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KINANTHROPOMETRY II

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Kinanthropometry: Traditions and New Perspectives

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As Western Canadians, we are awed by being at the Katholieke Universiteit Leuven, which is one of Europe's most venerated centers of learning. As scholars have, for centuries, come to this place, we too assemble to witness the emergence of a new scientific specialization. This seminar is the second international gathering devoted to kinanthropometry. The first was at the International Congress of Physical Activity Sciences held in Quebec City prior to the 1976 Montreal Olympic Games.

At the first seminar, held in conjunction with the allied discipline of ergometry, an attempt was made to define kinanthropometry (Ross, 1978). That definition was incomplete. As shown in Figure 1, we have rectified this by adding "with respect for individual rights in the service of humankind." We now view kinanthropometry as the application of measurement to the study of human size, shape, proportion, composition, maturation, and gross function. Its purpose is to help us to understand human movement in the context of growth, exercise, performance, and nutrition. We see its essentially human-enobling purpose being achieved through applications in medicine, education, and government.

It is not our role here to chronicle tragic misadventures in anthropometry. We must, however, recognize that our ability to apply measurement for service to humankind also is the ability to stigmatize for ignoble purpose. Our avowed commitment to "respect individual rights in the service of humankind" is not a matter for compromise — we will not rationalize misadventure as being for "the greatest good." Until such time as we kinanthropometrists in the international research community can make a group declaration of purpose, individually we should recognize the moral imperative and the essential constraint of our enterprise. We cannot sacrifice subjects, or in any way compromise their rights. This essential limitation may indeed not be a handicap but a challenge and invitation for new perspectives.

KINANTHROPOMETRY

"An emerging scientific specialization"

IDENTIFICATION	SPECIFICATION	APPLICATION	RELEVANCE
Kinanthropometry	For the study of human	to help understand	with implications for
MOVEMENT	SIZE	GROWTH	MEDICINE
HUMAN	SHAPE	EXERCISE	EDUCATION
MEASUREMENT	PROPORTION	PERFORMANCE	GOVERNMENT
	COMPOSITION	NUTRITION	with respect for individual rights in the service of humankind.
	MATURATION		
	GROSS FUNCTION		

Figure 1. A definition of kinanthropometry.

THE ROOTS OF KINANTHROPOMETRY

It is perhaps fitting that, at this historic occasion, we look to the future by appreciating whence we came. Although my colleagues and I are from a young country, we share all of humankind's cultural heritage. Our focus, however, is made somewhat nearsighted by our relatively short recorded Canadian history. At the first seminar in Quebec City, we strolled with our Belgian colleagues on the walkways that gird the citadel, high above the St. Lawrence River shore. Gazing down, we looked on the spot where, in 1608, Samuel de Champlain founded the third habitat of the de Monts Fur Trading Company, which became one of the oldest permanent settlements in Canada.

Our western Canadian perception of historical time must have amused our Belgian colleagues. When Champlain established Quebec in 1608, our present host university was 173 years old. It was over 100 years old when Andreas Vesalius (1514–1564) of Brussel began his medical studies here at the age of 17. Six years later, at the age of 23, he went to the University of Padua, where he lectured on anatomy and subsequently produced his epoch-making *De Humani Corporis Fabrica* in 1543. In the chronicle of civilization, the year 1543 might well serve as the beginning of the modern scientific era. It is marked by the publication of two books, Vesalius's *De Humani* and Copernicus's *De Revolutionibus Orbium Coelestium*. The circumstances of each work and some of the ensuing events invite modern analogy as we see kinanthropometry emerge as a new scientific specialization.

De Humani Corporis Fabrica is not only one of the great works of science, it is the culmination of an age-long aesthetic tradition and a masterpiece of graphic art and printing. In his splendidly vivid and dramatic figures Vesalius established with startling suddenness the beginning of observational science and research. Although he was committed to dissection as a means of learning about animal and human structures, he was totally immersed in the teachings of Galen (129–199 AD) and, as late as 1538, his published materials reflected this dominating influence. Saunders and O'Malley (1950) cite him as writing, "As the gods love me, I who yield to none in my devotion and reverence for Galen, neither can not enjoy any greater pleasure than praising him." He also avowed that he did not hold "in contempt the authority of Galen, the prince of physicians and perceptor of all." What he did was demonstrate "some fault is actually discernable in his books." Vesalius's contribution was not as an iconoclast; he subjected the classic Greco-Roman teaching and authority to scrutiny. His legacy is that of the observational method, whereby all works are subject to corroboration and redress.

Sadly, the publication of Vesalius's book marked the end of his productive career. He became a court physician and was embroiled in the intrigues of a bigoted and heresy-hunting Spain. He escaped this oppressive situation by making a pilgrimage, and there is some evidence that he intended to return to research. Fate intervened, and he died at the age of 50 during the return voyage from Jerusalem. Had he been spared to resume his past researches, which took him to the threshold of the secret of circulation of blood, he might have made such a breakthrough before Harvey. Nevertheless, Vesalius was the progenitor of Harvey and of all of us who relate human structure to function.

Although as kinanthropometrists we are primarily oriented in human biology, it is well to recognize that our roots are in many disciplines, including astronomy. In the same year as Vesalius published his masterpiece, the sick and dying Polish astronomer Nicolas Copernicus (1473-1543) published *De Revolutionibus Orbium Coelestium*. This was the culmination of his studies, which demoted the earth from its position at the center of the universe and declared science to be independent of religious orthodoxy. It was not however, a dramatic event, nor was the scientific revolution complete. As early as 1530, 14 years before publication of *De Revolutionibus*, Copernicus had prepared and distributed among European scholars a summary of his calculations of planetary motions in a heliostatic system. In his last year, at the urging of his pupil, the mathematician Georg Rheticus (1514-1576), Copernicus permitted the publication of the entire book, which was dedicated to Pope Paul III and others in the Catholic hierarchy. Unfortunately, due to doctrinal disputes, Rheticus left to assume a position in Leipzig and the task of editing the book fell to a Lutheran minister, Andreas Osiander. It was known that Martin Luther, founder of the Protestant revolution, was against Copernican theory. Trepidation at the assault the work would have on entrenched Catholic and Protestant orthodoxy led Osiander to add what Kepler in 1609 showed was an unauthorized preface. On the verso to the title page, Osiander declared the tenets of the following book were to be taken only as a mathematical hypothesis, a calculating device, and not as truth. This perhaps weakened the book and temporarily compromised Copernicus's reputation.

The reaction to *De Revolutionibus* was largely one of indifference for about a generation. It was overpriced, the initial publication was not a financial success, and it was allowed to go out of print. Second and third editions were issued 23 and 73 years later, respectively. According to Asimov (1964) Martin Luther in 1543 dismissed Copernicus as "the fool who would overturn the whole science of astronomy." Yet, according to Holton (1978): "From the first sentence of *De Revolutionibus*, one senses the source of energy of a major scientific idea. It was not some pedestrian piecing together of a corner in the puzzle. Nor does the work give us merely better astronomy and applications such as calender corrections, valuable as these are. Rather, his discovery is on the scale that produces an expansion of human consciousness, a change in cultural evolution — and it was so perceived by those who were converted to Copernicus's idea."

It is beyond the scope of this paper to discuss the burning at the stake of Bruno (1549–1600) or the formal recantation of Galileo (1564–1642) in 1636 for their views, which were consistent with Copernicus's heliostatic universe. The reaction of the Church was in defense of an ecclesiastic society. Copernicus's book was a symbolic target. It remained so until 1835, when it was removed from the list of books banned by the Catholic church. Let us recognize that prejudice and persecution are concomitants of progress. Those who innovate or dare to make substantive change in contemporary views more often are repressed than encouraged. We should also recognize that our own modern era is hardly one of social, political, and intellectual enlightenment.

Although our time to trace our scientific traditions is short, we must bide awhile with Galileo Galilei. According to Hall (1956), Galileo's greatest fame is as an astronomer, yet in intellectual quality and significance his one treatise on mechanics outweighs all the rest of his writings. He did much to establish our modern concept of the "experiment." Kinanthropometrists can look to him for their roots. In this area his own antecedent was Archimedes (287–212 BC), who gave us the concept of the ratio applied to geometric forms. In his book on mechanics, Galileo dealt with the strength of materials. He was the first to show that if structure increased in all dimensions equally it would grow weaker. He was the first to explain, on a theoretical basis of what is now known as the cube-square law, the fact that, if shape and composition are constant, volume (and mass) increase as the cube of linear dimensions but strength increases only as the square.

These concepts were further extended by his friend, Giovanni Alphonso Borelli (1608–1679). In addition to his influence in correcting some of the overconservatism of Galileo in astronomy, Borelli made notable contributions himself. In his book *De Motu Animalium* (Concerning Animal Motion), he successfully explained muscular action on a mechanical basis, describing bone and muscle action in terms of leverage. In a recent review of dimensionality in the expression of strength and maximal aerobic power (Ross et al., 1979), we felt a sense of historical kinship with Borelli, who attempted to carry mechanical principles to the functions of organs and body systems. Perhaps because of the reluctance to use dimensionality theory as a "calculation device," as suggested by Osiander of Copernicus's declaration, Borelli did not develop the concept of metaphorical models or use similarity systems (summarized in Table 1). Indeed, the use of conventional solutions whereby the unknown is described in terms of departures from purely inventive systems has not yet been fully realized. Einstein (1933) in his essays on science commented, "It seems the human mind first has to construct forms independently before we can find them in things." He considered Kepler's marvelous achievement (discovery of the true shape of the earth's orbit) to be a particularly fine example of the truth that knowledge cannot spring from experience

Table 1. Similarity systems

Similarity model	Dimensional assumptions		Rationale for dimensional assumptions
	L as 1^0 quantity	M as 1^0 quantity	
I Biological or kinematic (Gunther, 1975) Geometrical (McMahon, 1975) Physiological (Von Dobeln, 1956)	(a) $M \propto L^3$	$L \propto M^{1/3}$	Assume volume $\propto L^3$ and density is constant, ∴ mass/vol is constant and $M \propto$ volume or $M \propto L^3$
	(b) $T \propto L$	$T \propto M^{1/3}$	Assume all L values are in constant proportions independent of size, ∴, velocities L/T of any L must be constant. If L/T is constant $L \propto T$
II Elastic (McMahon, 1975)	(a) $d \propto L^{3/2}$	$d \propto M^{3/8}$	Assume animals of different size are similarly threatened by elastic failure under their own weight, ∴ $L \propto d^{2/3}$ (McMahon, 1975)
	(b) $M \propto L^4$	$L \propto M^{1/4}$	If vol $\propto L \times d \times d$, then vol $\propto L \times L^{3/2} \times L^{3/2}$ or vol $\propto L^4$, and, if constancy of density is assumed, $M \propto L^4$
	(c) $T \propto L$	$T \propto M^{1/4}$	As in I assume L/T is constant, ∴ $L \propto T$ (note: L/T is not, however, proportional to d/T)
III Static Stress (McMahon, 1975)	(a) $d \propto L^2$	$d \propto M^{2/5}$	If compressive stress is to remain constant between self-loaded beams of the same material, then $L \propto d^{1/2}$ (McMahon, 1975)

	(b) $M \propto L^5$	$L \propto M^{1/5}$	Vol $\propto L \times d \times d$ or vol $\propto L \times L^2 \times L^2$, $\therefore$ vol $\propto L^5$, and if constancy of density is assumed then $M \propto$ vol and $\therefore M \propto L^5$
	(c) $T \propto L$	$T \propto M^{1/5}$	Assume L/T is constant.
IV Mechanical or dynamic (Gunther, 1975)	(a) $M \propto L^3$	$L \propto M^{1/3}$	Assume constancy of density as in I
	(b) $T \propto L^{1/2}$	$T \propto M^{1/6}$	Assume constancy of acceleration, i.e., L/T^2 is constant, $\therefore L \propto T^2$ or $L^{1/2} \propto T$
V Hydrodynamic or transport (Gunther, 1975)	(a) $M \propto L^3$	$L \propto M^{1/3}$	Assume constancy of density as in I
	(b) $T \propto L^2$	$T \propto M^{2/3}$	Assume kinematic viscosity is constant, i.e., L^2/T is constant, $\therefore L^2 \propto T$
VI Thermal (Gunther, 1975)	(a) $M \propto L^3$	$L \propto M^{1/3}$	Assume constancy of body density
	(b) $T \propto L$	$T \propto M^{1/3}$	Assume heat flow per area time is constant, i.e., $H/(A \times T)$ is constant. If $H = ML^2T^{-2}$, then $ML^2T^{-2} \propto L^2T$ and $\therefore M \propto T^3$
	(c) $t \propto L^0$	$t \propto M^0$	Assume specific heat is constant, i.e., $H/(M \times t)$ is constant, $\therefore H \propto Mt$ or $ML^2T^{-2} \propto Mt$, $\therefore L^2/T^2 \propto t$ or $1 \propto t$

Key: L, linear measures, length, stature; M, mass; T, time; d, diameter (special case of L as a support structure); t, temperature.

alone, but only from the comparison of intellectual inventions with observed fact.

The kinship of scientists was exemplified by Torricelli (1608–1647), who was influenced by Galileo and attracted his theories. A book Torricelli had written on mechanics had so impressed Galileo that he invited him to Florence. There, during the last three months of the blind old master's life, Torricelli served as his secretary and companion, and, no doubt, discussed the problem of atmospheric pressure, for which Torricelli was himself to gain fame.

There are few more elegant examples of "crucial experiments," to borrow a term from Francis Bacon, than the series begun by Torricelli a year after Galileo's death. He was puzzled as was the master, by the well-known fact that a simple suction pump could not raise water more than 10.4 m (34 ft). He knew that all objects under the surface of the sea are subject to water pressure. Why not assume the air has mass and conceive of a "sea of air" that exerts pressure on all objects immersed in it? His "sea of air" was a metaphorical model that, when thought of in this way, led to his invention of the barometer. Its subsequent use by Blaise Pascal (1623–1662) showed reduction in pressure with altitude; this brought the theory of atmospheric pressure down to the level of an observational fact. It remained for Robert Boyle (1627–1691) to further extend the consequences of Torricelli's model by quantifying effects. Neither the concepts in Boyle's Law nor the law itself are matters of direct observation. Boyle took over Torricelli's metaphorical model that "air has weight." This is not directly experienced but can only be formulated in terms of other variables, e.g., heights of water and mercury columns in barometers. Thus, we have an example of a general law arising out of a metaphorical model. While all science is inspired by the elegance of these experiments, it is important to realize that they were initiated by a simple conceptualization of a "sea of air." It should also be noted that Boyle's Law itself cannot be treated as an absolute account of the relationship between volume and pressure since actual gases do not obey Boyle's Law exactly. Volumes of actual gases vary from predicted volumes, being somewhat greater above atmospheric pressure and lesser at lower pressures. Physicists refer to Boyle's Law as a model of the behavior of an "ideal" type of gas. The concept of an ideal gas is also a metaphorical model specifying a relationship if certain purely hypothetical conditions were realized.

STATISTICS AND METAPHORICAL MODELS

It is perhaps an impertinence to skip much of our scientific legacy, to omit discussion about the contributions of Isaac Newton (1642–1727), who developed fundamental laws basic to biomechanics and kinanthropometry, or, indeed, to exclude all but the direct conceptual antecedents of

Adolphe Quetelet, whom we might consider as the first kinanthropometrist. Among these direct antecedents, we must include Pierre Simon, Marquis de La Place (1749–1827), who was perhaps the successor to Newton in the scope and import of his studies. Among his contributions, in pure mathematics he developed the concept of the correlation coefficient and wrote a treatise on the theory of probability that gave this area of mathematics its basic foundation. The method of least squares developed by Johann Karl Friedrich Gauss (1777–1855), when he was 17 years of age, was a practical extension of probability theory that arose from study of the phenomenon of errors of astronomical observations tending to cluster in a definable pattern about a measure of central tendency or "true" value.

The Belgian astronomer and mathematician Lambert Adolphe Jacques Quetelet (1796–1874) might well be called the father of both kinanthropometry and physical anthropology. He was born in nearby Gent, became a professor of mathematics at the University of Gent in 1841, and later supervised the construction of the Royal Observatory in Brussel, where from 1828 until his death he was the director of the observatory. His great contribution to science and kinanthropometry was in the application of statistical methods to the study of human beings.

As was Francis Galton (1822–1911) in England, Adolphe Quetelet was greatly interested in social statistics. He discovered that the error distribution that worked so well in describing astronomical measures was also a reasonably good model for empirical distributions of anthropometric and other measures on humans. By 1835, he had recorded chest girths of Scottish soldiers, the stature of French army draftees, and other such measures, and found these distributed around the average in the same manner as one would expect from the random appearance of numbers on thrown dice or scatter of bullet holes about a bull's eye of a target. Later he used the 1846 Belgian census for statistical analyses and piloted many of our conventions in cross-sectional sampling and analysis. In graphing the results, he showed that the frequency of measures approximated the Gaussian, or bell-shaped, normal probability curve. His studies helped shape modern views on randomness. Quetelet's work gave rise to the concepts of the "average man" and "vital statistics" that subsequently formed the basis of the life insurance business. His work with that of Galton, Pearson, Spearman, Fisher, Stern, Burt, and Hotelling contributed to multivariate analysis and to what Catell (1966) refers to as the "second mainstream of psychological methodology and theory building," as contrasted with the limited experimental approach typified by Pavlov and Wundt.

Quetelet is not without his critics. Over a hundred years after his death, Hogben (1957) decries the "Quetelet Mystique," or that influence whereby investigators tend to regard the normal probability curve as the population archetype. For those who have a cultist worship of probability theory, the phenomenon of skewness is considered an artifact. Statistical authorities argued naively that it was a simple by-product of sampling and could be made to disappear if a sufficient number of observations were made. Van Dantzig and Hemelrijk (1954), in commenting on the almost reflex application of the normal probability paradigm, considered it to be like the proverbial Mephistophelian drink ''Mit diesem Trank im Leibe siehst man eine Helena in jedem Weibe'' (with this drink in the belly, one sees Helen of Troy in every woman), or, as quoted from a remark made by Lippmann to Poincaré (1912), ''Tout le monde y (à la loi des erreurs) croit. . . , car les expérimentateurs s'imaginent que c'est un théorème de mathématiques, et les mathématiciens que c'est un fait expérimental'' [Everyone believes in it (the law of errors) . . . , for the experimenters fancy it as a theorem in mathematics and mathematicians that it is an experimental fact].

Even when one recognizes that all distributions are not normal and makes the necessary adjustments or reverts to nonparametric or distribution-free statistical tests of the type described by Bradley (1968), standard treatment of raw data may be unrewarding. In looking at new perspectives for kinanthropometry, we must realize that contemporary statistical solutions are often inadequate to the problem. Kowalski (1972) succinctly summarizes the quandary of the human biologist who

> usually has an embarrassing profusion of variables and often employs multivariate techniques with the objective of achieving parsimony by introducing mathematical realizations in an attempt to reduce the dimensions of the problem. While this approach may in fact occasionally produce the required simplification, it is usually more the case that the new dimensions defy meaningful interpretation and that no real simplification is realized. These considerations lead to the following question: Is there something wrong with an idealization which CREATES difficult problems rather than serving to avoid them?

One of our colleagues would dismiss a student's question that was outside his particular area of expertise as being ''irrelevant to his answers.'' It seems, however, that too many basic questions about human structure and function are outside the pale of our standard methods of analysis, including our elaborate multivariate techniques. We cannot, if we believe kinanthropometry is an emerging scientific specialization, simply dismiss pertinent problems because our methods are presently inadequate. The challenge is, of course, to develop a new perspective because, indeed, as Vesalius extended his reach by standing on Galen's shoulders, so too must we go beyond our splendid legacy typified by Quetelet.

Fortunately, some recent work in Canada in our neighboring University of Victoria by Hayward et al. (1978) serves as a speculative example.

Table 2. Correlations between physical characteristics and cooling rates[a] (Males, $N = 20$)

Body mass	−0.14
Surface area	0.27
Skinfold thickness	−0.35
Endomorphy (I)	−0.28
Mesomorphy (II)	−0.27
Ectomorphy (III)	0.58

[a] Subjects above unprotected by survival suits. Similar r values were obtained using mean cooling rates for some subjects in 15 survival suits. Abstracted by permission from Hayward et al. (1978).

Their research centered around the practical problem of survival in accidental cold water immersion and the need to develop survival suits for military, industrial, and recreational users. They recognized at the outset of their investigations that the "critical" level of hypothermia was subject to controversy. They noted that Hall et al. (1968) used a figure of 32.8°C as an end point of "useful activity" or "tolerance time." Communication with Hampton (1976) of the research unit in the University of Leeds, elicited a suggestion of 33°C. Alexander (1946) in an intelligence report cited studies at Dachau concentration camps during the Second World War that showed cardiac failure in subjects during immersion hypothermia to be near 27°C. The Victoria group made an arbitrary decision. They established 30°C as a working definition of "incipient death" and assumed, on the best evidence available, that it could be extrapolated from a linear regression equation of decreasing rectal temperatures monitored by a recording system of thermistors inserted 15 cm from the anus. They also carefully checked their system and were satisfied that the apparatus yielded readings of rectal temperatures within 0.1°C of actual values.

With the metaphorical model of "incipient death," at some discomfort but no risk to themselves and their fellow subjects they were able to test the comparative insulating qualities of 23 survival suits, including an attractive insulated buoyancy jacket designed by the group for those who risk cold water immersion in the course of their occupational or recreational pursuits. They were also concerned with physique characteristics associated with cooling, and obtained the correlation coefficients shown in Table 2. The values shown were from unprotected subjects and were virtually identical with those based on the mean survival times obtained from exposure in 15 different suits, as discussed in a paper by Hayward et al. (1978). Surprisingly, in viewing cooling rates assumed to be a function of body surface area, the correlation coefficient was only 0.27. Hayward et al. then viewed the phenomenon in terms of the Heath-Carter somatotype described by Carter (1975). The cooling rate was related to the estimate of ectomorphy by a coefficient of 0.58.

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There are undoubtedly more elegant ways to determine anthropometric concomitants of cooling. Our intuition is to use a tactic for anthropometric fractionation of body mass (see Drinkwater and Ross, this volume). This we believe could be extended in applicability by applying metabolic constants to the constituent fractions. Nevertheless, the Heath-Carter somatotype relationship to cooling was more than merely adequate to lead us to infer from other models about the particular hazard to children of cold water immersion.

We know from the Heath-Carter somatotype method that ectomorphy is simply a stature and body mass ratio. It is predicated on a geometric similarity system, where it is assumed that density and shape are constant, i.e., that stature has the dimension L in length and body mass has the dimension L^3 in length. Any stature:body mass ratio that preserves this dimensional relationship can be used to scale ectomorphy. Sheldon et al. (1940) used the English measurement system where stature in inches was divided by the cube root of body mass in pounds. If one looks closely at the nomogram in the *Atlas of Man* (Sheldon et al., 1954), one can see where they removed the metric scale. Since their intended readership was primarily English-speaking, they elected a popular rather than scientific mode. Hebbelinck et al. (1973) extended Sheldon's nomogram to children and provided a metric option. Our preference is to dispense with nomograms based on cube roots of body mass. The advent of cheap hand calculators make nomograms passé. Perhaps the easiest way to obtain ectomorphy is to geometrically scale body mass by the formula where mass is multiplied by the quotient of a constant stature (170.18 cm) and obtained stature raised to the third power (shown with other procedures in Table 3). This eliminates the need to find cube roots and also has the advantage that the obtained proportional mass or proportional weight has meaning in real terms [e.g., if the subjects were all the same stature (170.18 cm), what would be their geometrically scaled body mass?]. Mean proportional body mass values thus obtained from the participants in the 1976 Montreal Olympic Games are shown in Table 4. The weight throwers had the largest proportional mass, were lowest in ectomorphy, and presumably would be least susceptible to the hazard of cold water immersion.

Another way of looking at proportionality phenomena is to relate obtained anthropometric measures to a single unisex reference human or phantom by a general formula, as prescribed by Ross and Wilson (1974):

$$z = \frac{1}{s}\left[v \left(\frac{170.18}{h} \right)^{d} - p \right]$$

where z is a proportionality value; s is a standard deviation from a hypothetical human population for variable (v); p is the designated phantom value for that variable; the ratio (170.18/h) scales obtained stature (h) to

Table 3. Heath-Carter somatotype, third component (ectomorphy) — height: weight ratios[a]

Reciprocal of ponderal index		Hirata F index (ponderal index)	Ross-Wilson proportional body mass	Heath-Carter III component (ectomorphy)
$h/w^{1/3}$	$\mathrm{h/w}^{1/3}$	$(h/w^{1/3})\,10^3$	$w\cdot(170{,}18/h)^3$	
up to 11.99	up to 39.65	above 25.03	above 79.01	0.5
12.00–12.32	39.66–40.74	25.02–24.55	79.00–72.84	1.0
12.33–12.53	40.75–41.43	24.54–24.14	72.83–69.26	1.5
12.54–12.74	41.44–42.13	24.13–23.74	69.25–65.87	2.0
12.75–12.95	42.14–42.82	23.73–23.35	65.86–62.74	2.5
12.96–13.15	42.83–43.48	23.34–23.00	62.73–59.92	3.0
13.16–13.36	43.49–44.18	29.99–22.63	59.91–57.12	3.5
13.37–13.56	44.19–44.84	22.62–22.30	57.11–57.64	4.0
13.57–13.77	44.85–45.53	22.29–21.96	54.63–52.19	4.5
13.78–13.98	45.54–46.23	21.95–21.63	52.18–49.86	5.0
13.99–14.19	46.24–46.92	21.62–21.31	49.85–47.69	5.5
14.20–14.39	46.93–47.58	21.30–21.02	47.68–45.73	6.0
14.40–14.59	47.59–48.24	21.01–20.73	45.72–43.88	6.5
14.60–14.80	45.75–48.94	20.72–20.43	43.87–42.03	7.0
14.81–15.01	48.95–49.63	20.42–20.15	42.02–40.30	7.5
15.02–15.22	49.64–50.32	20.14–19.87	40.29–38.66	8.0
15.23–15.42	52.33–50.99	19.86–19.61	38.65–37.16	8.5
15.43–15.63	51.00–51.68	19.60–19.35	37.15–35.69	9.0

[a] *H*, inches; *w*, pounds. All other ratios, *h*, centimeters; *w*, kilograms. For the Hirata F index, over 24.0 is stout, 24.0–22.0 is meso, and under 22.0 is lean. The Ross-Wilson unisex phantom weighs 64.58 kg, with an assumed population standard deviation of 8.60 kg.

the phantom stature constant; and *d* is a dimensional exponent [when *v* is body mass, as discussed previously, $d = 3$; when *v* is any linear measure (length, breadth, girth, skinfold thickness), $d = 1$].

Table 4. Proportional body mass of participants in the 1976 Montreal Olympic games (males) [$w\cdot(170.18/h)^{**}3$]

Sport	Mass (kg)
Shot, discus, hammer throw	80.8
Javelin throw	74.50
100-, 200-, 4 × 100-m races	65.60
Unisex phantom	64.58
Rowing	64.20
Gymnastics	64.20
5000- and 10,000-m races	61.30
High, long jumps	60.20
Marathon	58.90
Basketball	58.60

Proportional body mass expressed in phantom *z* values has the same mathematical meaning as "ectomorphy"; however, there is an inverse relationship — the greater the proportional body mass the lower the level of ectomorphy. Proportional body mass has been used by Vajda et al. (1977) and Vajda and Hebbelinck (1978) to show secular trends in Belgian children through comparison of data reported by Quetelet (1842) with other cross-sectional samples, including those reported by Hebbelinck and Borms (1969, 1973). In both vintage and modern data, they showed *z* values declining to minimal levels during the growth spurt and then increasing. A similar phenomenon in secular trend data on Hungarian children was reported by Eiben (1978). A redrawn graph of the most recent data from the study is shown in Figure 2. Clearly, there is a declining value of proportional mass for both boys and girls until the growth spurt, hence, there is a propensity to ectomorphy and the possibility of greatly increased susceptibility to the hazard of hypothermia.

Individual growth characteristics cannot be inferred from cross-sectional data. Longitudinal proportional body mass data for 100 boys from the Saskatchewan Growth Study (Bailey, 1968) (treated as discussed by Leahy et al., this volume) are displayed tridimensionally and shown as two variations in Figure 3. Most of the proportional body mass values over the age range of 7 to 16 years were below those of the unisex phantom, which is represented as a 0.00 halo in the top graph. When 0.00 was set as a cut-off level, the preponderance of the proportional mass values, as shown in the lower graph, were below this level. The relatively few exceptions appeared as emerging peaks. The inference is that, in the group studied, the greater-than-adult threat of hypothermia extends across the whole age range.

As indicated by the Hayward somatotype ratio, mesomorphy and endomorphy appear to have insulating qualities. The somatotype model may not be the best way to show age-related changes in muscularity and subcutaneous fat. In another paper in this seminar, Marshall et al. (this volume), using allometric equations on the longitudinal Saskatchewan data, show increasing girths obtained over muscular parts, decreasing appendicular skinfolds, and increasing midriff skinfolds. The implication is that children have less muscularity and fat deposits on the appendages than on the vital midriff sites, hence, they should be more vulnerable to cold water immersion than better-insulated adults.

The same phenomenon is illustrated by mean phantom-derived proportional girths, shown in Figure 4. Apart from the early stage of proportional chest girth, all of the girths show a consistently increasing value with increasing age. If the increases were largely muscular, then geometrically the inference is that the volume at this time would increase as the cube, hence, one would expect considerable increase in muscular insulat-

Figure 2. Proportional body mass in Hungarian boys and girls studied cross-sectionally in 1968 (Eiben, 1977).

ing qualities. The younger the boy, the greater the hazard of hypothermia. Presumably this would become progressively less until adult dimensions were achieved.

The proportional mean skinfold values for the 100 boys are shown in Figure 5. Again, as pointed out by allometric analysis by Marshall et al., the proportional skinfolds on the appendages declined with age, whereas those in the midriff increased. Because the younger boys had proportionally smaller skinfolds at midriff sites, one can infer that they are less protected from hypothermia in vital parts of the body than the older boys or adults.

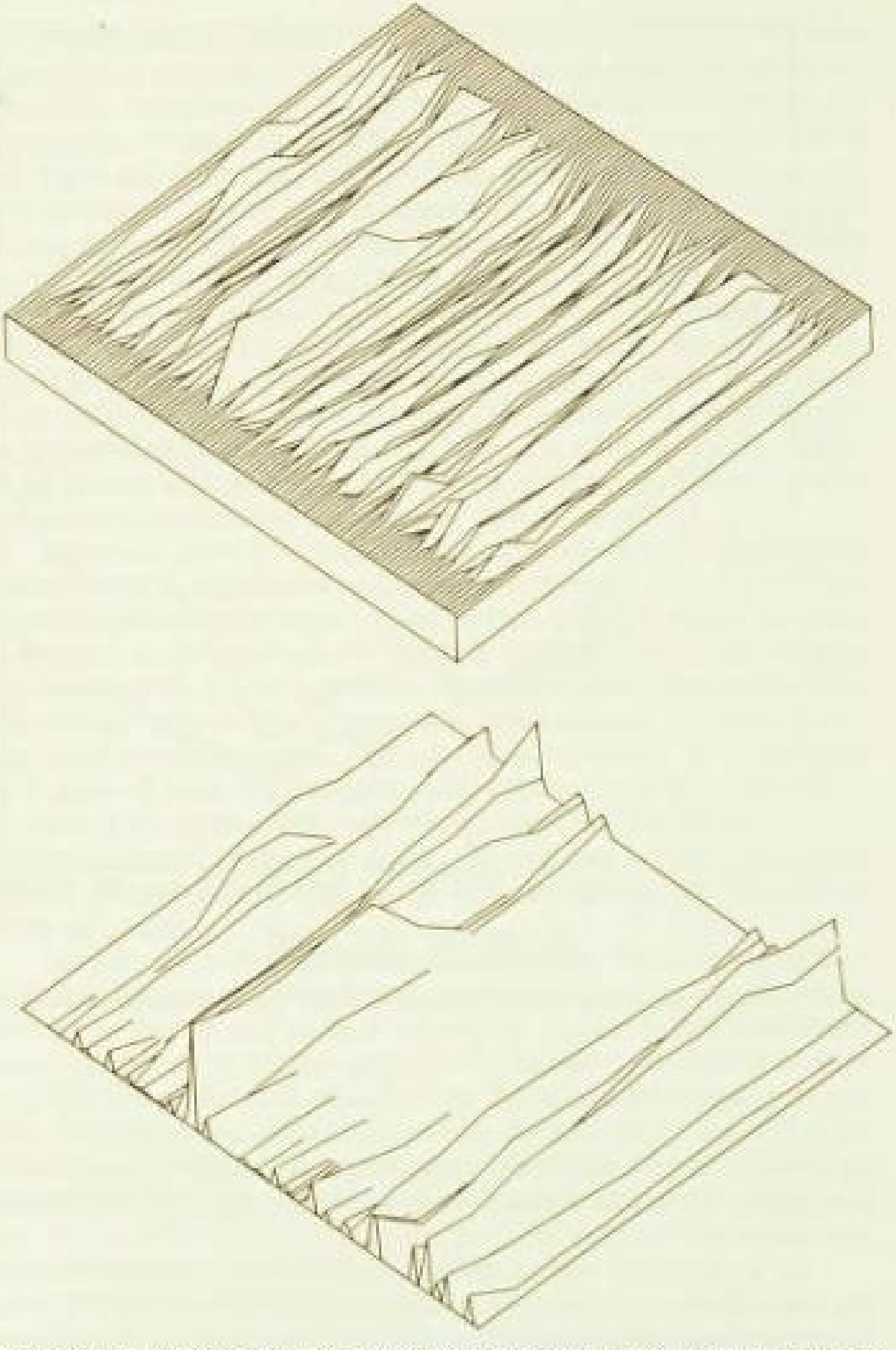

Figure 3. Proportional body mass or product of obtained body mass (*w*) and the ratio of 170.18 and obtained stature (*h*) raised to the third power and scaled to a unisex human phantom for reference. $Z = 1/8.6\ (w(170.18/h)^3 - 64.58)$. *Upper graph* shows longitudinal data on Saskatchewan boys obtained over an age range of 6–16 years, with age on the *x* axis, proportional mass on the *y* axis, and individual subjects on the *z* axis. The graph is set in a halo of 0.00 values for the phantom. *Lower graph* shows same information truncated at the 0.00 values, thus identifying the characteristics of subjects who at any age had greater proportional body mass than the phantom.

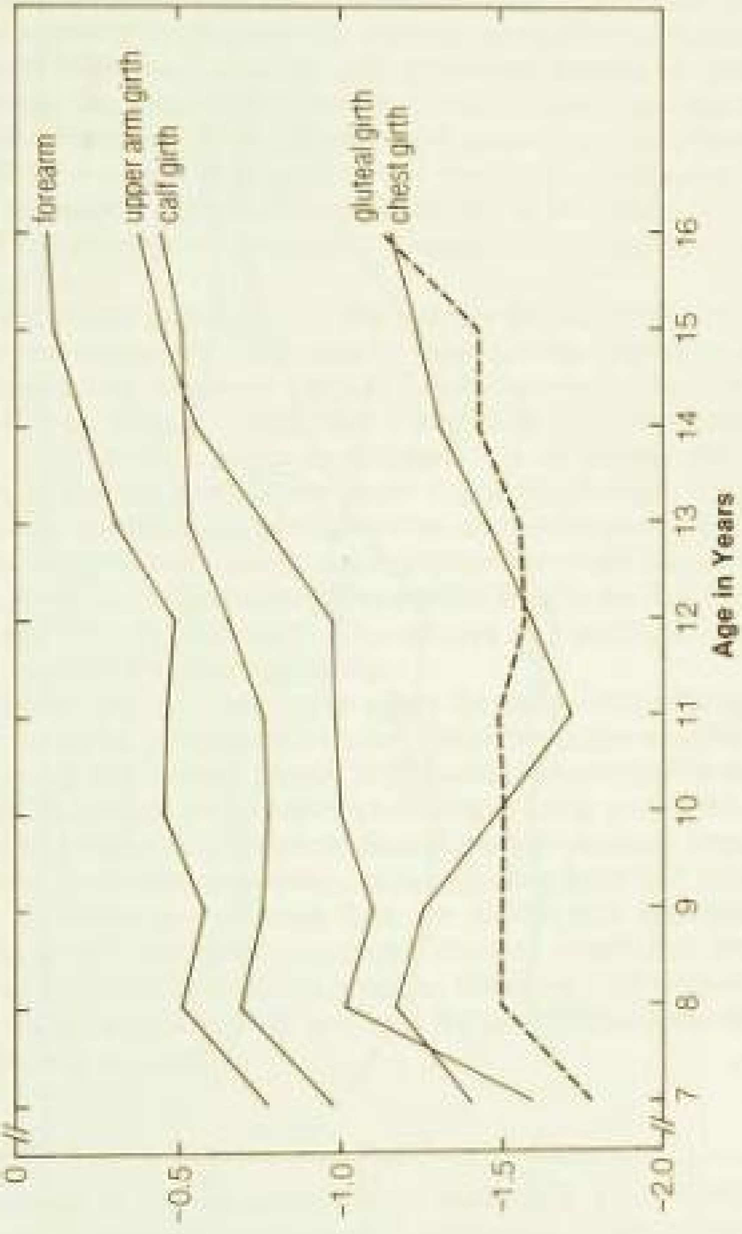

Figure 4. Mean proportional girths in 100 boys over an age range of 6–16 years, showing general increase with age.

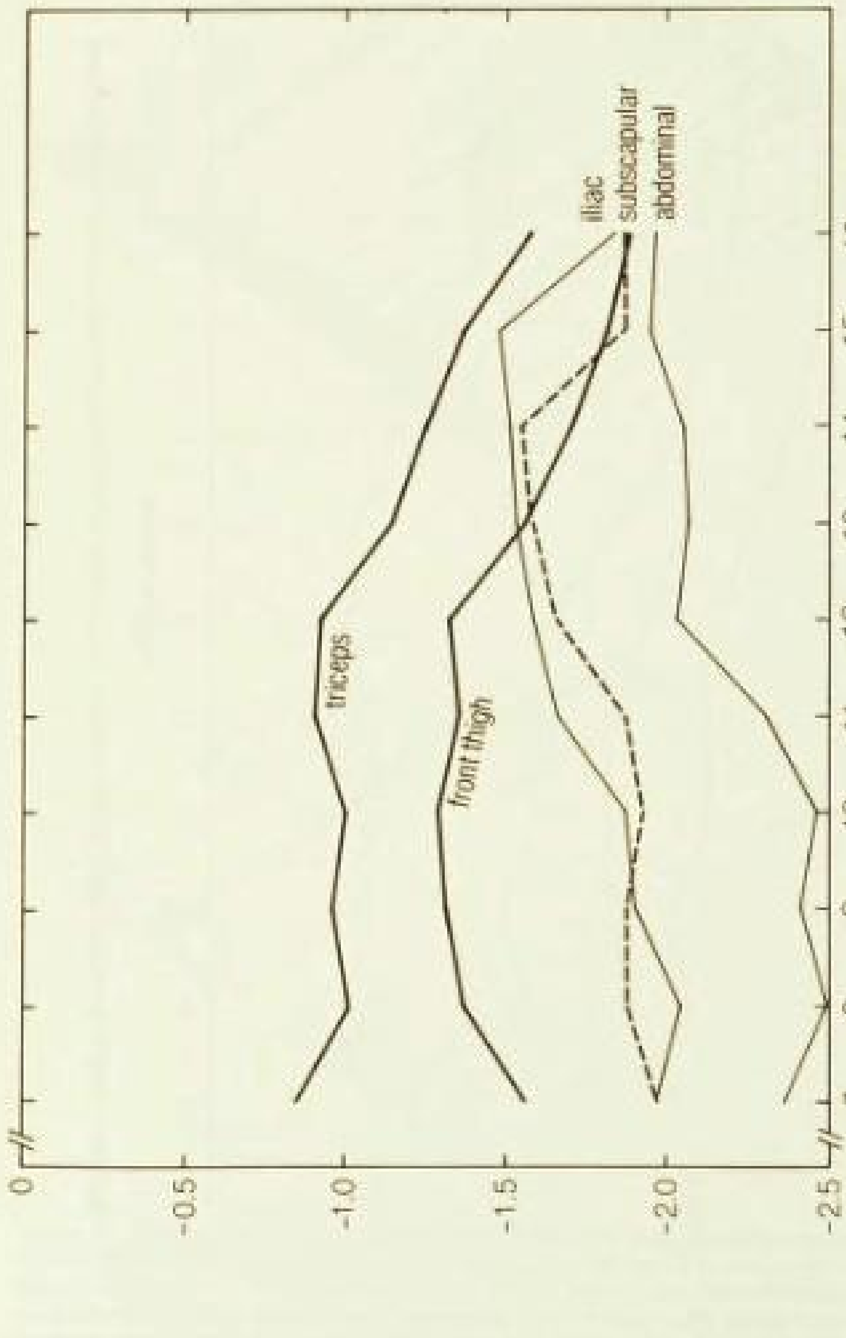

Figure 5. Mean proportional skinfolds on 100 boys over an age range of 6–16 years, showing appendicular decline and midriff increase.

Mean values, however, often misrepresent individuals. As in the tridimensional proportional body mass graph, we have displayed six proportional girths and five proportional skinfolds as shown in Figures 6 and 7. Each of the eleven graphs displays proportionality values for 100 subjects on the *z* axis for 10 measurement occasions on the *x* axis. The *y* value range is from greatest positive to greatest negative value. Further scaling, differentiation, and analyses with probability statements are possible. However, the visual impression gives an appreciation that there are individual differences, and the display itself assures that the individual is not lost in the analyses. Moreover, by virtue of the preponderance in the raw data of negative values for proportional girths and skinfolds, it is postulated that children are particularly vulnerable to the hazard of cold water immersion.

We should point out that our concern for the additional threat of cold water immersion of children by virtue of their physique characteristics is based on inference. Hayward's cooling model, the Heath-Carter somatotype, allometry with respect to similarity systems, proportional body mass, and the phantom strategem are all metaphorical models. Each, as charged by Osiander about Copernicus's work, should be regarded as "merely a calculation device, and not as truth." Perhaps had Borelli accepted that models showing departures from theoretical expectancy often are as illuminating as models that fit the data, his goal of showing the anthropometric concomitants of organic function would have been resolved many years ago.

To be sure, our speculations about the threat of hypothermia in children, based on metaphorical models, must eventually be subject to corroboration and redress. Herein, with the methods devised by the University of Victoria group for safely monitoring cooling, a critical experiment could be conducted on children selected by their physique characteristics as being particularly susceptible to hypothermia from cold water immersion. However, the inference from our models and available data are strong enough by themselves to justify medical, educational, and governmental programs to focus on research, safety, and preventive measures for children who subject themselves to the hazard of hypothermia in their recreational pursuits.

EPILOGUE

In our view of "Kinanthropometry: Traditions and New Perspectives," we come to new appreciations and conclusions. Kinanthropometry, although still an emerging scientific specialization, has a long and distinguished tradition. Because it essentially focuses on the human condition, it has moral constraints. In the continuum from verifiable truth to subjective judgment, kinanthropometry cannot aspire to being an exact science,

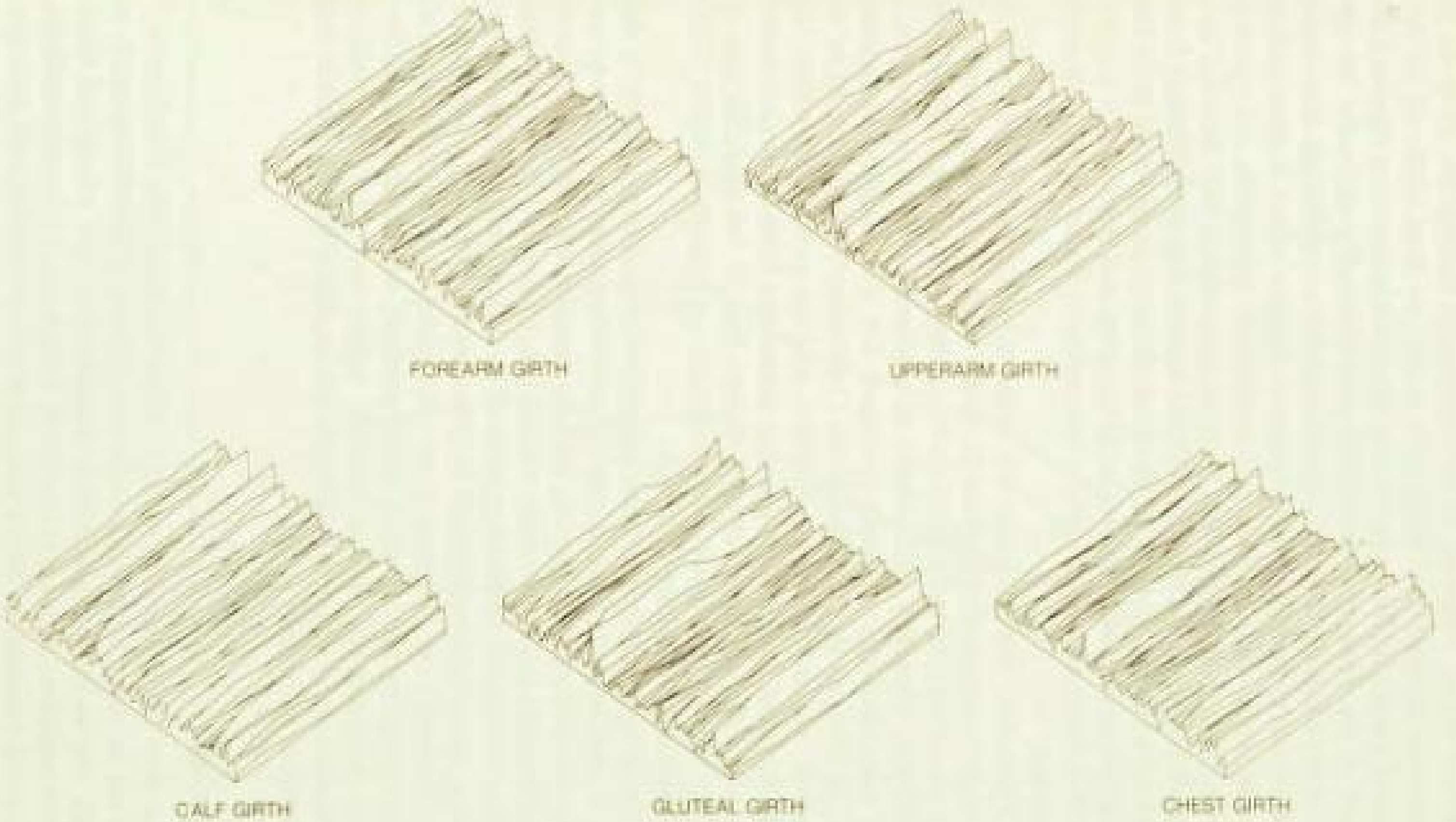

Figure 6. Proportional girths obtained over fleshy parts of the body. Height of y axis set at greatest positive to greatest negative z value; subjects on z axis; 10 measurement occasions over ages 7 to 16 years on x axis. Data from the Saskatchewan Growth Study (boys, $N = 100$).

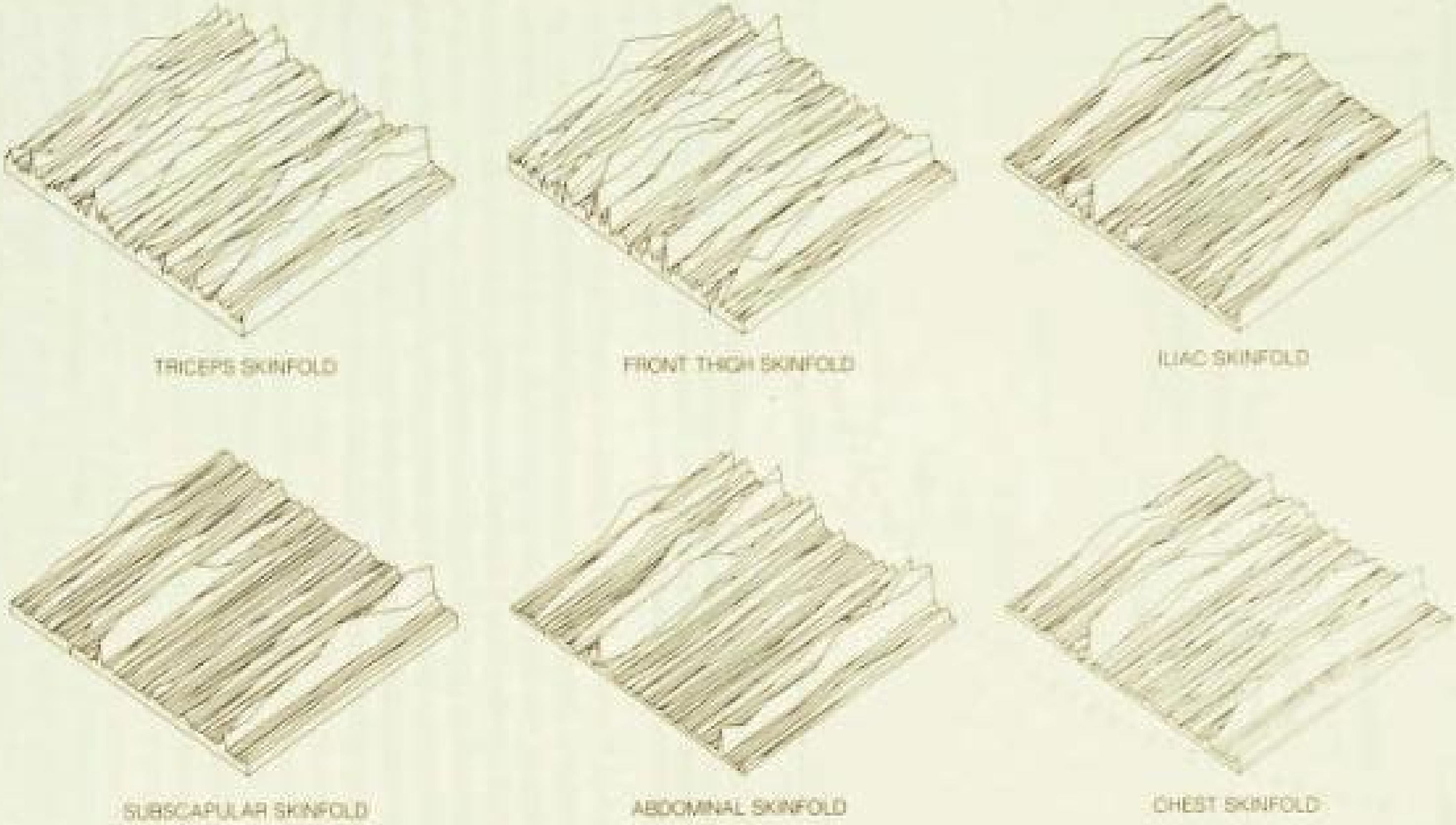

Figure 7. Proportional skinfold thickness. Height of y axis set at greatest positive to greatest negative z value; subjects on z axis; 10 measurement occasions over ages 7 to 16 years on x axis. Data from the Saskatchewan Growth Study (boys, $N = 100$).

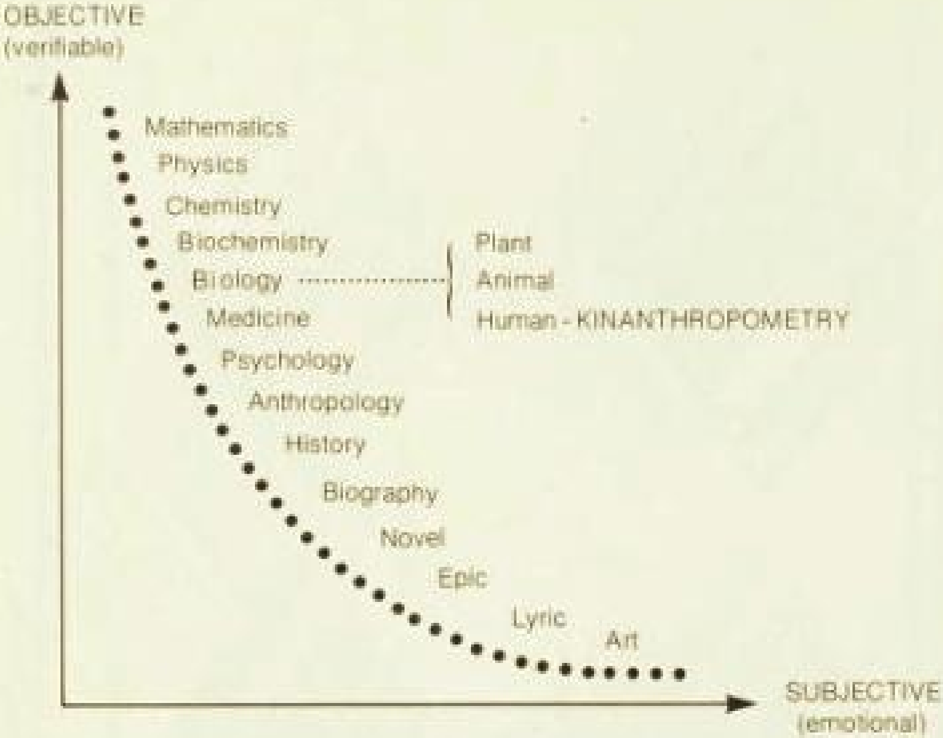

Figure 8. The criteria for truth and beauty are developed from an interplay of objective and subjective processes. The moral imperative in kinanthropometry and biological research imposes limits on experiments, hence the need for innovative analysis and use of inferential models. Modified from Koestler, 1964.

as shown in Figure 8. There are limits to human experimentation. Exploration in kinanthropometry must proceed by careful data collection, organization of the chaos of these data by all available methods, development of new methods and models, and cooperative use of data and computer technology, particularly those techniques that reveal individual differences in group trends. In establishing new perspectives, we embrace all levels of conceptual organization and recognize that innovation and creativity are largely matters of up- and down-scale transition, as illustrated in Figure 9.

In our admittedly brief review of the historical roots of kinanthropometry, we were impressed by the kinship that existed among our scientific forefathers. They were citizens of the world and looked on all human knowledge as their domain. We noted that the method of least squares we use today was developed by Gauss when he was 17 years old and that Vesalius started his great work when he was 23 and completed it before he was 28. Age is no barrier. In 1716 when Newton was 75, a problem was sent to him by Leibniz for the avowed purpose of stumping him. Newton solved it in an afternoon. We note also that Galileo at 78, blind and aging, was still able to inspire Torricelli to great work.

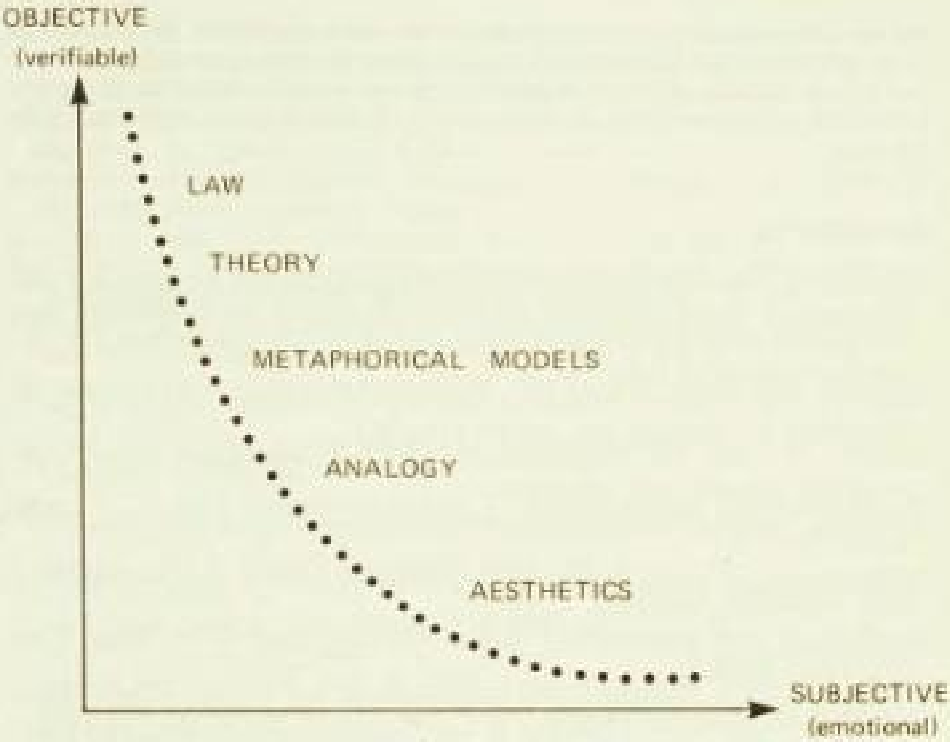

Figure 9. Conceptual organization for science and art showing various perspectives. Innovation in kinanthropometry or any other creative endeavor is largely a matter of up- or down-scale transition from one conceptual organizational level to another. Experiments on humans have absolute constraints, whereas analysis is limited only by the inventiveness of the mind (Ross, 1978).

Perhaps the function of science is really to make people participants and witnesses in research. In our emerging area, let us welcome into our family all those who wish to share the adventure of discovery in the service of humanity. Let us disregard age, sex, profession, and academic and political affiliation in our noble pursuit of truth and beauty. Let us also recognize that in this quest our colleagues here at this ancient seat of learning have met the challenge of providing international leadership. They have given all of us the splendid prospect of advancing science and serving all humanity as, together, we draw strength from our traditions and seek new perspectives.

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