182 + 0.1451(X) - 0.00068(X)^2 + 0.0000014(X)^3$, where "X" is the sum of triceps, subscapular, and supraspinale skinfolds.

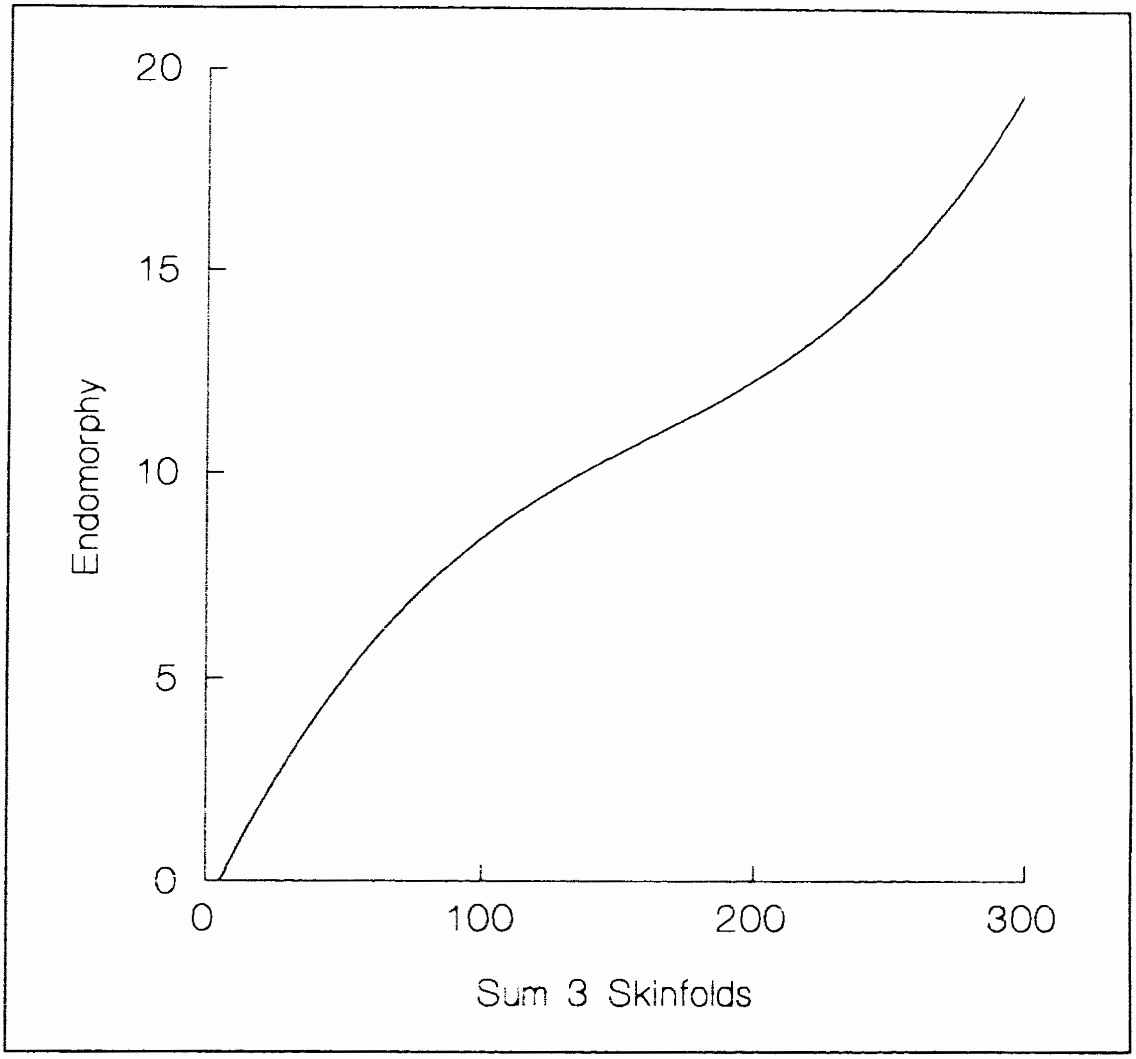


Figure 7 : The Difference Between the Heath-Carter Endomorphy Table and Equation

The Heath-Carter endomorphy rating table, minus the Heath-Carter endomorphy equation over a range of skinfolds corresponding to endomorphy ratings 0.1 - 12 (8 - 200 mm). Because the rating form produces an answer to the nearest ½ unit, while the equation produces a decimal answer, oscillations confined between (-0.25) and (+0.25) units would indicate perfect agreement.

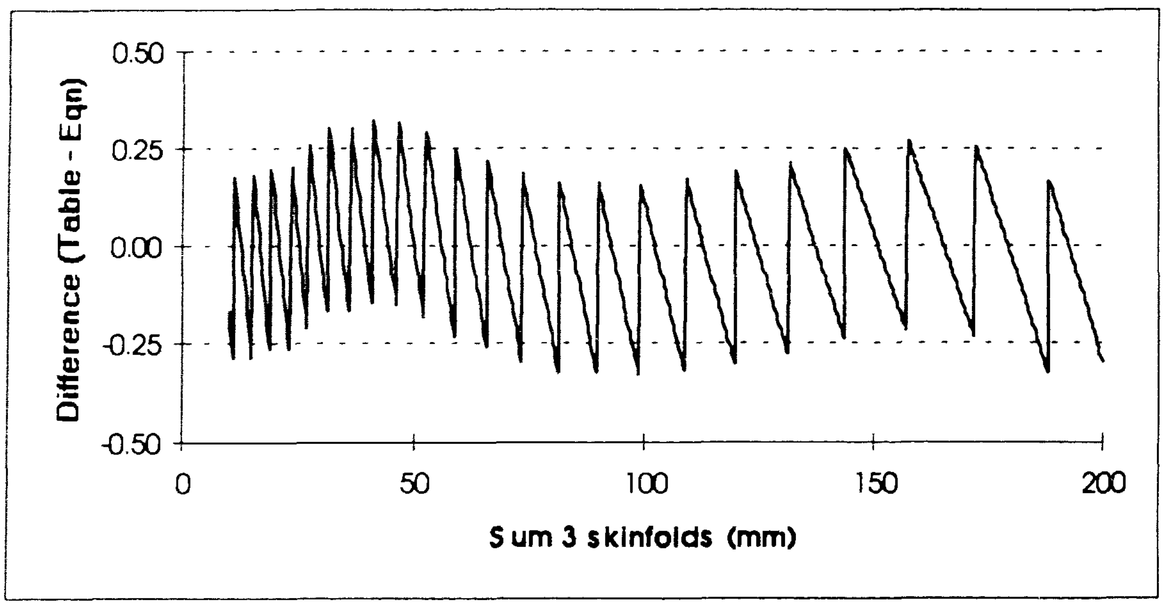


Figure 8 :The Difference Between the Heath-Carter Ectomorphy Table and Equation

The Heath-Carter ectomorphy rating table, minus the Heath-Carter ectomorphy equation(s) over a range of height-weight ratios ($HWR = \frac{height}{\sqrt[3]{weight}}$) corresponding to ectomorphy ratings 0.1 - 9 .

Because the rating form produces an answer to the nearest ½ unit, while the equations produces a decimal answer, oscillations confined between (-0.25) and (+0.25) units would indicate perfect agreement.

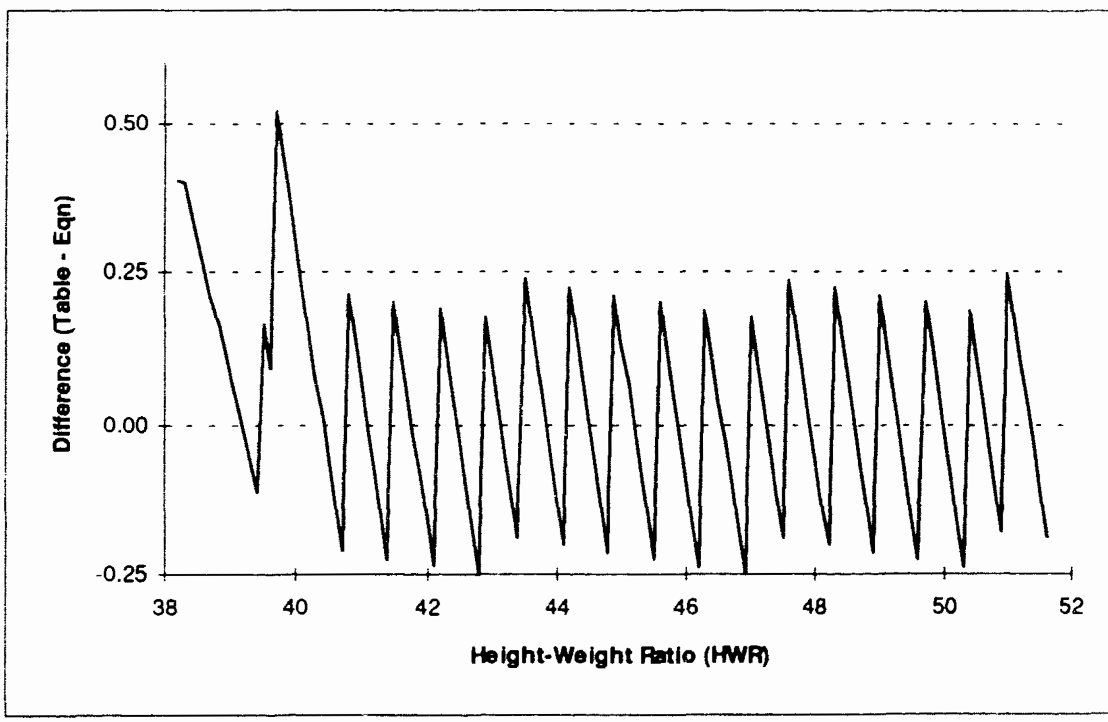


Figure 9: Sheldon's Ht/Cube Root of Weight Table

Taken from Sheldon, Stevens, & Tucker (1940), *Varieties of Human Physique*. This table allowed the user to ascertain the most likely somatotypes for a subject based on their (height)/($\sqrt[3]{weight}$) ratio.

Ratio-Index																	
11.2	711																
11.3																	
11.4	731																
11.5	721																
11.6																	
11.7	641		712														
11.8																	
11.9																	
12.0	551	631															
12.1	371	461															
12.2	621		632														
12.3	271	541	622														
12.4	361		542														
12.5	171		612			623											
12.6	261	451	362			613											
12.7			172	452	532	543											
12.8			262	352	522												
12.9			162	442		453	533										
13.0			252			263	353	523	534								
13.1						163	443		354	524							
13.2						253	343	433	444								
13.3									434	514							
13.4									254	344	424						
13.5									154	244	334	435	515				
13.6												345	425				
13.7												245	335	415			
13.8												235	325				
13.9												145	225		326		
14.0															236	316	
14.1															136	226	
14.2															216		
14.3															126		
14.4																	217
14.5																	127
14.6																	
14.7																	
14.8																	117

Figure 10: Parnell's 1954 Deviation Table

Taken from Parnell (1954), "Somatotyping by Physical Anthropometry". This table was to be used to aid the Sheldonian somatotyper in their original assessment of dominance of somatotype components. It also provided a direct estimate of endomorphy and ectomorphy based on the subject's anthropometric measurements.
The androgyny section of the table has not been reproduced.

Deviation chart of physique

Name ______________________ Age ______ Ref. no. ______________

Somatotype ______________

STANDARD SCALE	-5	-4½	-4	-3½	-3	-2½	-2	-1½	-1	-½	mean	+½	+1	+1½	+2	+2½	3
Height (ins.)	57.5	58.8	60.1	61.4	62.6	63.8	65	66.3	67.5	68.8	70	71.2	72.4	73.6	74.9	76.1	77.3
Weight (lbs.)	60	69	78	87	96	105	114	123	132	141	150	158	167	176	185	193	202
H.W. Ratio	10.5	10.75	11.0	11.3	11.6	11.8	12.1	12.4	12.6	12.9	13.2	13.5	13.7	14.0	14.3	14.5	14.8
Bone: Humerus	5.0	5.2	5.4	5.56	5.74	5.9	6.1	6.3	6.4	6.6	6.8	7.0	7.1	7.3	7.5	7.7	7.8
(cm) Femur	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.9
Muscle: Biceps	19.8	20.9	22.0	23.2	24.3	25.4	26.5	27.6	28.7	29.9	31.0	32.1	33.2	34.3	35.4	36.5	37.6
(cm) Calf	26.2	27.2	28.2	29.2	30.2	31.2	32.3	33.3	34.3	35.3	36.3	37.3	38.3	39.4	40.4	41.4	42.4
Fat: Subcut. subscapular					5.0	6.0	7.0		10.5	12.5	15.0	18.0	21.5	26.0	31.0	38.0	+
(mm) Subcut. suprailiac					3.0	4.0	5.0		8.0	10.0	12.0	15.0	19.0	23.0	28.0	35.0	+
Subcut. over triceps					3.5	4.5	5.0		7.5	9.0	10.5	12.5	15.0	18.0	21.0	25.0	30.0
Total of 3 subcut. (T.F.)					12	14	17	20	24	29	35	42	50	60	72	87	104
Androgyny:																	
H.W. Ratio					12.2	12.3	12.5	12.7	12.9	13.1	13.2	13.4	13.6	13.8	14.0	14.2	14.4
					or less	12.4	12.6	12.8	13.0		13.3	13.5	13.7	13.9	14.1	14.3	+
Provisional estimate Ectomorphy at ages 16-20 yrs.					1	1½	2	2½	3	3½	3½ or 4	4½	5	5½	6	6½	7
Provisional estimate Endomorphy from T.F. column above					1.0	1.5	2.3	3.0	3.2	3.5	3.8	4.1	4.75	5.4	6.1	6.5	7.0
Column code	8	8.5	9	9.5	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7

Figure 11: Parnell's 1954 Deviation Table, with sample data

Figure 10, with sample data from section A.III indicated. Circles have been placed mid-way between columns when the data fell mid-way; Parnell gives no rules for dealing with this type of data.

Deviation chart of physique

Name: Parnell's example #3 Age: 24 Ref. no. ______

Somatotype ______

STANDARD SCALE	-5	-4½	-4	-3½	-3	-2½	-2	-1½	-1	-½	mean	+½	+1	+1½	+2	+2½	3
Height (ins.)	57.5	58.8	60.1	61.4	62.6	63.8	65	66.3	67.5	68.8	70	71.2	72.4	73.6	74.9	76.1	77.3
Weight (lbs.)	60	69	78	87	96	105	114	123	132	141	150	158	167	176	185	193	202
H.W. Ratio	10.5	10.75	11.0	11.3	11.6	11.8	12.1	12.4	12.6	12.9	13.2	13.5	13.7	14.0	14.3	14.5	14.8
Bone: Humerus	5.0	5.2	5.4	5.56	5.74	5.9	6.1	6.3	6.4	6.6	6.8	7.0	7.1	7.3	7.5	7.7	7.8
(cm) Femur	7.7	7.9	8.1	8.3	8.5	8.7	8.9	9.1	9.3	9.5	9.7	9.9	10.1	10.3	10.5	10.7	10.9
Muscle: Biceps	19.8	20.9	22.0	23.2	24.3	25.4	26.5	27.6	28.7	29.9	[illegible]	32.1	33.2	34.3	35.4	36.5	37.6
(cm) Calf	26.2	27.2	28.2	29.2	30.2	31.2	32.3	33.3	[illegible]	35.3	36.3	37.3	38.3	39.4	40.4	41.4	42.4
Fat: Subcut. subscapular					5.0	6.0	7.0		[illegible]	12.5	15.0	18.0	21.5	26.0	31.0	38.0	+
(mm) Subcut. suprailiac					3.0	4.0	5.0		8.0	10.0	12.0	15.0	19.0	23.0	28.0	35.0	+
Subcut. over triceps					3.5	4.5	5.0		7.5	9.0	10.5	12.5	15.0	18.0	21.0	25.0	30.0
Total of 3 subcut. (T.F.)					12	14	17	20	24	29	35	42	50	60	72	87	104
Androgyny:																	
H.W. Ratio					12.2	12.3	12.5	[illegible]	12.9	13.1	13.2	13.4	13.6	13.8	14.0	14.2	14.4
					or less	12.4	12.6	[illegible]	13.0		[illegible]	13.5	13.7	13.9	14.1	14.3	+
Provisional estimate Ectomorphy at ages 16-20 yrs.					1	1½	2	[illegible]	3	3½	3½ or 4	4½	5	5½	6	6½	7
Provisional estimate Endomorphy from T.F. column above					1.0	1.5	2.3	3.0	3.2	3.5	[illegible]	4.1	4.75	5.4	6.1	6.5	7.0
Column code	8	8.5	9	9.5	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7

Figure 12: A Sample of one of Parnell's five 1954 Endo-Meso tables

Taken from Parnell's "Somatotyping by Physical Anthropometry" (*American Journal of Physical Anthropology*, 1954). These tables were used to calculate the relative endomorphy to mesomorphy for a subject's somatotype based on their anthropometry.

Only the section of the table relevant to the example in section A.III has been reproduced.

Men aged 17 - 24 Height/cubed root (Weight) 13.00 - 13.45 inclusive										
HEIGHT INCHES	ENDO-MESO ESTIMATE	2	2½	3	3½	4	4½	5	5½	6
[redacted]										
68 - 69.9	Humerus, cm	6.4	6.5	6.7	6.9	7.0	7.2	7.4	7.5	7.7
	Femur, cm	8.9	9.1	9.3	9.5	9.7	[illegible]	10.1	10.3	10.5
	Biceps, cm	25.0	26.1	27.2	28.3	[illegible]	30.6	31.7	32.8	33.9
	Calf, cm	31.2	32.3	33.3	34.3	[illegible]	[illegible]	37.3	38.4	39.4
	Total Fat, mm	19	23	28	33	40	48	58	69	83
[redacted]										

Figure 13: Parnell's 1958 M.4 Deviation Chart

Reproduced from *Behavior and Physique* by R.W. Parnell (1958), p. 21, representing the first self-contained anthropometric somatotyping system.

ADULT DEVIATION CHART OF PHYSIQUE (Male Standards)

NAME ________ AGE ________ DATE ________

OCCUPATION ________ Married/Single. Ch.: M___ F___ REF No. ________

Fat:		Age																		
(mms.)	Over triceps ----	16-24					12	15	18	22	27	33	40	48	57	68	83	100	120	
	Subscapular ----	25-34					15	18	22	27	33	42	50	59	70	84	101	120	142	
	Suprailiac ----	35-44					17	21	25	30	37	46	55	66	78	95	116	138	162	
	Total Fat ----	45-54					18	22	27	32	40	49	59	71	84	102	124	147	172	
ENDOMORPHY Estimate							1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Height (ins.)	----		55.0	56.5	58.0	59.5	61.0	62.5	64.0	65.5	67.0	68.5	70.0	71.5	73.0	74.5	76.0	77.5	79.0	80.5
Bone:	Humerus ----		5.34	5.49	5.64	5.78	5.93	6.07	6.22	6.37	6.51	6.65	6.80	6.95	7.09	7.24	7.38	7.53	7.67	7.82
(cms.)	Femur ----		7.62	7.83	8.04	8.24	8.45	8.66	8.87	9.08	9.28	9.49	9.70	9.91	10.12	10.33	10.53	10.74	10.95	11.16
Muscle:	Biceps ----		24.4	25.0	25.7	26.3	27.0	27.7	28.3	29.0	29.7	30.3	31.0	31.6	32.2	33.0	33.6	34.3	35.0	35.6
(cms.)	Calf		28.5	29.3	30.1	30.8	31.6	32.4	33.2	33.9	34.7	35.5	36.3	37.1	37.8	38.6	39.4	40.2	41.0	41.8
First estimate of mesomorphy							1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Correction for fat (T.F. mms.)							12	15	18	22	27	33	40	48	52	68	83	100	120	140
Age:	16-24						+½	+½	+¼	+¼	0	-¼	-½	-1	-1½	-2	-2½	-3	-4	
	25-34						(+½)	+½	+¼	+¼	0	-¼	-½	-¾	-1¼	-1¾	-2¼	-2¾	-3½	-4
	35+						(+½)	(+½)	+¼	+¼	0	-¼	-¼	-½	-1	-1½	-2	-2½	-3	-3½
MESOMORPHY (corrected estimate)							1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Weight	Wt.lb. H.W.R.	Age																		
Present		18					12.1	12.3	12.5	12.7	12.9	13.1	13.3	13.5	13.7	13.8	14.0	14.2	14.4	
H.K.W.		23					11.7	12.0	12.2	12.5	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.2	14.4	
Usual		28					11.5	11.8	12.1	12.4	12.6	12.8	13.0	13.3	13.5	13.7	13.9	14.2	14.4	
At 18 years		33					11.3	11.7	12.0	12.3	12.5	12.7	12.9	13.2	13.4	13.6	13.9	14.1	14.4	
At 23 years		38					11.2	11.5	11.8	12.1	12.4	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.4	
Recent change		43+					11.1	11.4	11.7	12.0	12.3	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.4	
ECTOMORPHY							1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	

Figure 14: Parnell's 1958 M.4 Deviation Chart with sample data

Figure 13, with sample data from section A.IV indicated.

ADULT DEVIATION CHART OF PHYSIQUE (Male Standards)					NAME Parnell's 1954 subject #3			OCCUPATION			Married/Single.		AGE 24		Ch.: M___ F___		DATE		REF No.		
Fat			Age																		
(mms.)	Over triceps	----	16-24					12	15	18	22	27	33	40	48	57	68	83	100	120	
	Subscapular	----	25-34					15	18	22	27	33	42	50	59	70	84	101	120	142	
	Suprailiac	----	35-44					17	21	25	30	37	46	55	66	78	95	116	138	162	
	Total Fat	20.0	45-54					18	22	27	32	40	49	59	71	84	102	124	147	172	
ENDOMORPHY Estimate								1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Height (ins.)		----		55.0	56.5	58.0	59.5	61.0	62.5	64.0	65.5	67.0	68.5	70.0	71.5	73.0	74.5	76.0	77.5	79.0	80.5
Bone:	Humerus	----		5.34	5.49	5.64	5.78	5.93	6.07	6.22	6.37	6.51	6.65	6.80	6.95	7.09	7.24	7.38	7.53	7.67	7.82
(cms.)	Femur	----		7.62	7.83	8.04	8.24	8.45	8.66	8.87	9.08	9.28	9.49	9.70	9.91	10.12	10.33	10.53	10.74	10.95	11.16
Muscle:	Biceps	----		24.4	25.0	25.7	26.3	27.0	27.7	28.3	29.0	29.7	30.3	31.0	31.6	32.2	33.0	33.6	34.3	35.0	35.6
(cms.)	Calf			28.5	29.3	30.1	30.8	31.6	32.4	33.2	33.9	34.7	35.5	36.3	37.1	37.8	38.6	39.4	40.2	41.0	41.8
First estimate of mesomorphy								1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Correction for fat (T.F. mms.)								12	15	18	22	27	33	40	48	52	68	83	100	120	140
Age:	16-24							+½	+½	+¼	+¼	0	-¼	-½	-1	-1½	-2	-2½	-3	-4	
	25-34							(+½)	+½	+¼	+¼	0	-¼	-½	-¾	-1¼	-1¾	-2¼	-2¾	-3½	-4
	35+							(+½)	(+½)	+¼	+¼	0	-¼	-¼	-½	-1	-1½	-2	-2½	-3	-3½
MESOMORPHY (corrected estimate)								1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	
Weight	Wt.lb.	H.W.R.	Age																		
Present	146	13.2	18					12.1	12.3	12.5	12.7	12.9	13.1	13.3	13.5	13.7	13.8	14.0	14.2	14.4	
H.K.W.			23					11.7	12.0	12.2	12.5	12.8	13.0	13.2	13.4	13.6	13.8	14.0	14.2	14.4	
Usual			28					11.5	11.8	12.1	12.4	12.6	12.8	13.0	13.3	13.5	13.7	13.9	14.2	14.4	
At 18 years			33					11.3	11.7	12.0	12.3	12.5	12.7	12.9	13.2	13.4	13.6	13.9	14.1	14.4	
At 23 years			38					11.2	11.5	11.8	12.1	12.4	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.4	
Recent change			43+					11.1	11.4	11.7	12.0	12.3	12.6	12.8	13.1	13.3	13.6	13.9	14.1	14.4	
ECTOMORPHY								1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7	

Figure 15: Heath-Carter (1967) Somatotype Rating Form

Reproduced from "A Modified Somatotype Method", *American Journal of Physical Anthropology,* by Barbara Honeyman Heath & J.E. Lindsay Carter (1967), representing the first true phenotypic (assessing current physique) somatotype rating system based on anthropometry.

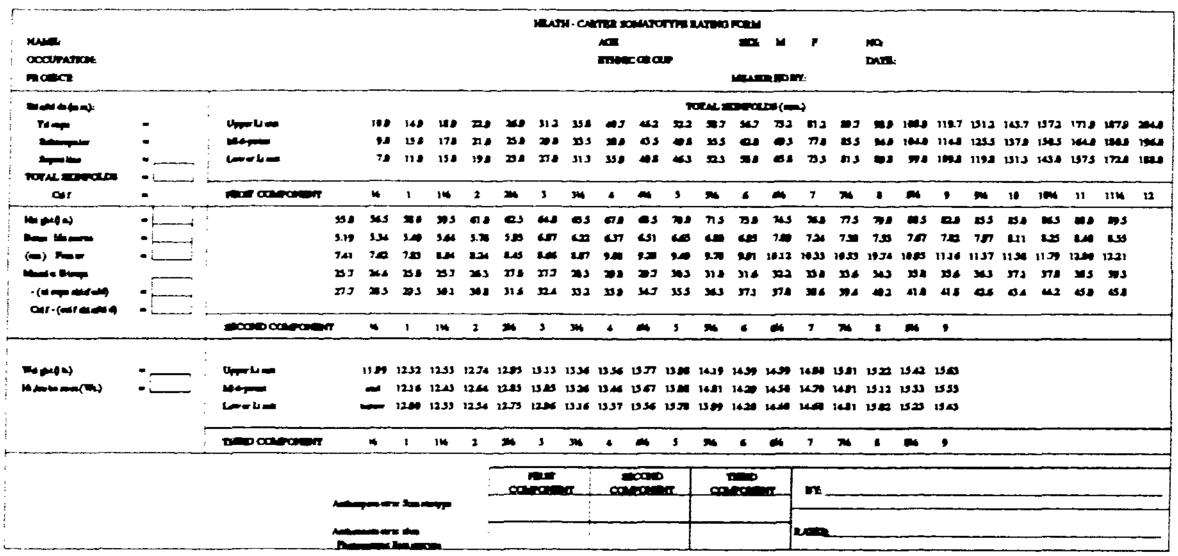


Figure 16: Heath-Carter (1967) Somatotype Rating Form with sample data

Figure 15 with sample data from section A.V. The right portion of the rating form has been truncated to improve readability.

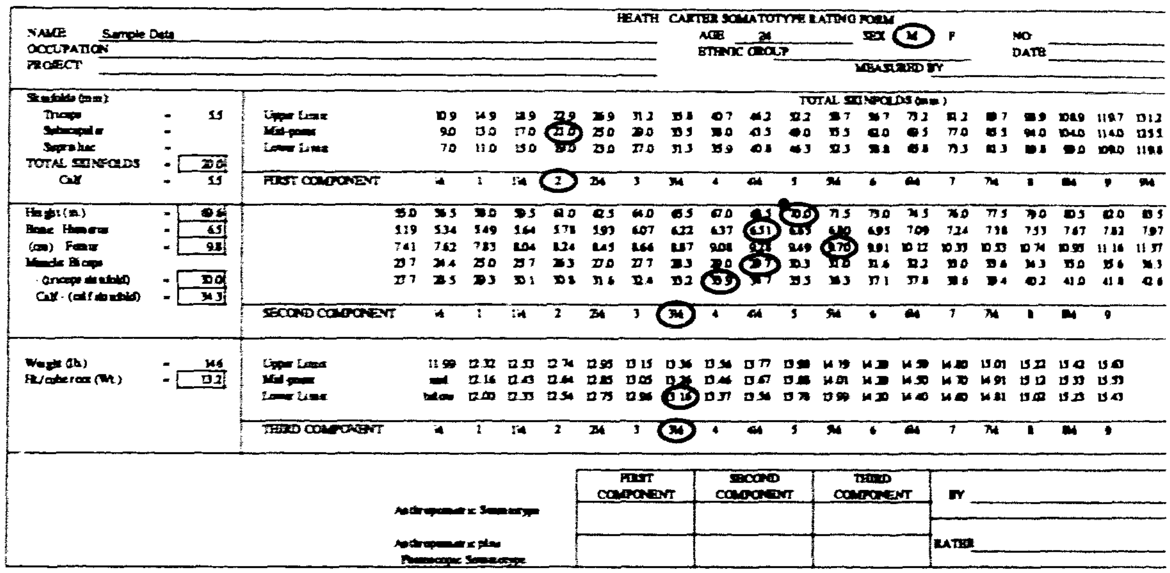


Figure 17: Heath-Carter (1990) Somatotype Rating Form

Reproduced from *Somatotyping Development and Applications*, by Carter & Heath (1990). This rating form is nearly identical to the form reproduced as Figure 15, but uses metric measurements for height and weight, and includes a height correction for endomorphy. The right portion of the rating form has been truncated to improve readability

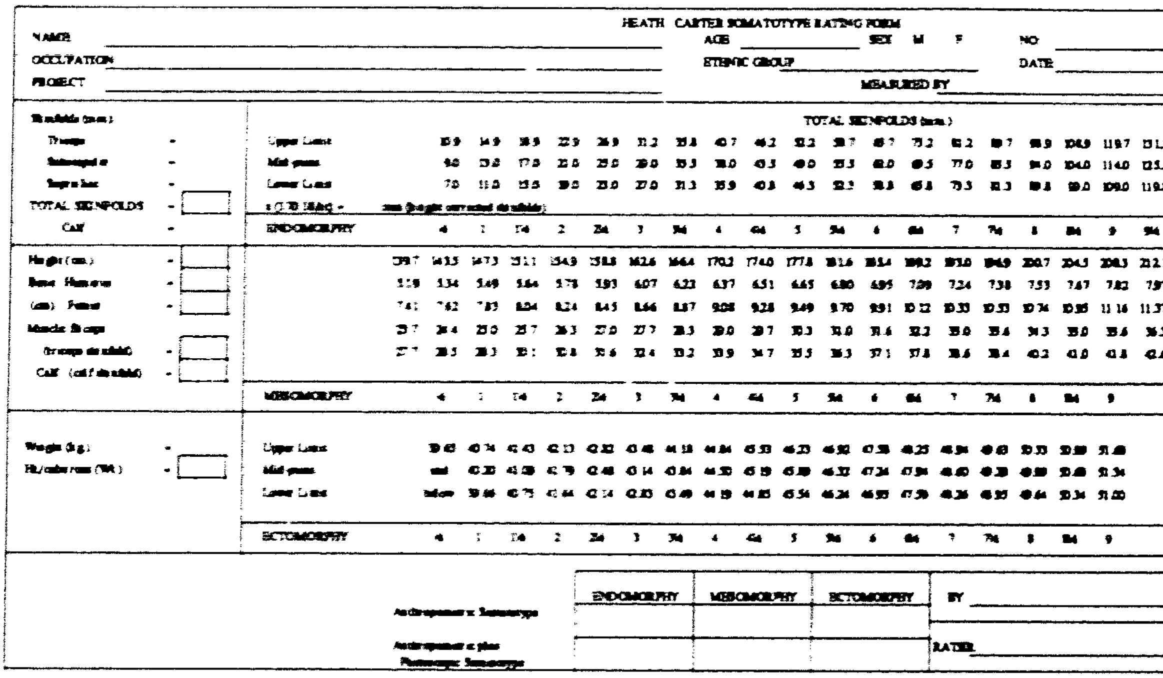


Figure 18: The New Rating Form: Look-up version

The Look-up table version of the new somatotype rating form. Endomorphy and ectomorphy are derived with simple look-up tables.

Subject Information

Name: ______________________ (last) ______________________ (first)

Sex: M / F

Date Measured: ___ / ___ / ___ (YY MM DD)

Date Born: ___ / ___ / ___ (YY MM DD)

Age: ______

Anthropometric Somatotype

Endomorphy - Mesomorphy - Ectomorphy

Anthropometry

Height (cm) [ ]

Height Adjustment Factor (HAF) = (170cm / Height) [ ]

Measured — Ht. Adjusted

Skinfolds (mm)

Triceps [ ] × (HAF) [ ]
Subscapular [ ] · [ ]
Supraspinale [ ] · [ ]
Calf [ ] · [ ]

Total of Four Skinfolds [ ]

Bone Widths (cm)

Humerus [ ] × (HAF) [ ]
Femur [ ] · [ ]

Girths (cm)

Arm (flexed) [ ] × (HAF) [ ]
Calf [ ] · [ ]

Weight (kg) [ ] × (HAF)³ [ ]

Skinfold Adjusted (S.A.) Girths (cm)

S.A. Arm Girth (Arm girth 10 x (TricepSF)) [ ]

S.A. Calf Girth (Calf girth 10 x (CalfSF)) [ ]

Endomorphy

Total of Four Skinfolds (mm)

Upper Limit	16	17.3	20.2	23.5	27.4	31.9	37.2	43.4	50.6	59.0	68.7	80.1	93.4	108.8	126.8
Lower Limit	0	16.1	17.4	20.3	23.6	27.5	32.0	37.3	43.5	50.7	59.1	68.8	80.2	93.5	108.9
Endomorphy	Below ½	½	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7

Mesomorphy

Columns of Deviation

	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
Humerus	5.27	5.38	5.49	5.60	5.71	5.82	5.93	6.04	6.14	6.25	6.36	6.47	6.58	6.69	6.80	6.91	7.02	7.13	7.23	7.34	7.45
Femur	7.52	7.68	7.83	7.99	8.14	8.30	8.45	8.61	8.76	8.92	9.08	9.23	9.39	9.54	9.70	9.85	10.01	10.16	10.32	10.48	10.63
S.A. Arm Girth	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0
S.A. Calf Girth	28.1	28.7	29.3	29.9	30.5	31.1	31.6	32.2	32.8	33.4	34.0	34.5	35.1	35.7	36.3	36.9	37.5	38.0	38.6	39.2	39.8

Deviation

Humerus [ ]
Femur [ ]
S.A. Arm Girth [ ]
S.A. Calf Girth [ ]

Mesomorphy = Total Deviations (______ / 10) + 4 = [ ] (round to nearest ½ unit)

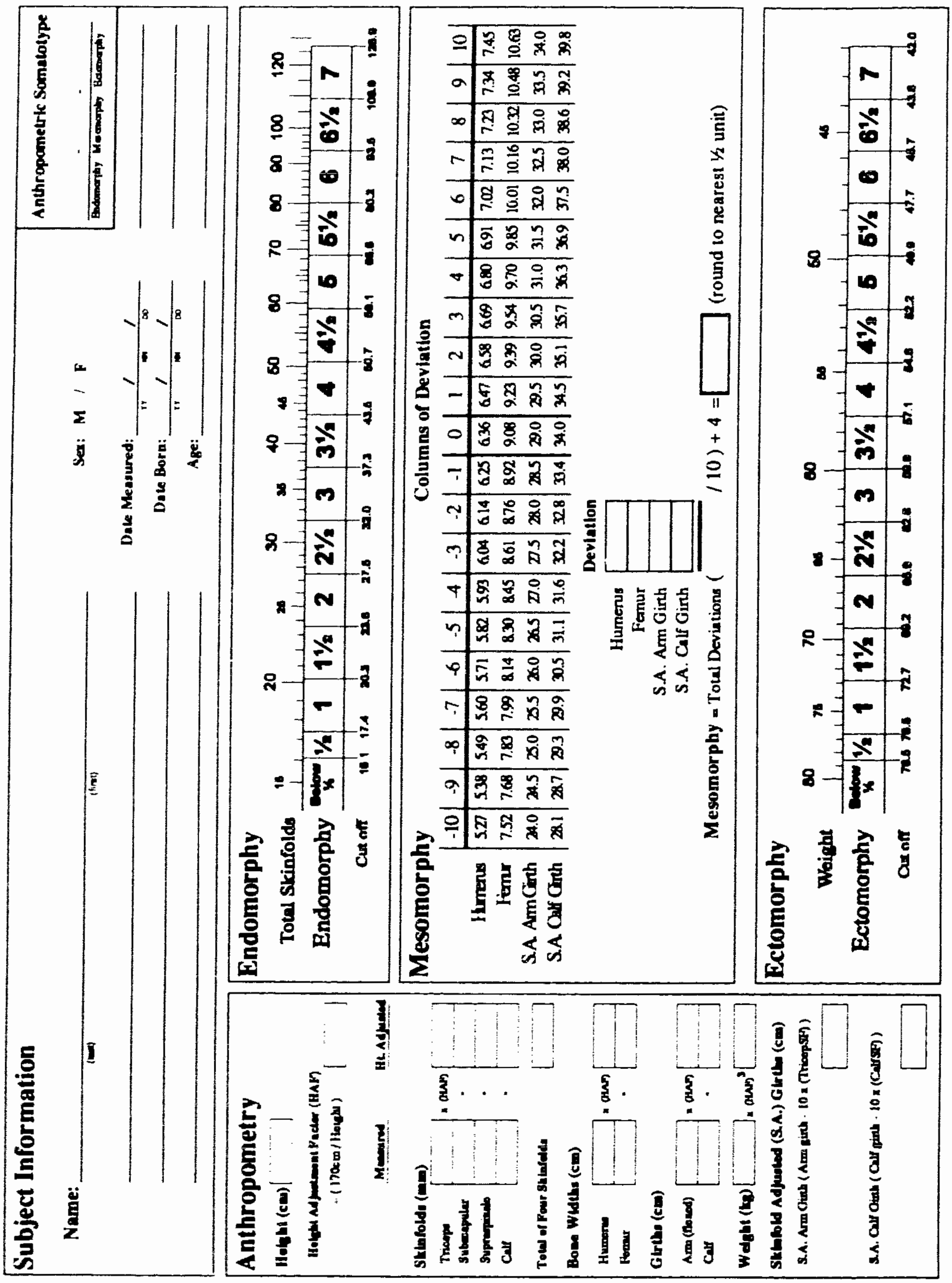
Ectomorphy

Weight (kg)

Upper Limit	∞	78.5	76.5	72.7	69.2	65.9	62.8	59.9	57.1	54.6	52.2	49.9	47.7	45.7	43.8
Lower Limit	78.6	76.6	72.8	69.3	66.0	62.9	60.0	57.2	54.7	52.3	50.0	47.8	45.8	43.9	42.1
Ectomorphy	Below ½	½	1	1½	2	2½	3	3½	4	4½	5	5½	6	6½	7

Figure 19: The New Rating Form: Number-line version

The Number-line version of the new somatotype rating form. Endomorphy and ectomorphy are derived from number lines, similar to conversion scales on rulers and slide-rulers.



	-10	-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10
Humerus	5.27	5.38	5.49	5.60	5.71	5.82	5.93	6.04	6.14	6.25	6.36	6.47	6.58	6.69	6.80	6.91	7.02	7.13	7.23	7.34	7.45
Femur	7.52	7.68	7.83	7.99	8.14	8.30	8.45	8.61	8.76	8.92	9.08	9.23	9.39	9.54	9.70	9.85	10.01	10.16	10.32	10.48	10.63
S.A Arm Girth	24.0	24.5	25.0	25.5	26.0	26.5	27.0	27.5	28.0	28.5	29.0	29.5	30.0	30.5	31.0	31.5	32.0	32.5	33.0	33.5	34.0
S.A Calf Girth	28.1	28.7	29.3	29.9	30.5	31.1	31.6	32.2	32.8	33.4	34.0	34.5	35.1	35.7	36.3	36.9	37.5	38.0	38.6	39.2	39.8

Figure 20: Endomorphy Ratings for All Subjects, Old & New Equations

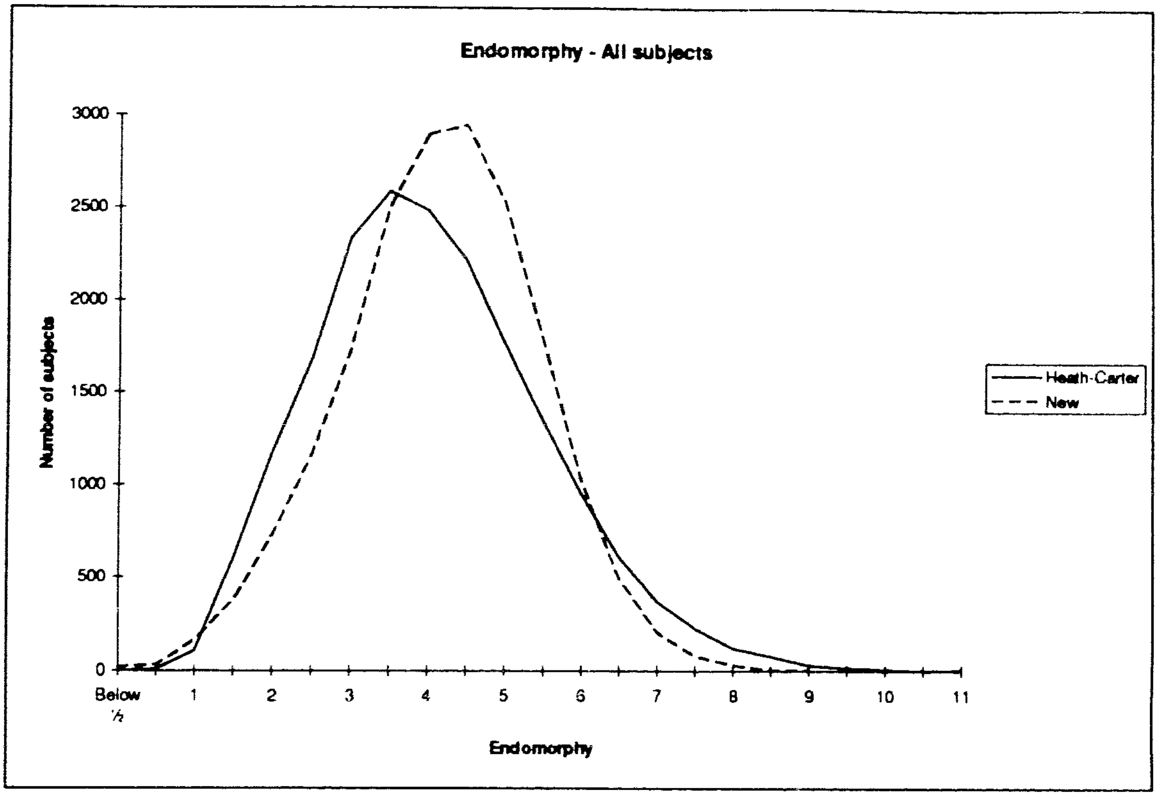


Figure 21: Endomorphy Ratings for Female Subjects, Old & New Equations

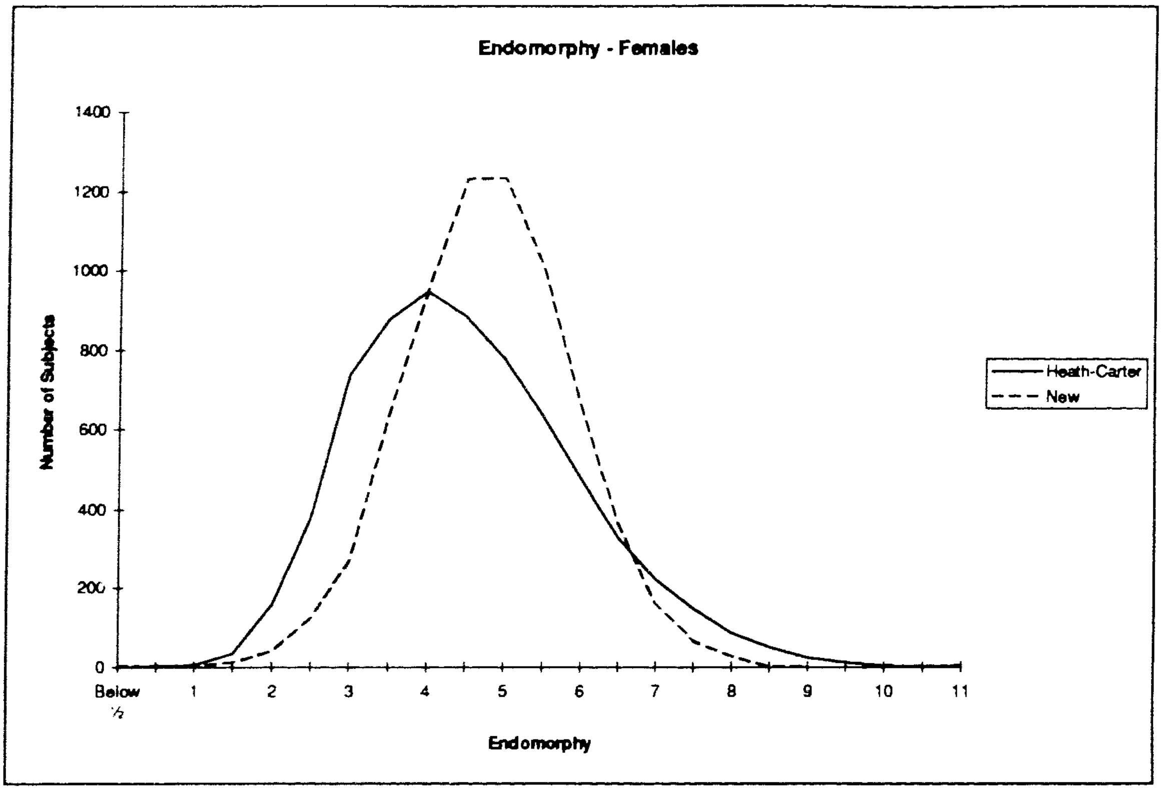


Figure 22: Endomorphy Ratings for Male Subjects, Old & New Equations

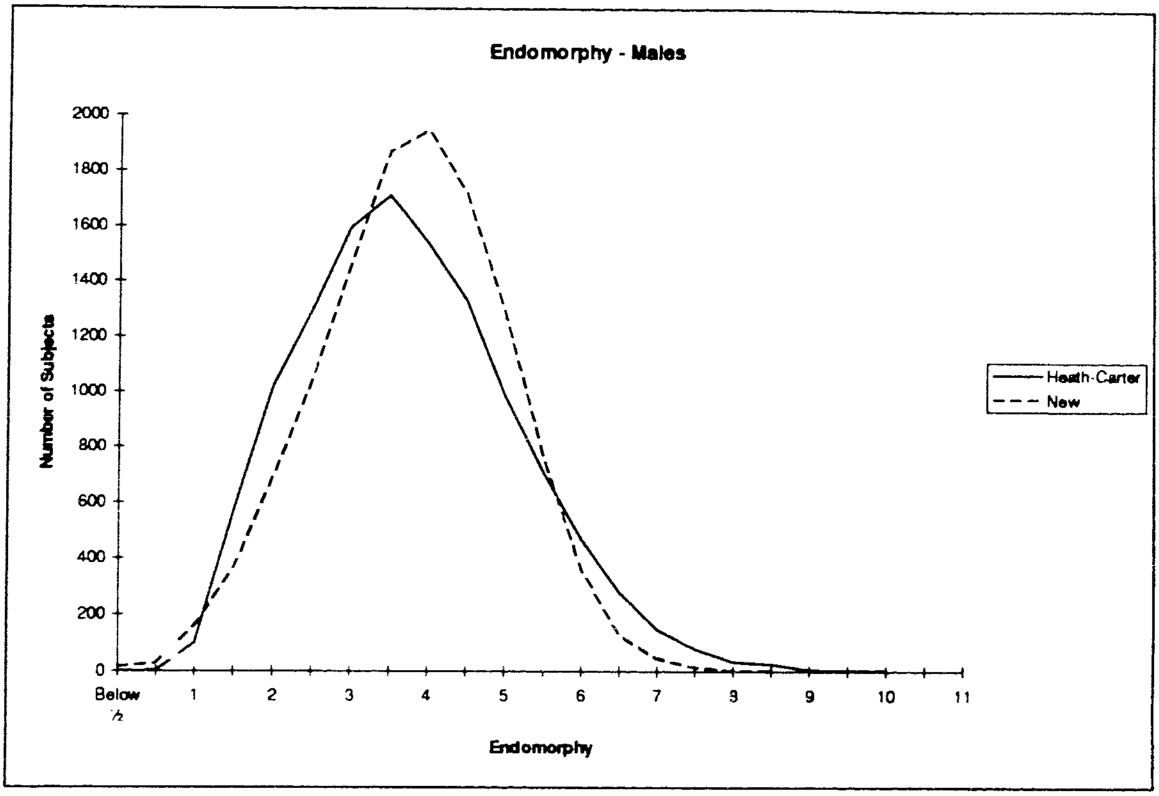


Figure 23: Mesomorphy Ratings for All Subjects, Old & New Equations

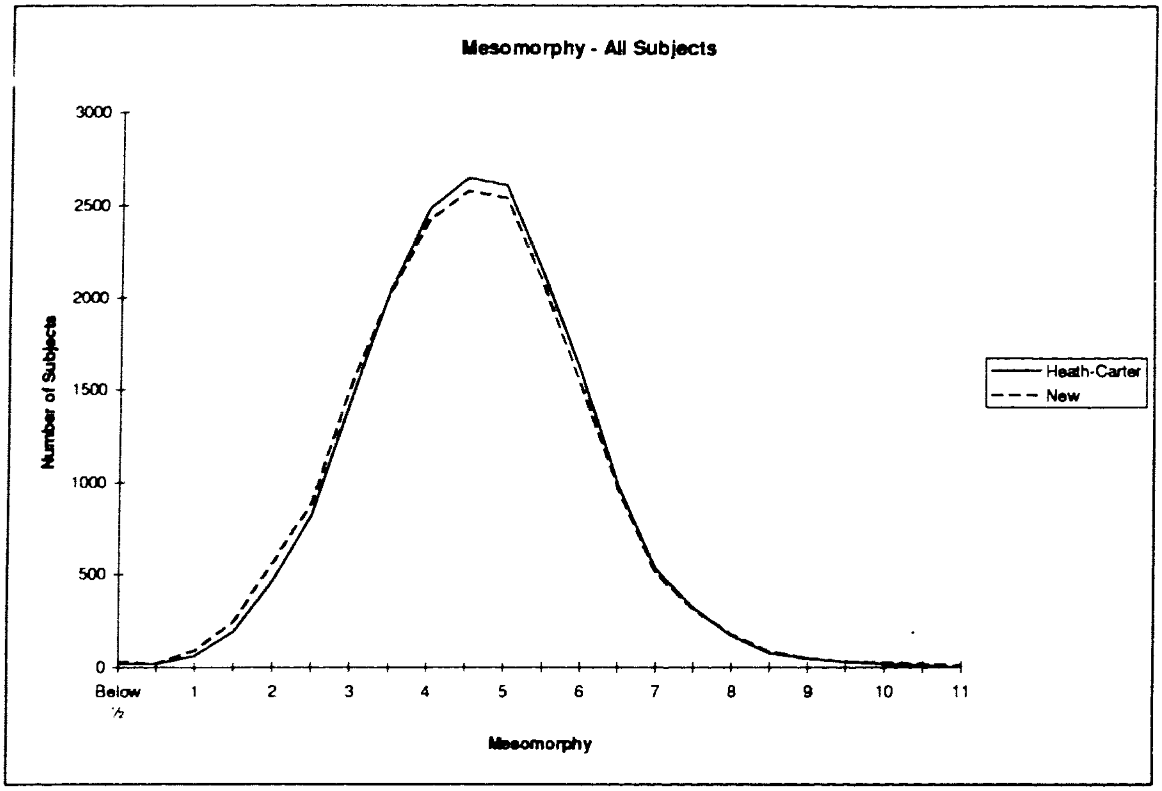


Figure 24: Mesomorphy Ratings for Female Subjects, Old & New Equations

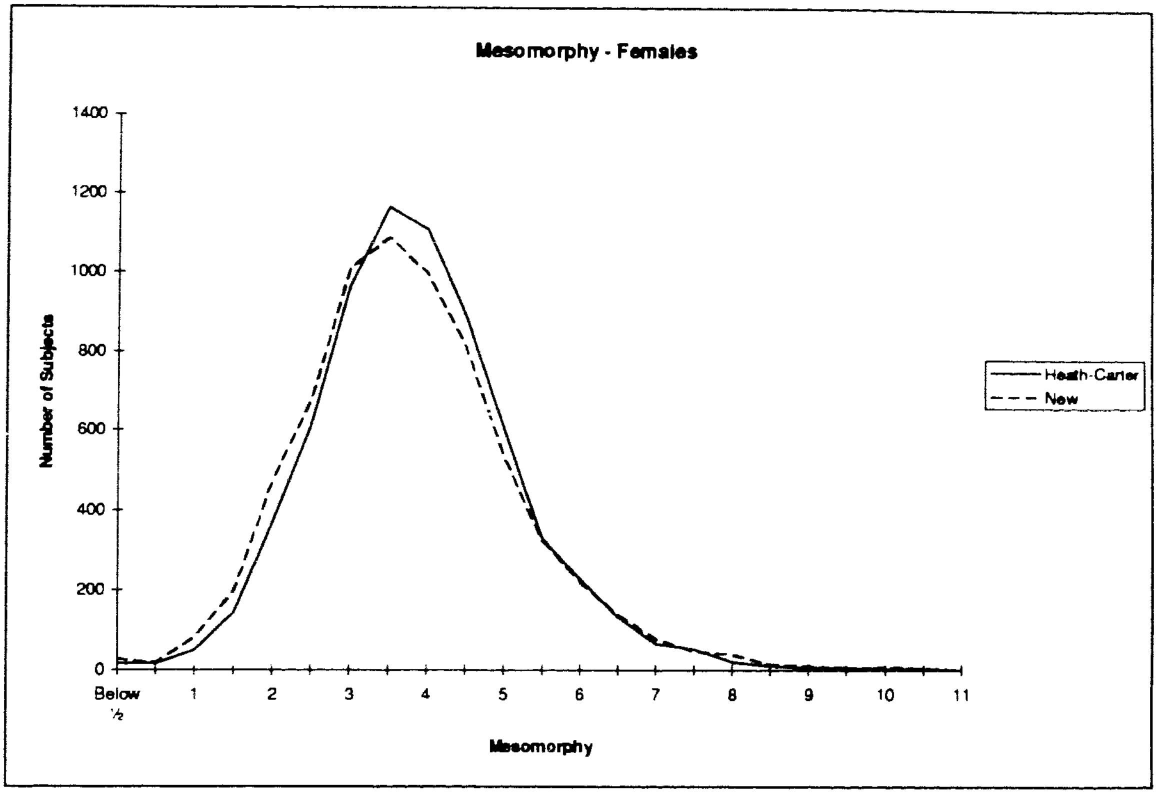


Figure 25: Mesomorphy Ratings for Male Subjects, Old & New Equations

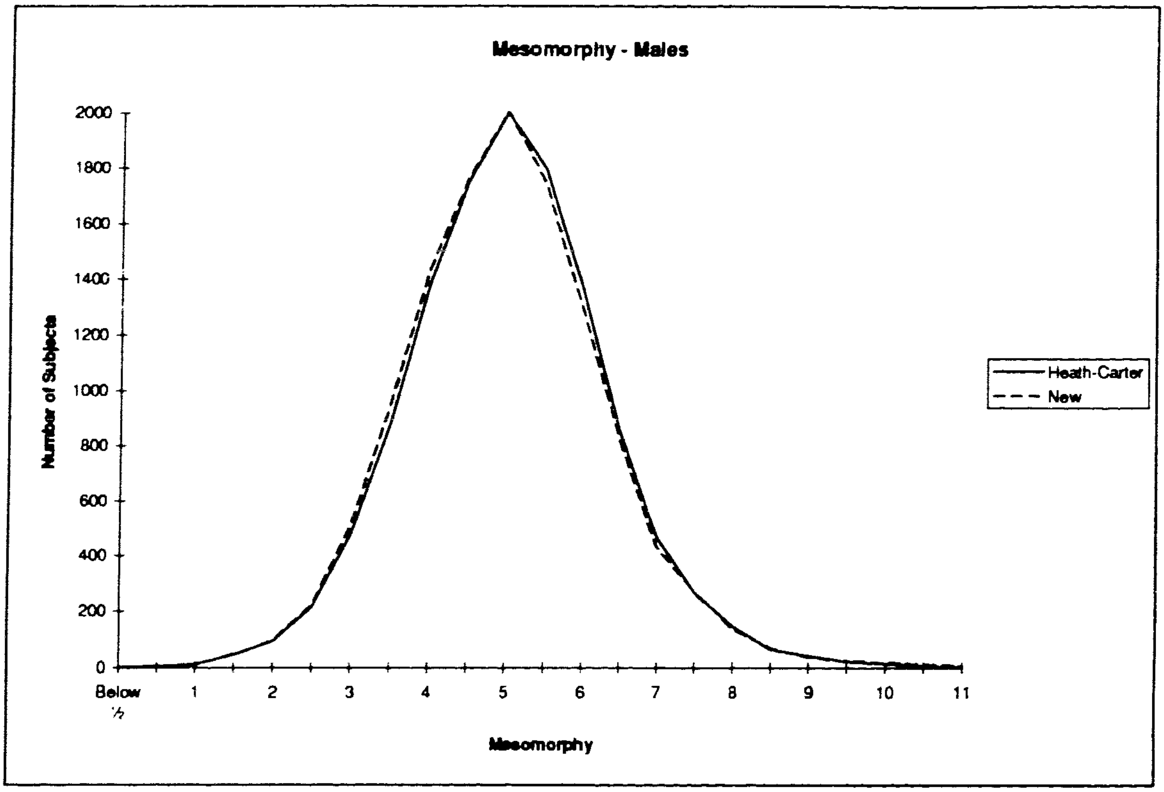


Figure 26: Ectomorphy Ratings for All Subjects, Old & New Equations

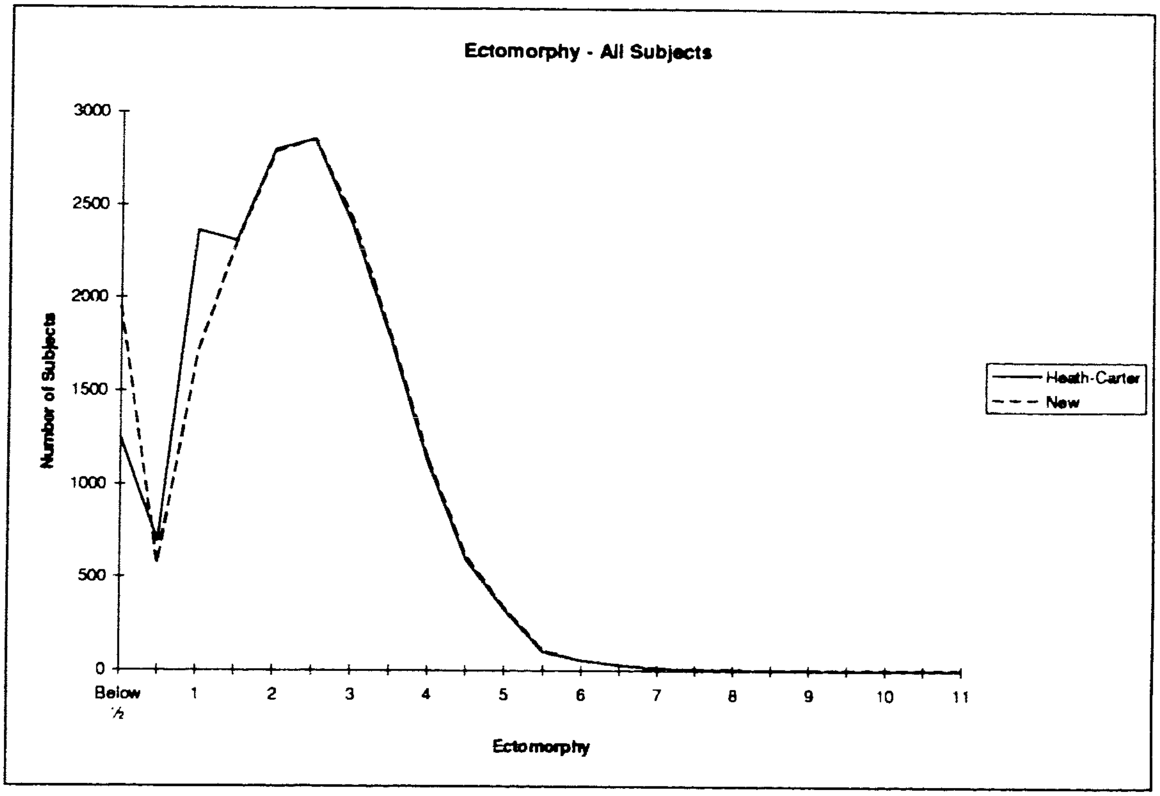


Figure 27: Ectomorphy Ratings for Female Subjects, Old & New Equations

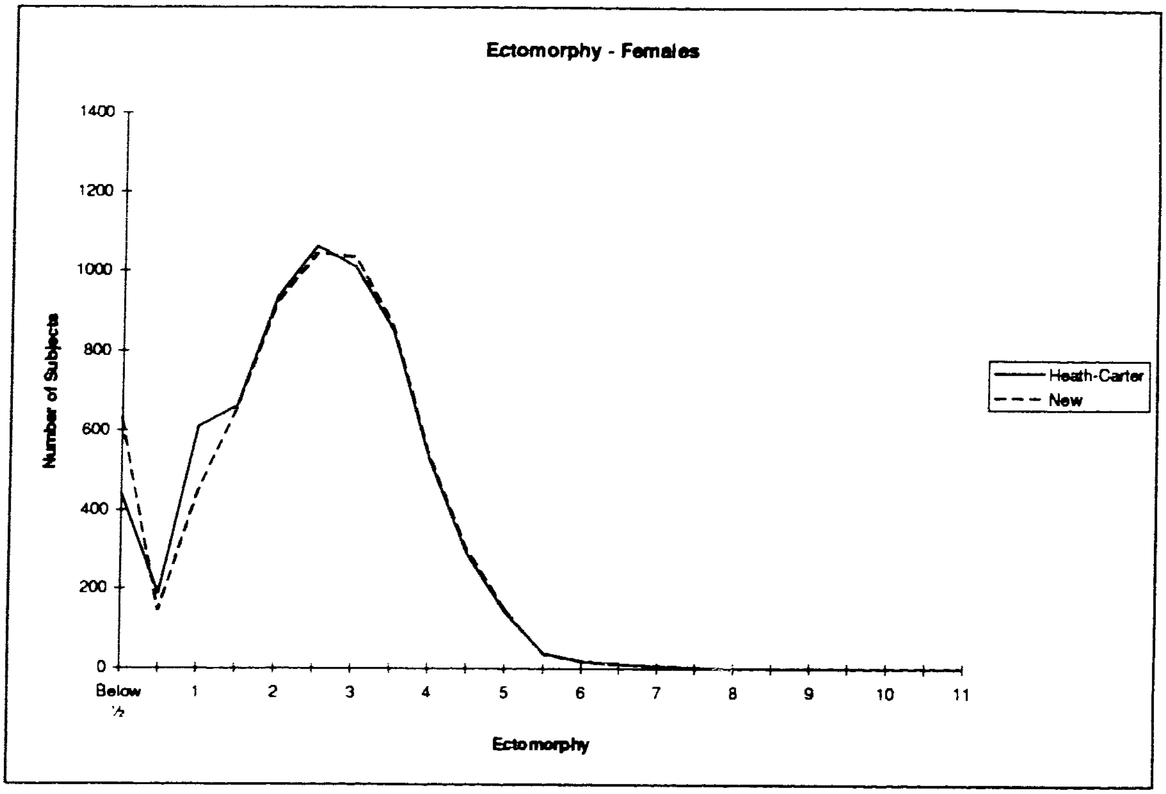


Figure 28: Ectomorphy Ratings for Male Subjects, Old & New Equations

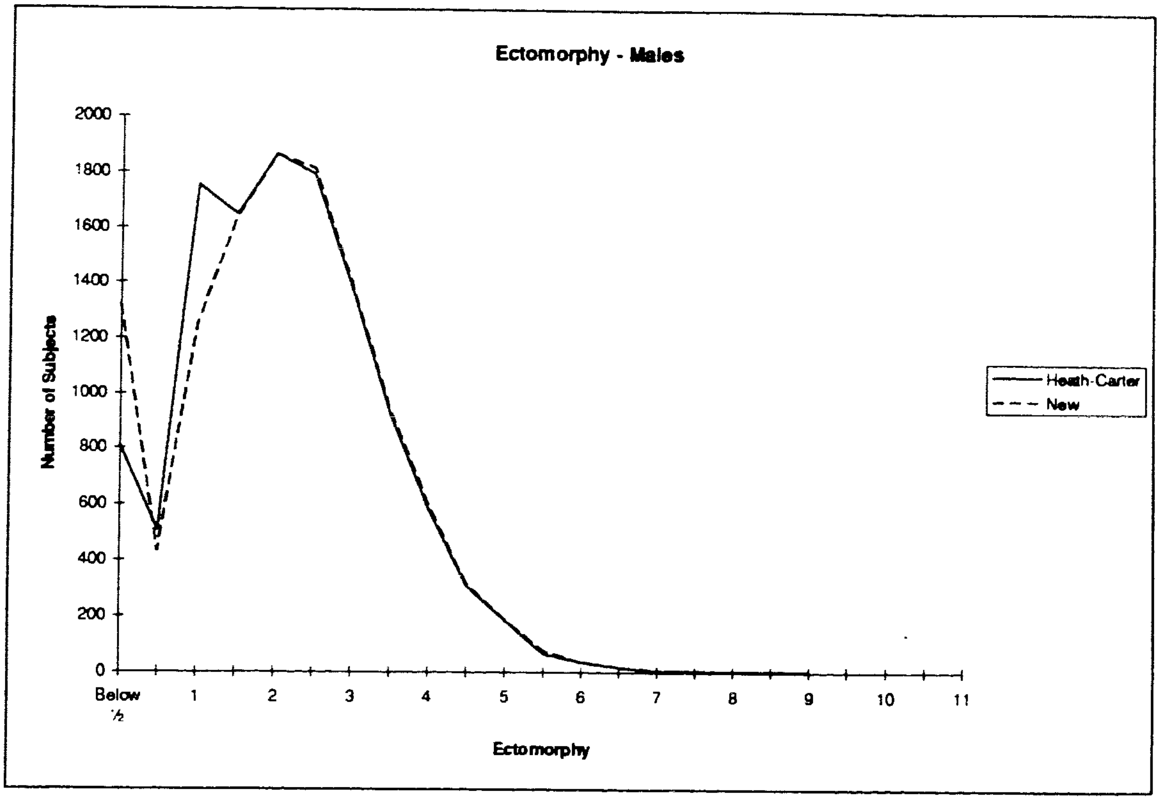


Figure 29: Difference between Old and New Prediction Equations for Endomorphy

Heath-Carter equation-predicted endomorphy minus endomorphy predicted with the new equation versus the sum of 3 skinfolds (triceps, subscapular, and supraspinale) for 546 subjects selected at random from the sample population (approximately 3% of the population).

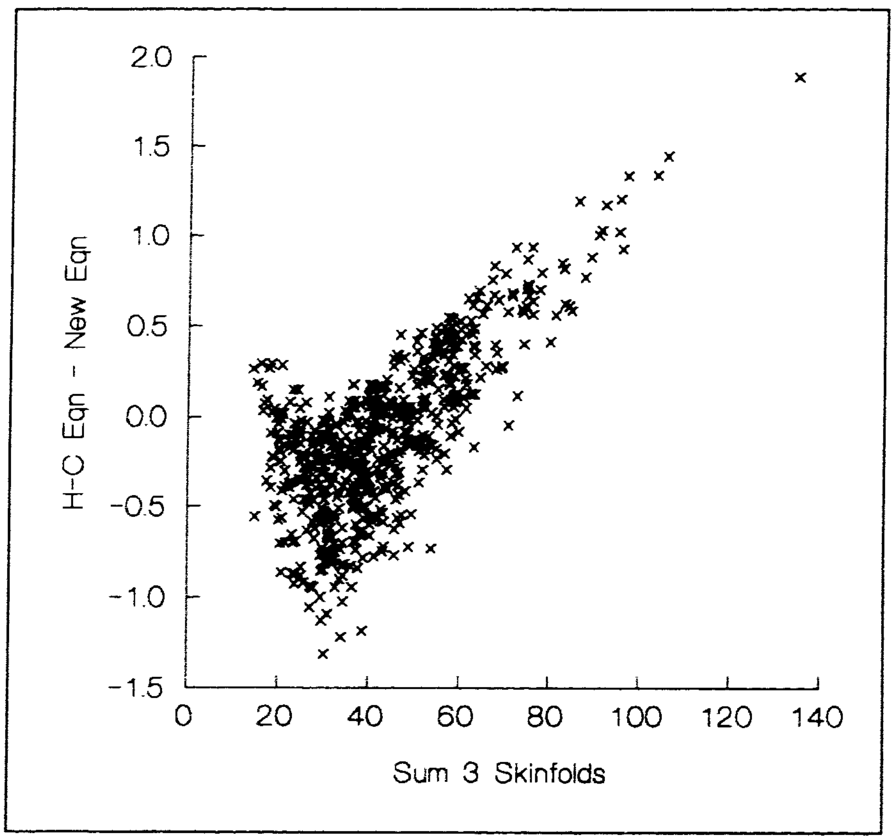


Figure 30: Difference between Old and New Prediction Equations for Mesomorphy versus Height

Heath-Carter equation-predicted mesomorphy minus mesomorphy predicted with the new equation versus subject height for 542 subjects selected at random from the sample population (approximately 3% of the population).

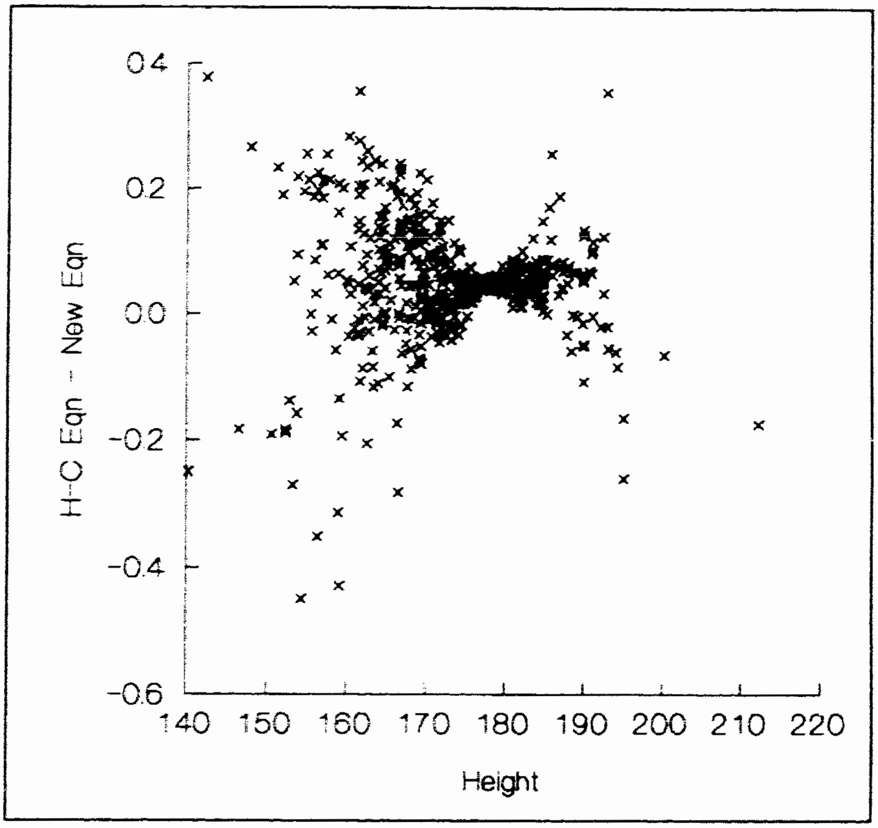
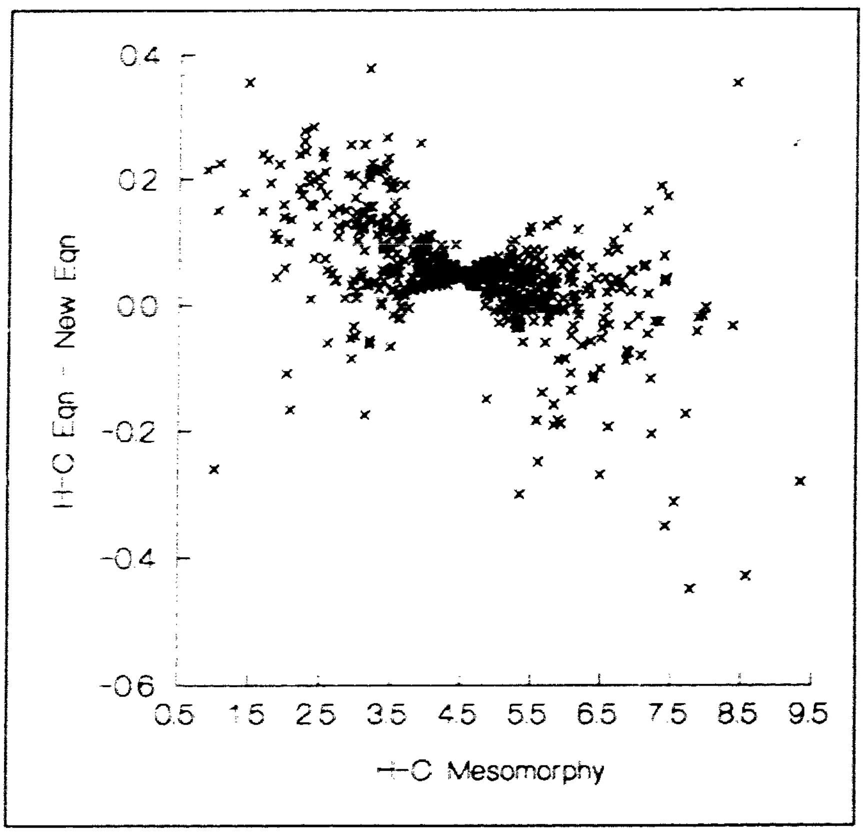


Figure 31: Difference between Old and New Prediction Equations for Mesomorphy versus Heath-Carter Mesomorphy

Heath-Carter equation-predicted mesomorphy minus mesomorphy predicted with the new equation versus the Heath-Carter predicted mesomorphy for 542 subjects selected at random from the sample population (approximately 3% of the population).



Appendix: Historical Methods of Somatotype Assessment

This section chronicles the development of modern somatotyping by following the methodological evolution. Enough information is given to allow the reader to understand how each method was used and, where the information is available and relevant, how the method was developed, but it does not represent step-by-step instructions for the use of each system. Interested readers are directed to the original sources cited.

A.I Sheldon's 1940s Somatotype

The following description is summarized from *The Varieties of Human Physique* (Sheldon, Tucker and Stevens, 1940), primarily chapter 4: How to Proceed in Somatotyping.

> Photographs of the subjects in minimal or no clothing are taken following well described procedures and suggestions, producing the classic "somatotype photographs" which show the subject in approximately anatomical position from the front, rear, and left sides.
>
> The photographs are assessed to determine a "first approximation" of somatotype. This was to be done based on experience, in conjunction with written descriptions for the 76 somatotypes encountered by Sheldon to that time (given in chapter 6 of the same book).

The subject's height-weight ratio, $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$, was then calculated and compared to a table (reproduced as Figure 9). Possible somatotypes were extracted from the table and ranked based on their likelihood; from the row matching the subject's height-weight ratio all somatotypes were extracted if (i) they maintained the component dominance of the original somatotype estimate (mesomorphy larger than endomorphy, larger than ectomorphy, for example) and (ii) they differed from the original estimate by no more than 1 unit in any somatotype component. This same extraction was performed for 1,2,3, and 4 rows above and below the subject's height-weight ratio. The possible somatotypes were then ranked based on how much their row deviated from the subject's height-weight ratio row, those in the same row receiving a ranking of "0", one row away receiving a ranking of "1", and so on.

The photographs were then visually reassessed, considering the body as five distinct regions: (I) head and neck, (II) thoracic trunk, (III) arms and hands, (IV) abdominal trunk, and (V) legs and feet. Only very slight descriptive help was given for this task and only 76 photographs were included for comparison (not encompassing all 76 possible somatotypes); presumably one relied on "experience" for this step.

Measurements were taken from the photographs to represent each of the five regions of the body, four in the head and neck, three in the thoracic trunk, three in the arms and hands, three in the abdominal trunk, and four in the legs and feet. Each of these measurements was expressed as a percentage of the subject's height and looked up in a table, identical in format to the height-weight ratio table for the whole body. For each region of the body the somatotype with the lowest average ranking extracted from the tables was used as a somatotype for that region of the body.

The five regional somatotypes were averaged to produce a final somatotype for the subject, with each component rounded to the nearest ½ unit.

Sheldon claimed only that the tables were reasonable for males between 16 and 20 years old. He suggested that future publications would include tables for other age groups, and potentially for females.

It is important to note that Sheldon was recommending the combination of measurement and photoscopic assessment at this time. He acknowledged that it would be possible to determine somatotype from anthropometry (actually photogrammetry - measurements from photographs - not strictly in accordance with the current use of the term anthropometry) (Sheldon, et. al, 1940, p.103):

> *"The question is often asked, however, as to whether by objective anthropometry alone the somatotype can be determined. Given only the height and weight of a subject plus the 17 ratio-indices determined by measurements on his photograph, could the experimenter arrive at the*

same somatotype obtained by the procedure just described? The answer is Yes. With only slight qualification, the anthropometric methods presented in this volume are adequate to meet the requirement of complete objectivity ...".

A.II. Sheldon's 1954 Atlas

Sheldon's 1954 *Atlas of Men* (with Dupertuis and McDermott) represented a pivotal work in somatotyping, both for what it contained and what it did not contain. The work contained some 1100+ photographs with their regional somatotype ratings as well as height-weight ratio tables for males in five-year increments from 18 to 63 years of age. It also contained entertaining animal analogs for each of the 88 somatotypes then accepted to exist.

Perhaps more interesting is what the *Atlas* did not contain. Despite being used as a *de facto* reference for Sheldonian somatotyping by those later writing in the area, it contained absolutely no information for how to determine somatotype from the photographs; this despite claims in the preface that this was precisely the purpose of the book. Detailed information was given as to how to take the pictures, but no information was given as to what to do with these photos once obtained. We were given Sheldon's opinions as to why measurement-based somatotyping was inadequate, witty barbs fired at his critics, entertaining prejudices about the various somatotypes, but no useful information on how to actually assess somatotype.

If a reader was already familiar with photoscopic assessment of somatotype the *Atlas* represented an incredibly useful reference work. If they "lacked the gift" (as Sheldon put it in *Varieties of Delinquent Youth*, 1949, p.40) to assess photographs to determine somatotype, the *Atlas* was nothing more than entertaining reading.

A.III. Parnell's 1954 Table

The following was summarized from "Somatotyping by Physical Anthropometry" by Parnell (1954).

> Parnell developed a deviation table to aid in the visual assessment of the relative dominance of somatotype components - the critical part of Sheldonian somatotyping as described in *Varieties of Human Physique*. This table (reproduced as Figure 10) allowed the somatotyper to look at the sum of three skinfolds (an indicator of endomorphy), humerus width, femur width, flexed arm girth, and calf girth (indicators of mesomorphy), all relative to the subject's height and make an assessment of relative dominance of somatotype.
>
> More detailed steps were given to use the anthropometry to determine a close somatotype estimate which involved five additional tables. An example of this procedure is given below.

Parnell's stated purpose was to make it faster to obtain the necessary information to aid a somatotype rater using Sheldon's system, not to fully objectify somatotyping. That this would indeed be possible with his tables was discussed with some trepidation by Parnell.

Parnell acknowledged that the tables were based on relatively limited data, and were most effective with subjects of approximately average height. Some discussion of their application for somatotyping older males and females was put forward.

(example #3 from Parnell's paper):

Height	=	69.6 in.	Weight	=	146 lbs	Age	=	24 yr.
Humerus	=	6.5 cm.	Femur	=	9.8 cm.	Biceps	=	30.5 cm.
Calf	=	34.8 cm.	Total fat	=	20.0 mm.			

$$\frac{\text{height}}{\sqrt[3]{\text{weight}}} = 13.2$$

- This height-weight ratio and the anthropometry were circled on the deviation chart. The direction of the line connecting the subject's height and their fatness and the position of the bone and girth measurements relative to this line were used - in conjunction with some prototypical relationships given by Parnell - to assess the relative strength of the somatotype components.

- Parnell gave no suggestions on how to handle data that lay between values on the rating form. Coincidentally, both bone breaths and both girths for this subject lie exactly mid-way between columns; it was decided to place circles at the mid-way points, rather than producing a consistent "round up" or "round down" rating bias. This was done because the pattern of the data around the line was the critical indicator used at this point, and because Parnell gave no indications how to deal with the problem.

- For this subject the first indication is that endomorphy is the lowest component. Either mesomorphy and ectomorphy are equal, or mesomorphy is slightly larger; it is unclear because the subject's pattern does not exactly match any of Parnell's prototype patterns.

- The subject's height-weight ratio was to be used with this information to extract from Sheldon's original table (reproduced as Figure 9) the most likely candidates for their somatotype. For this subject, with a height-weight ratio of 13.2 the only likely somatotypes with endomorphy lowest and mesomorphy slightly larger or equal to ectomorphy are 3-5-4 and 2-5-4. Photographic comparisons could be used to narrow down this estimate further.

- If the subject was in good health and approximately of average height - Parnell never commented on the precise problems imposed by taller or shorter individuals - further information could be extracted directly from the table. A provisional estimate of endomorphy could be obtained by direct inspection below the subject's sum of three skinfolds (abbreviated TF, or total fat on the table). For this subject this results in a provisional estimate of 3 for endomorphy. Likewise a provisional estimate for ectomorphy could be read from the table based on the subject's $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ ratio; for this subject the provisional estimate is 3½ or 4. Based on these provisional estimates and the previous information from Sheldon's table, the best working estimate for this subject at this point would be 3-5-4.

- To this stage, no anthropometry has been used for prediction of mesomorphy. If a more precise estimate of the subject's somatotype was desired the anthropometry could be looked up one of a series of tables to calculate a better estimate of the subject's relative ectomorphy to mesomorphy ratio. For our sample subject with a height-weight ratio of 13.2 we have to look at table for ratios between 13.00 and 13.45 inclusive. The relevant subsection of the table is for subject's with heights between 68.0 and 69.9 cm.; this section is reproduced as Figure 12.

		Endo-meso estimate
Humerus	6.5 cm.	2½
Femur	9.8 cm.	4¼
Biceps	30.5 cm.	4½
Calf	34.8 cm.	3.75
		$\frac{15}{4} = 3\frac{3}{4}$

Total fat 20.0 mm = 2

- The endo-meso estimates and value for total fat were selected from the appropriate table for the subjects height-weight ratio and for his height The average value for the muscle and skeletal measurements were used to indicate the relative dominance of mesomorphy, and the sum of three skinfolds ("total fat") was used to represent the relative dominance of endomorphy. This indicates that the final rating for the sample subject should contain endomorphy and mesomorphy in a ratio of approximately 2 : 3¾.

- Taking this information and the original estimates of 3-5-4 and 2-5-4 into account a reasonable estimate for the subject's somatotype is 3-5-4 or 2½-5-4.

- Parnell, working through the same example, came to a conclusion of 2-4½-4. No indication of how he arrived at this result was included in the work.

It is important to note that Parnell's 1954 contribution was not a single specific technique for estimating somatotype from anthropometry; it was a collection of three different tools that could be used individually, or combined to estimate somatotype. Parnell considered this primarily in the context of a quick clinical method of estimating somatotype that agreed well with Sheldonian somatotype under some conditions.

A.IV Parnell's 1958 M.4 Deviation Table

The following was summarized from *Behavior and Physique* by Parnell (1958), primarily Chapter 1: Technique.

Parnell took his 1954 table and made logical modifications to allow the prediction of somatotype (or at least a phenotype to approximate a somatotype) from anthropometry alone. The resulting M.4 deviation table is reproduced as Figure 13.

The sum of three skinfolds - triceps, subscapular, and suprailliac (now called supraspinale) - was still used to estimate endomorphy. Where the 1954 table was only designed to be used for subjects from 17 to 24 years of age, the new M.4 table had values for ages 16 to 54 years. That older subjects were expected to be fatter than younger subjects for the same endomorphy rating was apparently an attempt to keep aligned with Sheldon's view that a subject's somatotype should not change, even if the subject put on adiposity while aging.

The relationship between the sum of three skinfolds and the predicted endomorphy was logically adjusted; Parnell commented on the fact that skinfolds are not normally distributed, being skewed towards the higher values, and that the natural logarithm of the values was much more normally distributed for the samples to which he had access. This resulted in the use of the natural logarithm of the sum of the three skinfolds being linearly related to the predicted endomorphy rating. Figure 1 displays this change graphically.

The subject's $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ ratio was still to be used to estimate an ectomorphy rating. The relationship between height-weight ratio and predicted ectomorphy was maintained almost identically from the 1954 table for 18 year olds. Additional scales were given for older subjects in five year increments, again acknowledging the Sheldonian idea that most individuals got heavier as they aged, but that their somatotype should not change.

The deviation of the subject's bone and muscle measurements from their height was to be used as an indicator of the subject's mesomorphy deviation from a rating of 4. This fundamental change from the 1954 table - allowing a direct prediction of mesomorphy - was the basis of the name: "M.4 deviation table".

The "4" column for mesomorphy estimation was derived from existing data. For all other columns height was increased or decreased in 1.5 inch units, and the equivalent value was calculated based on geometric similarity. For example, the humerus value for a subject 70.0 inches tall (the "4" column) was 6.80 cm. The humerus value under the 73.0 inch tall column was set equal to 6.80 cm. $* \frac{73 \text{ cm.}}{70 \text{ cm.}} = 7.09$ cm.

The 1.5 inch increments in the mesomorphy deviation columns was chosen to allow the average deviation of the bone and girth measurements about the subject's height column to best estimate the somatotype.

Parnell acknowledged that there was a contribution to girth and bone measurements from overlying adipose tissue. The original estimate for mesomorphy was corrected for this adiposity; again, the correction was age-based to allow for "normal" changes with aging not effecting the somatotype estimate.

- Using the same data as used to illustrate the 1954 table, an example will be worked through to illustrate the use of the M.4 deviation table, although Parnell gives no directions or hints of how to proceed when the subject's values do not correspond exactly to a table figure. The use of the M.4 table with this data is demonstrated in Figure 14.

- The subject's sum of three skinfolds, 20 mm. falls half-way between two table values for subjects aged 16 to 24. Although Parnell gave no method for resolving difficulties such as this, a choice has to be made between a rating of 2 and of 2½ for endomorphy. Presumably the rater should examine the photograph and history of weight change to make a decision. Since this information is not available for this subject a decision is made based on the age of the subject (not a method suggested by Parnell) - if he was only a year older the chart give a rating of 1½ to 2 for endomorphy, so the lower of the two choices is chosen. The subject is given a rating of 2 in endomorphy.

- The subject's height of 69.6 inches is very close to the table value of 70.0 inches, so this value is circled. The subject's humerus width, biceps girth, and calf girth also fall close to table values and are circled. The subject's femur width of 9.8 cm. is almost exactly half-way between table values of 9.70 and 9.91 cm. Again, Parnell has given no indication of how to deal with such data; the circle is placed half-way between the columns for this example.

- The first estimate of mesomorphy was derived from this section of the chart as follows: The number of columns each bone and girth measurement deviated from the chosen height column was determined and summed. For example, the femur width for the sample subject is two columns to the left of the height column = -2.

The four indicators of muscular and skeletal development total (-2) + (+½) + (-1) + (-2) = -4½ columns of deviation from the height column. -4½ / 4 = -1.1, or -1 (rounded) column of average deviation from height. To determine the first estimate of mesomorphy the rater started with a rating of 4 and counted the number of columns calculated from the deviation estimates; for this subject one column to the left of 4, corresponding to the -1 average deviation, results in a first estimate of 3½ for mesomorphy - the value is circled on the chart.

- To determine the correction factor to apply to this first estimate due to overlying fatness, the subject's sum of skinfolds of 20.0 mm was again located on the appropriate table. For the sample subject it again falls half-way between two table values, but they both result in the same correction factor of +¼. 3½ + ¼ = 3¾. Since somatotype components were to be recorded to half-units only, and Parnell gave no indication on dealing with intermediate values, no change is made; resulting in a final estimate of 3½ for mesomorphy for the sample subject.

- The subject's weight of 146 pounds and height of 69.6 inches gives a $\frac{\text{height}}{\sqrt[3]{\text{weight}}} = 13.2$. This value is located on the table in the row closest to the subject's age - the 23 year old row for this subject - and the corresponding value for ectomorphy is circled below. The subject is rated 4 in ectomorphy, giving a somatotype of 2-3½-4.

A.V Heath and Carter's 1967 Somatotype Rating Form

The following was summarized from "A Modified Somatotype Method by Heath and Carter (1967). Their rating form is reproduced as Figure 15.

It is possible to look at the Heath-Carter somatotyping table as an "extension", or possibly a "correction" to Parnell's M.4 table; Heath and Carter felt that the somatotype calculated should be an indication of the subject's current physique, and modified Parnell's table accordingly. Also, for the first time in somatotype development Heath and Carter used data from both adult men and women. Their table is reproduced as Figure 15.

In Parnell's table endomorphy was linearly related to the natural logarithm of the sum of three skinfolds with a different scale for different age groups. Heath and Carter's table was developed by taking the same sum of three skinfolds, but using Heath's visual rating of endomorphy as the criteria for comparison. The resulting relationship between skinfolds and endomorphy rating (referred to as F-scale rating occasionally in the original work) was smooth, but not linear for either the absolute sum of skinfolds or for the logarithm of this value. This is shown in Figure 2.

When they comparing Parnell's M.4 table to Heath's photoscopic mesomorphy assessment for a broad range of subjects Heath and Carter found unsatisfactory agreement and a systematic difference. To correct the systematic difference Parnell's height row from his M.4 mesomorphy table was shifted one column to the left, effectively increasing all calculated results by one-half mesomorphy unit. The authors claimed that Parnell's method of correcting for adiposity over-compensated, and they suggested a direct correction of the arm and calf girth by subtracting the triceps and medial calf skinfold respectively. The authors acknowledged that it was not a perfect correction for adiposity, only that it was simple, in the right direction, and produced results that were closer to Heath's visual assessment (used as criterion values) than those produced by Parnell's table.

The authors were hampered in their validation because most of the studies they were using to create and validate their system did not include one or more of the skinfolds, and for many of their samples they were forced to estimate the required measurement(s).

After constructing a table of somatotype - visually assessed by Heath - versus $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ the data contained were plotted showing the ratio versus the third component rating. Although more than one ectomorphy rating was regularly given to subjects with the same height-weight ratio, and subjects with different height-weight ratios were regularly given the same ectomorphy ratio, a clear, linear relationship was evident. The equation (ectomorphy) = 2.42 (height-weight ratio) - 28.58 showed no systematic difference (except with athletes where an average difference of 0.2 units appeared, and was ascribed to a rater bias towards a slightly less linear rating for athletes) and had an agreement of plus-or-minus one-half unit 91% of the time. This equation was used to calculate the midpoints for the ectomorphy section of the rating form.

Subject's with a height-weight ratio of 12.0 or lower were given a rating of ½ for ectomorphy. Heath and Carter suggest that with these subjects a visual assessment be used to determine if ½ or 1 was the more appropriate rating.

Using the same data used to illustrate Parnell's 1954 table and his M.4 table, an example will be worked through to illustrate the use of the Heath-Carter somatotype rating form. In Parnell's example no values were given for the individual skinfolds; for this example the values for the triceps and medial calf skinfolds were calculated as the average value for males between 20 and 34 years old with a sum of three skinfolds of 20.0 mm, from the Canada Fitness Survey. This somatotype determination is demonstrated as Figure 16.

Height	=	69.6 in.	Weight	=	146 lbs	Age	=	24 yr.
Humerus	=	6.5 cm.	Femur	=	9.8 cm.	Biceps	=	30.5 cm.
Calf	=	34.8 cm.	Total fat	=	20.0 mm.			

Triceps skinfold = 5.5 mm. *Medial Calf skinfold = 5.5 mm.*

$$\frac{\text{height}}{\sqrt[3]{\text{weight}}} = 13.2$$

- The subject's sum of three skinfolds, 20 mm., found in the appropriate section of the rating form and circled, results in a rating of 2 for endomorphy.

- The subject's height of 69.6 inches is very close to the table value of 70.0 inches, but Heath and Carter do not have the rater circle the nearest value. A mark is to be made showing the actual position of the subject's height in the height scale. Since the subject's height of 69.6 inches is three-quarters of the way between 68.5 inches and 70.0 inches a mark (in this case a large, black dot) is placed appropriately. The subject's humerus width and femur widths are located and circled; the subject's femur width of 9.8 cm. is again almost exactly half-way between table values of

9.70 and 9.91 cm. In this work Heath and Carter explicitly state that the closest values are to be circled, so 9.70 cm. is circled. Similarly the skinfold corrected arm and calf girths are calculated and circled (for example, corrected arm girth = 30.5 cm. - $\frac{5.5 \text{ mm.}}{10 \text{ mm/cm.}}$ = 29.95 cm., the closest value is 29.7 cm. on the table).

Mesomorphy was derived in a similar manner to that used with Parnell's M.4 table, the average deviation of the bone and girth measurements was used to indicate the deviation from a mesomorphy score of 4. The four indicators of muscular and skeletal development for this subject total (-¾) + (+1¼) + (-¾) + (-1¾) = -2 columns of deviation from the height column. $\frac{-2}{4}$ -= -½, or -1 (rounded) column of average deviation from height. To determine mesomorphy the rater started with a rating of 4 and counted the number of columns calculated from the deviation estimates; for this subject one column to the left of 4, corresponding to the -1 average deviation, results in an estimate of 3½ for mesomorphy - the value is circled on the chart.

- The subject's weight of 146 pounds and height of 69.6 inches give a $\frac{\text{height}}{\sqrt[3]{\text{weight}}}$ = 13.2. This value is located on the table and the corresponding value for ectomorphy circled. The subject is rated 3½ in ectomorphy, giving a somatotype of 2-3½-3½.

A.VI Hebbelinck's et. al. 1973 Modification to Heath-Carter Endomorphy

In "A Practical Outline for the Heath-Carter Somatotyping Method Applied to Children", Hebbelinck, Duquet, and Ross (1973) considered the application of the Heath-Carter somatotype rating form for the assessment of children. They acknowledged that the Heath-Carter method does consider the different relative contribution to perceived mesomorphy in adults and in children, but made no suggestion as to its effect or correction. They point out that, while Heath-Carter determination of mesomorphy and ectomorphy control for the size of the subject, endomorphy determination did not; a small child with a sum-of-three-skinfolds of 25 mm. would visually appear much fatter than a tall man with the same 25 mm. sum-of-skinfolds, and should logically receive a higher endomorphy rating.

The authors suggested that the sum of skinfolds should be adjusted to an arbitrary height before using the table. The authors suggested multiplying the subject's sum of three skinfolds by $\frac{170.18 \text{ cm}}{\text{subject's height in cm}}$, geometrically scaling all subjects to a common height of 5'7" (170.18 cm.) before determining an endomorphy rating.

A.VII Heath and Carter's Modern Somatotype Rating Form

The current somatotype rating form for the determination of a Heath-Carter anthropometric somatotype has been reproduced from Carter and Heath (1990, p.370) as Figure 17. It is effectively the same as the 1967 table, with the following changes:

- Height and weight are measured in centimeters and kilograms instead of in inches and pounds. The necessary conversions have been made in all parts of the table.
- The height correction for endomorphy suggested by Hebbelinck, et. al. has been included.

A.VIII Carter's 1980 Equations

The following was summarized from "The Heath-Carter Somatotype Method, 3rd. edition", by Carter (1980).

The author claimed that the following equations "produce an exact decimalized rating based on the measurements provided" (p. 5-22b).

$$\text{Endomorphy} = -0.7182 + 0.1451(X) - 0.00068(X)^2 + 0.0000014(X)^3$$

where X = sum of (triceps, subscapular, suprailliac skinfolds)

and $X = [\text{sum of (triceps, subscapular, suprailliac skinfolds)}] * \frac{170.18\text{ cm}}{\text{subject's height in cm}}$

for height-corrected endomorphy.

$$\text{Mesomorphy} = 0.858(\text{humerus}) + 0.601(\text{femur}) + 0.188(\text{corrected arm girth}) + 0.161(\text{corrected calf girth}) - 0.131(\text{height}) + 4.5$$

$$\text{HWR} = \frac{\text{height}}{\sqrt[3]{\text{weight}}}.$$

If HWR > 40.75: Ectomorphy = 0.732(HWR) - 28.58

If 40.75 > HWR > 38.25: Ectomorphy = 0.463(HWR) - 17.63

If HWR > 38.25: Ectomorphy = 0.1

No information in this or in any later work explained the methodology used to produce these equations, although the ectomorphy calculation for height-weight ratios greater than or equal to 40.75 is the same equation cited by Heath and Carter (1967), with the units converted from imperial to metric.

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