ADDITIONAL NOTES ON SASQUATCH FOOT ANATOMY

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Abstract

Three methods are described which can be used to measure body weights of the sasquatch. Heel breadths of the footprints, squared, are directly proportional to weight; level lengths in the reconstructed foot indicate probable lifting power; and the volume of a filmed subject is determined. These measurements agree with previously collected data on the approximate stature to body-weight relationship which is the equivalent of a 6 ft. man weighing 300 lbs.

In a previous paper, I described several characteristics found in casts and photographs of sasquatch footprints which argue for the reality of the animal that has been so often reported (Krantz 1972). An 8 ft. tall, heavily built hominid would require certain structural modifications in its feet because of its great absolute body weight. In many cases these same modifications can be detected in the footprints.

My earlier work was concerned primarily with showing in what direction these modifications should occur, but with little attempt at quantifying them. This will be remedied here with the description of at least three new ways of determining body weights from the evidence available at present. Each of these methods was worked out separately and gave surprisingly similar results.

Throughout the following discussion, it is necessary to keep clearly in mind the changing relationships among length, surface, and volume of any structure as absolute size is increased. When length is increased by a particular ratio from a standard, surface increases by the square of that ratio, and volume increases by the cube of that same ratio. This is assuming that shape is kept constant.

If the human body is doubled in stature (increased by a ratio of 1:2), then its surface area is increased by four times (1:2 squared is 1:4), and its volume is increased by eight times (1:2 cubed is 1:8). On a lesser scale, an increase of half-again-more is a ratio of 1:1.5 for stature, when squared it becomes a ratio of 1:2.25 for surface area, and when cubed it becomes a ratio of 1:3.375 for volume.

Pulling strength is directly proportional to the cross-sectional area of a muscle so it increases with the square of the linear dimension. Breaking strength of tendons and ligaments, and crushing strength of cartilage likewise increase with surface area. Body weight, however, is a measure of volume and increases with the cube of a linear dimension. As a structure such as an animal body is increased in size, its volume (weight) increases faster than its surface areas (strength), thus making any relationship between weight and strength very much dependent on absolute body size.

There are some aspects of anatomy where a constant relationship must be maintained between volume and surface. When larger versions occur of a particular animal type, then some changes in shape are necessary in order that certain surfaces can keep up with increasing body weights. Articulating surfaces in the joints of the limbs are an outstanding case in point.

All supporting structures in the limbs must do exactly that—support the body. As body weight increases with the cube of linear dimension, cross-sectional areas in the limbs must also increase with the cube of linear dimension. Since surface areas do not normally increase at this rate, certain anatomical changes in design are required in progressively larger animals of a similar type. The limbs of the larger animals are more stoutly built simply in order that their weight-bearing surfaces can keep up with the body weight.

Cartilage surfaces of supporting joints will be damaged if too much weight is applied. On the other hand, a metabolic waste would be involved if the joint surfaces were made larger than the body weight required. A close correspondence ordinarily occurs.

A good example of this relationship in similar animals of different absolute sizes is found in American pronghorn antelope and elk. The elk is four times as heavy as the pronghorn—big healthy specimens weigh about 500 lbs. and 125 lbs., respectively. If they were built exactly the same, joint surfaces in the elk would be only 2.52 times as great. I measured the rather flat articulating surface on the underside of the talus (ankle bone) of both species and found that the elk actually had four times greater area than did the pronghorn—just the same as the ratio of body weights. The elk talus is thus built relatively larger than might be expected in a uniformly enlarged version of the pronghorn.

As a similar test, I measured the upper surface areas of a series of fourteen human tali including European males and both sexes of California Indians. The largest talus had nearly twice the surface area of the smallest, 1,156 sq. mm. as compared with 676 sq. mm. A range of almost 2:1 in body weights (excluding abnormalities) might well be expected in such a sample of people.

The surface area of the sole of the foot (in hominids) may vary greatly in relation to body weight. Elaborations of the epidermis, for example, can differ enough that no close ratio of pounds per square inch can be postulated. The surface area of the talus may be quite another matter, since articulative cartilage has little variation in its crushing strength. My measurements indicate about the same amount of weight per unit area for the human talus as for those of pronghorn and elk, allowing for bipedal versus quadrupedal support.

With each step, the bipedal hominid transmits his entire body weight from one tibia onto the corresponding talus through the cartilaginous surfaces between these two bones. The talar surface is somewhat longer than it is wide, and is broader anteriorly than it is posteriorly. Since the tibia moves over the talus, the latter has the greater surface area. The actual area of contact, at any one moment, can be approximated by measuring the breadth of the mid-talar surface and squaring this figure. The exact procedure of measurement is not critical as long as all comparisons are made in the same manner.

The breadth of the articulating surface of the talus, squared, is directly proportional to the body weight. Thus, a hominid talus with twice the breadth of the average for modern man has four times the surface area and is designed to carry four times the body weight. A talus half-again broader than man's would be designed for 2.25 times the weight, etc.

The upper articulating surface of the talus is not directly imprinted on the ground in a footprint. However, the upper talus breadth appears to be a very nearly constant percentage (about 50%) of the breadth of a bare heel imprint.

Direct evidence is lacking for sasquatch (we have no tali, let alone matching them with footprints) but some reasonable deductions can be made. If the talus were wider than the human in relation to the bottom of the heel, it would be perched upon a comparatively narrow and, presumably, wobbly base. If the talus were relatively narrower than human, then its weight-bearing potential would be less than possible for a given footprint size, and thus rather inefficient in this respect. An exact relationship cannot be demonstrated, but I shall proceed on the assumption that the same breadth ratio of talus to heel exists as in man.

It should now be evident that the squared breadth of a clearly imprinted bare heel is a good indication of body weight. A modern man of average body build and standing 6 ft. tall will weigh about 190 lbs. (the 4-4-4 somatotype of Sheldon 1954). Such men have an average heel breadth of 2.8 in. (my own observation, based on a series of measurements). This may be compared with a commonly reported adult sasquatch heel breadth of 5.5 in. These two heel breadths, squared, are 7.84 and 30.25. This is a ratio of nearly 1:4 which should also be the ratio of the surface areas of the two tali. The sasquatch in question would then weigh almost four times 190 lbs., or somewhat less than 760 lbs.

This reconstructed body weight would refer to normally built and reasonably healthy specimens. It is subject to the same kinds of variation to be expected in any other wild animal. Probably the majority of individuals with 5.5 in. heel breadths would weigh within 10%, more or less, of the indicated body weight, barring seasonal fluctuations.

A series of heel breadths and their corresponding body weights can be calculated on the above basis. I offer the following in English measurements simply because this has been almost exclusively the system used by sasquatch investigators in North America so far. (A table of similar measurements in the metric system is also given below.)

Heel Breadth (inches)	Squared (inches)	Weight (pounds)
2.8	7.84	190
3	9	218
3.5	12.25	297
4	16	388
4.5	20.25	491
5	25	606
5.5	30.25	733
6	36	872
6.5	42.25	1,024

Footprints with heel breadths over 6 in. are not very reliably reported. Still, one claim of about an 8 in. heel has been made on correspondingly enormous footprints (Green 1970). This heel should carry a weight of about 1,550 lbs. if it is correct.

The following is a set of similar measurements in the metric system. The first and last figures are the same as in the list of English measurements, but there is one fewer in between, so these are not equivalents.

Heel Breadth (millimeters)	Squared (millimeters)	Weight (kilograms)
71	5041	86.2
75	5625	96.3
90	8100	138.5
105	11025	188
120	14400	246
135	18225	312
150	22500	385
165	27225	463

Some interesting comparisons can be made of lever lengths in the feet of higher primates. The major lever of the foot is that running from the tip of the calcaneum to the end of the third metatarsal. It is divided by the tibio-talar axis of rotation into a posterior power arm and an anterior load arm. A relative elongation of the posterior, or power, arm gives the foot a greater weight-lifting capacity.

In my previous paper on footprints, there is a photograph of casts of the prints left by a sasquatch with a badly crippled foot. On these casts I had drawn the outlines of the bones as indicated by the deformity of the one foot. Now, two years later, I have measured exactly the lever lengths I had drawn on the normal foot of this pair. Its power arm is 120 mm. and its load arm 223.5 mm. The former is 53.7% of the latter (Fig. 1).

The foot-lever lengths of other higher primates are reported by Schultz (1963:110). Each of these is given here as the percentage that the power arm represents of the load arm, and is compared with "Cripple Foot."

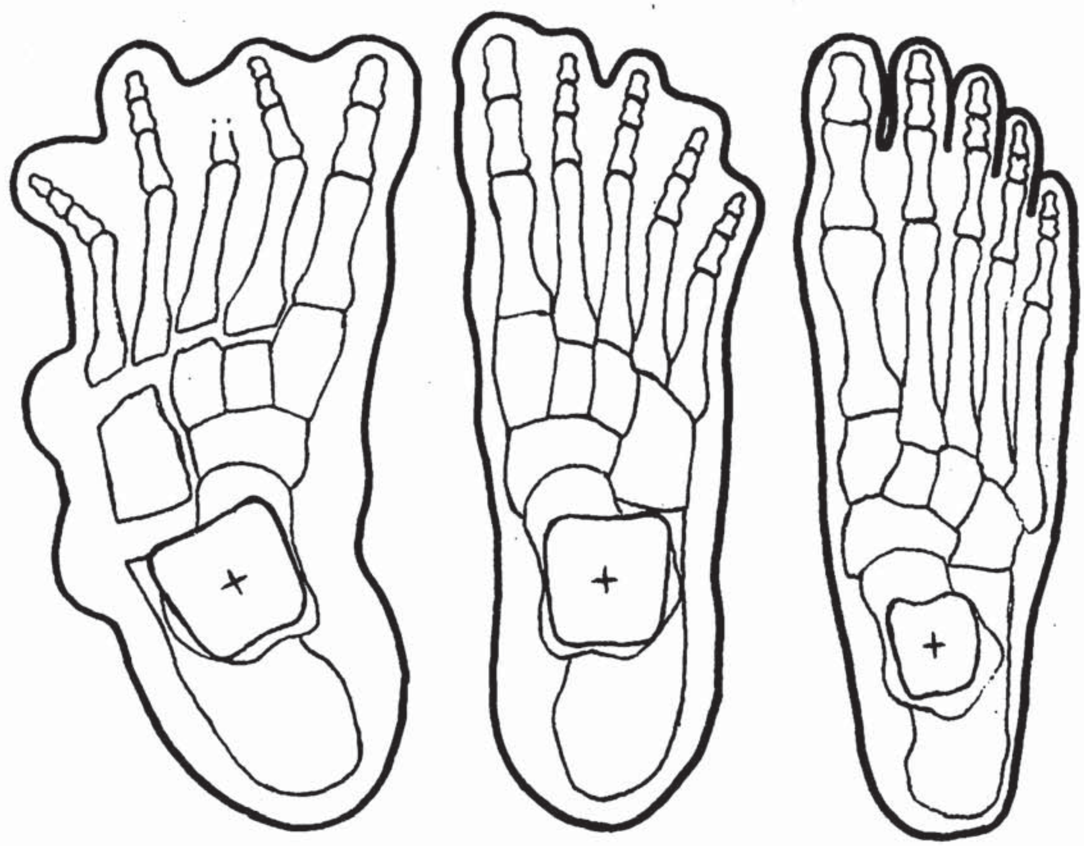

Fig. 1. On the left and center are outlines of the footprint casts of Cripple Foot with reconstructed bones drawn in as they would appear from above. On the right is a normal human foot on the same scale. The sasquatch feet are traced directly from a photograph in an earlier publication (Krantz 1972:102) except that the talar surfaces are enlarged and the tarsal-metatarsal joint is slightly altered. These minor adjustments do not affect the foot-lever lengths as originally reconstructed. These 17 in. long feet are reversed to facilitate comparison with the human foot which was redrawn from Marshal and Lazier (1955:65).

Sasquatch	53.7%
Gorilla	45.2%
Man	38.5%
Chimpanzee	26.8%

Not surprisingly, as body weights increase, so does the relative length of the power arm of the foot lever. As might be expected, the sasquatch foot lever considerably exceeds that of the gorilla in power. The fact that two of these primates are primarily quadrupedal when walking on the ground and the other two are bipedal seems to have no obvious effect on the foot levers.

Macaques and gibbons have still shorter power arms in order of descending weights. The orang-utan has an unusually short power arm (19.4%) considering his weight, but this animal does not walk on his soles and use the foot lever as the others do.

At first glance the difference between the human leverage figure of 38.5% and the sasquatch's 53.7% does not look impressive when one considers the great contrast in body weights. In order just to double the lifting power of the human foot lever, its power arm must be doubled in relative length from 38.5% of the load arm to 77%. The sasquatch power arm extension shows less than half this amount of change. A careful consideration of just how much the sasquatch power arm should be extended came as somewhat of a surprise to me.

The casts of Cripple Foot have heel breadths of 5.75 in. on the right side and 5.5 in. on the left. The average of 5.625 in. can be used to calculate the probable body weight on this individual, and this works out to 767 lbs. by the method described above.

It has been suggested previously (Krantz 1972), and will be repeated below with more evidence, that the sasquatch body build is comparable to that of a 6 ft. man weighing 300 lbs. The following comparison of Cripple Foot's pedal leverage will be that of a modern man of this very stout body build. Such a heavy-set body should have about the same muscular strength per unit weight as a 190 lb. man of the same stature. Still, the comparison should be made with the heavier type because this assumption determines the probable stature of Cripple Foot, which in turn affects his weight-to-strength ratio.

A hominid of 300 lbs. is contrasted with one of 767 lbs. with comparable body builds. The larger one is not only heavier, but also has greater muscular strength, though not to the same degree. The ratio by which strength lags behind body weight is equal to the ratio of the cube roots of the weights, as will be seen.

The cube root of 300 is 6.694, and that of 767 is 9.154. The ratio of 6.694 to 9.154 is the difference between the two in linear dimensions. The squares of these numbers (or two-thirds power of the weights) are 44.81 and 83.79, and this is the ratio of surface areas, hence of muscular strength, between the two. When the difference between the weights of the two hominids is reduced by the difference between their strengths, what remains is the ratio of 6.694 to 9.154. So the sasquatch is only 37% heavier, in excess of his strength, than is the stout man.

The foot lever of this particular sasquatch needs to be modified only enough to handle this 37% increase in weight over strength. Where the human foot's power arm is 38.5% of the load arm, in this sasquatch foot the relative length of the power arm should be increased by the ratio of 6.694 to 9.154. This would be an increase from 38.5% up to 52.7% of the load arm. Since this measured percentage of the power arm in my reconstruction of two years ago is 53.7%, or just a trace greater, this is a remarkably close coincidence.

One could also reverse these calculations and deduce from the foot-lever lengths that Cripple Foot should have weighed 814 lbs. This is just 47 lbs., or 6.1%, more than the estimate of 767 lbs. based on his heel breadth.

I had previously argued how improbable it would have been for a track faker to know that the bulges on the edge of the crippled foot should be placed forward of the positions they would occupy in a human foot. To this I can now add that the hypothetical faker somehow also knew almost exactly how far in front to put them.

In October, 1967, the late Roger Patterson obtained a unique movie film in the mountains of northern California. This shows seventeen seconds of what appears to be a heavy-set hairy primate walking past at about 100 ft. away and then off into the forest. It is in color and only slightly out of focus, but the hand-held camera moved a great deal during much of the filming. (See Green 1968 for details.)

Early this year I had the opportunity to view this film about twenty times, forward and backward, and to stop it on any frame for more careful study and measurements. There are two frames which clearly show the full length of the foot together with the anterior-posterior diameter of the ankle. In both of these, the foot length was exactly twice the ankle diameter.

A rough reconstruction of some major foot and ankle proportions from the profile can be made based on an outline of the human foot given by Lewin (1940:51). Allowing for one inch of hair thickness around the ankle accounts for the straight line upward from the heel tip, and also locates the anterior edge of the ankle proper.

With normal internal proportions in this enlarged ankle, one can approximate the position of the center line of the tibia. This line divides the total fleshy foot length so that about 31% of it is in the posterior part. This contrasts with about 25% in the posterior part of the human foot, and appears to be identical with the tibia position in the reconstruction of Cripple Foot. It is clearly indicated that Patterson's movie subject had similar foot-lever lengths. This ankle position shows it was designed for supporting a very great weight, but the details are too imprecise to make any specific estimate (Fig. 2).

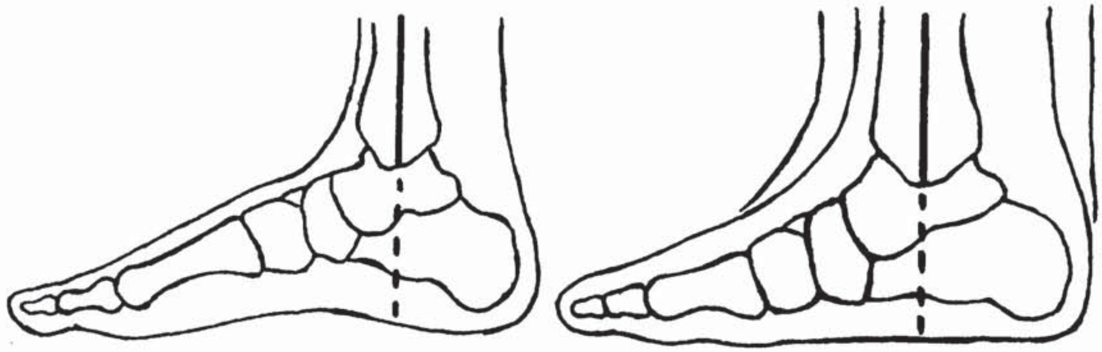

Fig. 2. At the left is an outline of the human foot viewed from the medial side with the bones drawn in from Levin (1940:51). At the right is the same view, drawn to the same length, of the sasquatch foot based on Patterson's film. The center line of the tibia in the human foot is about 25% forward from the heel tip to the toe tip, but in the sasquatch foot it is 31% forward.

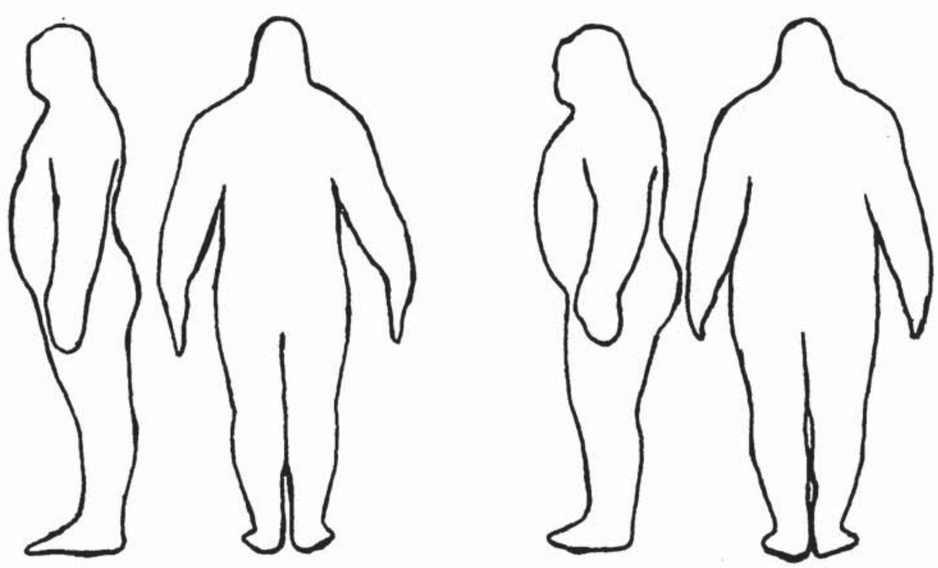

Fig. 3. Outlines traced from photographs of stoutly built men (Sheldon 1954:248) with an allowance for sasquatch-like body hair. Their height to cube-root-of-weight ratios are 10.92 (left) and 10.58 (right) compared with 10.75 estimated for the sasquatch. Both men are of somatotype 4-7-1.

There are still two other methods of estimating the body weight of this particular individual other than by the depth of impression of the footprints which was considerable. I have casts of eight footprints taken from the movie site, three of which are clear enough to measure the heel breadth. Two of these measure almost 4.5 in. and the third about 4.25 in. for an average of 4.41 in. By the method described earlier, this indicates a body weight of 471 lbs., give or take 10%.

The other method is to use the dimensions of all parts of the subject from the film image and to calculate its volume. These dimensions are fairly reliable as the height of the subject is known. The figure is 5.9 times as tall as its foot length, which is known from casts to be 14.25 in. Another check is a duplicate film made from the same camera position of a tall man walking in the old footprints. Both methods show the subject to be almost exactly 7 ft. tall.

From the stature and foot length, Green (1968) has obtained numerous measurements of various bodily parts. I have used these figures, and some taken myself from the film, to determine its total volume, allowing for hair thickness of one inch over virtually the whole body. This volume works out to be 8.44 cu. ft., but this estimate may vary considerably according to the person who makes the calculations. Since the subject is probably just slightly less dense than water, its volume can be multiplied by 60 lbs. per cubic foot, for a total of 506 lbs.

The two figures of 471 and 506 lbs. are acceptably close. Patterson himself called the creature 500 lbs. and he was very good as estimating human weights.

Stature estimates of the sasquatch, which are commonly reported, are often based on fleeting glimpses or are made under emotionally trying circumstances. Other estimates are based on claimed careful observations. These and other, more concrete, lines of evidence can now be combined to form a fairly clear picture of the relationship between heights and weights.

Since volume increases with the cube of a linear dimension, the cube root of the weight will be at a constant ratio to stature for any given body type. Three different body types can be considered here to see how well each fits the most reliable sasquatch data.

1. A body build like that of a typical modern man 6 ft. tall would weigh 190 lbs. This is a stature to cube-root-of-weight ratio of 12.52.

2. The body build of a very heavy-set man 6 ft. tall could weigh 300 lbs. This is a stature to cube-root-of-weight ratio of 10.75.

3. Some investigators who think the sasquatch is extremely heavy because of the depth of footprints would use 400 lbs. for a 6 ft. specimen. Here, the ratio of stature to cube-root-of-weight is 9.77.

The differences among these three ratios can best be illustrated by the three different body weights each would call for at a given stature. (Metric measurements are also given below.)

Stature (feet)	12.52 (pounds)	10.75 (pounds)	9.77 (pounds)
6	190	300	400
7	302	476	635
8	450	711	948
9	641	1,012	1,350
10	880	1,389	1,852
11	1,171	1,848	2,465

(All figures in this chart which are much in excess of 1,000 lbs. can probably be ruled out as being beyond the weight-bearing capacity of the ankle.)

The following is a set of similar measurements in the metric system. The first and last lines are essentially the same as the corresponding English measurements, and those in between are very similar to the English ones.

Stature (centimeters)	Human (kilograms)	Heavy (kilograms)	Heaviest (kilograms)
182.9	86.2	136.1	181.4
215.0	140.0	221.1	295.0
245	207	327	436
275	293	463	617
305	400	631	841
335	530	836	1,115

(All figures in this chart which are in excess of 500 kg. can probably be ruled out as being beyond the weight-bearing capacity of the ankle.)

The best test of the three sets of figures given above is Patterson's movie subject. In this case the height is known to be almost exactly 7 ft. Patterson estimated its weight at 500 lbs., I calculated its body volume which indicated 506 lbs., and its heel breadth calls for 471 lbs. All these weights are acceptably close to the 476 lbs. given in the middle column, and clearly out of range of the other two figures.

In 1884, a wild, hairy, bipedal creature was reported captured in Canada near Yale, British Columbia. A full newspaper account of the event is extant, though there is no information yet known on the ultimate fate of this animal. The most obvious identification is that it was a young sasquatch. Fortunately, its height and weight were measured; it stood 4 ft. 7 in. tall and weighed 127 lbs. (Green 1968).

Compared to adults, very young humans are relatively heavy because their legs are short, while teen-agers are relatively light. The age of the Yale, British Columbia, specimen is unknown; but, if the adults were as tall as 8 ft., it was the equivalent of about a four-year-old human child. This should make it, relatively, a bit heavy as compared with the adult scale. However, since it was measured after capture, possibly by some days or weeks, it could have lost considerable weight. We can only compare its dimensions directly with adult figures.

If the Yale specimen had an average human body build, its height of 55 in. would call for a weight of only 85 lbs. With a body build of 6 ft.—300 lbs., it should have weighed 134 lbs. If it were built on the scale of 6 ft.—400 lbs., a body weight of 178 lbs. would be expected. Its reported weight of 127 lbs. is only 7 lbs. less than the middle column figure, and over 40 lbs. away from the other two. Its height to cube-root-of-weight ratio is thus very close to that of Patterson's movie subject.

A general consensus of sighting reports tends to center on about 8 ft. as a typical stature of obviously adult specimens. Likewise, what appear to be full-sized footprints have heel breadths of about 5 in. or slightly more. These height and weight tendencies also support the 6 ft.—300 lb. body build.

Some modern men are similarly heavy-set, though with nowhere near the absolute statures claimed for sasquatch sightings. The physical appearance of a 6 ft. man weighing 300 lbs. should approximate that of a sasquatch in terms of bodily proportions. In Sheldon's *Atlas of Men* there are several subjects shown who have nearly the same ratio of height to cube-root-of-weight (10.75) as is indicated for sasquatch.

In Fig. 3, I have traced the outlines of two of these men from Sheldon's photographs with some minor but necessary modifications. The body outlines were drawn just outside the contours on the photographs so that the visual effect of an inch-thick covering of body hair was added. On the head, this same pen line was drawn inside the contours of the brain case to minimize this feature.

These body outlines are remarkably similar to the proportions described by those who claim to have seen sasquatches. Most reports also indicate more massive arms and shoulders than these pictures show, though no adjustment was made here to illustrate this characteristic.

From several quite diverse lines of evidence, height and weight estimates have been made for the reputed sasquatch. Each such item of evidence by itself could easily be dismissed as interesting, but inconclusive. Taken together, however, the close correspondence of all of them to each other appears to be more than can be accounted for by a combination of chance and deliberate faking of evidence. To this might be added the anatomical consistencies found in the handprints (Krantz 1971).

The height and weight of Patterson's 1967 movie subject were each determined by two quite separate methods which gave the same specific ratio between them. The same relationship between height and weight is found in the reported measurements of the specimen captured in 1884 near Yale, British Columbia. Heavily built modern men can have the same relationship between height and weight, and show proportions remarkably similar to the movie subject as well as to descriptions by claimed eyewitnesses.

Lever lengths in the foot have been determined which indicate a weight-lifting ability which agrees closely with the indicated weight. This weight, in turn, can be closely approximated from a different measurement of the heel imprint.

It may be noted that the evidence used in this description comes from only a few sources—two sets of tracks, a movie, an old newspaper item, and some generalizations from sightings and other footprints. These are merely the most definitive items selected from a great mass of data. To this, one could also add the many native American accounts, evidently of this same animal (Suttles 1972).

This is not to say all sasquatch reports are equally reliable. One could safely say that at least one-half of the evidence reported in recent years is in error in some way, or is wholly false. A demonstration of the probable reality of part of the available data does not prove anything about the remainder.

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