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The Individuality of Human Footprints

An aspect of human identification that has received scant attention from forensic anthropologists is the study of human feet and the footprints made by the feet. During the last ten years, I have worked with archaeologists from Washington University (St. Louis) in studying the use of caves by prehistoric peoples in the Flint-Mammoth Cave region of Kentucky [*1,2*]. In some isolated sections of the caves, footprints of the early peoples have been found in dust and in soil that once was mud. Some of the footprints were made by bare human feet; others are of sandal (moccasin) impressions. When found, the footprints are recorded and photographed, usually by a Cave Research Foundation photographer, and left in situ. I measured some of the dust footprints in the lower passage of Salts Cave (Flint Ridge Cave system) in 1972, but at that time equipment was not available to "lift" a footprint so that it could be examined more fully in the laboratory.

In 1976 Dr. Patty Jo Watson, archaeologist in charge of our research group, was informed of possible prehistoric human activity in caves in Fentress County, Tennessee. The evidence for human presence was in the form of footprints and charred cane fragments, the latter representing the debris of a common light source of prehistoric cave dwellers. During our first trip into Wolf River Cave (Fentress County), several hundred human footprints were found in a winding passage off a major trunk passage. Most of the footprints were of bare feet, but a few sandal impressions could also be delineated. Since charred cane fragments were found inside some of the bare foot impressions, they were tentatively assessed as having been made during prehistoric times. Subsequent radio-carbon dates from charcoal samples of 2460 ± 75 B.C. from the footprint passage and 2580 ± 85 B.C. from the adjoining trunk passage verified the antiquity of the footprints. For our study of the activity patterns of those prehistoric people, we needed to determine the number of individuals represented by the footprints, the directions of their movements through the passage, and the frequency with which the passage was used. Thus, we began the study by sorting out footprints of different individuals.

Methods

The identifiable prehistoric footprints were numbered and initially measured for foot length and ball, arch, and heel width to aid in later determinations of probable height, weight, sex, and age of each person. The variations in morphology of different footprints suggested that the many footprints were made by a limited number of individuals (nine) but not in a single trip. Differential mineral accretion in some footprints and slight stream wash through others indicated that there had been at least two trips through the passage. According to footprint measurements and morphologies, though, the same individuals

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apparently made both trips. Our plans called for a cast to be made of each person's footprint for further analysis in the laboratory and for a permanent record of their existence. Different casting materials were tried, but the paraffin wax technique (Fig. 1) has proven to be the most satisfactory in the cave environment of that passage.

A preliminary search through the literature for comparable studies of feet or footprints revealed that little attention has been given to the feet and none to footprints. Particular bones of the foot (that is, calcaneus and talus) have been used for sexual identification [*3,4*]. Macdonnel [*5*] calculated stature on the basis of foot length in a large sample of English subjects. Randall et al [*6*] examined the anthropometric data that were collected on the feet of 5575 white Army males in the 1940s for a project on shoe design (a copy of some of the original data was received by the writer from the widow of Dr. Charles E. Snow, a participant in the project, in 1968). Davenport [*7*] conducted chronological studies of overall dimensional foot growth in selected samples of subjects, noting sexual and racial differences. Meredith [*8*] synthesized the results of many previous studies (about 60) in his own investigation of foot length growth. Some studies, like those of Venning [*9*], Anderson et al [*10*], and Hill [*11*], emphasized growth changes in the feet of children over a period of time. Although there is a small body of knowledge on the dimensional changes in the feet, virtually no information exists on distinctive morphological features of the feet [*12,13*].

Finding no reference standards in the literature with which to compare the footprint data of the prehistoric people, I began to collect data on contemporary subjects. Footprints and vital statistics have thus far been collected from more than 500 living subjects who range in age from 8 to 79 years. Since the prehistoric footprints are "walking" footprints, and some sandal impressions are present, footprint data on the contemporary subjects consist of stationary footprints, foot outlines, shoe outlines, and walking footprints of a subject as he or she walks along a length of transparent acetate paper. The walking footprints are made of obtain information on dimensional and morphological changes in the footprint, weight distribution along each foot, and length of stride. The materials for

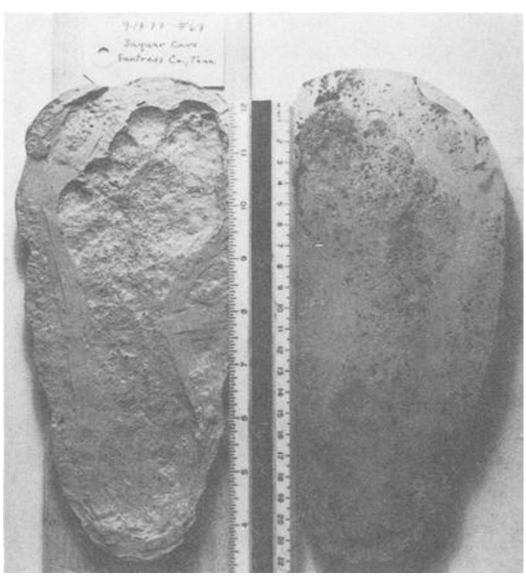

FIG. 1—(left) *A positive impression (Duplicast® cast) of a prehistoric human footprint from Wolf River Cave (also called Jaguar Cave), Fentress County, Tennessee;* (right) *a paraffin wax negative impression of the footprint.*

obtaining the data are Faurot's sensitized fingerprint equipment, standard fingerprint ink, washable black latex paint, 203- by 280- and 203- by 355-mm (8- by 11- and 8- by 14-in.) white paper (lined and unlined), lengths of acetate, and tracing pencils and pens.

Vital statistics of sex, age, height, weight, shoe size, handedness, and ethnic affiliation are recorded for each subject. A number is assigned to each subject to preserve identities. Twin subjects are assigned the same number with the addition of a letter to distinguish their footprints. Subjects from the same family are numbered sequentially and given a subcode to denote familial relationships.

I have developed techniques for taking measurements and observing morphological characteristics for the analysis of the prehistoric and contemporary footprints. Standard length-width landmarks of the foot are used for points of measurement [*6,12,13*], but other landmarks have been added (Fig. 2). For example, length and width dimensions of the toes, toe pads, toe "stems" (first phalanges), and angles of declination from toe 1 to 5 and from the ball to its juncture with the arch aid in distinguishing the footprint of one individual from another. For the morphological analysis, the footprint is divided into ten sections: individual toes, ball, ball-arch juncture (midshafts of metatarsals), arch, arch-heel juncture (distal calcaneus), and heel. The anterior, posterior, medial, and lateral size and shape of the contours in each section of the footprint are examined before a composite description of it is recorded.

In an effort to describe explicitly particular morphological contours, an archaelogical technique (the grid, in centimetres and millimetres) is used to examine the footprint. The grid overlies the footprint with the zero point positioned at the medially posterior point of the heel and the zero line parallel to the longitudinal axis of the foot (Fig. 3). By using the grid, the morphological contours can be analyzed qualitatively and quantitatively. For

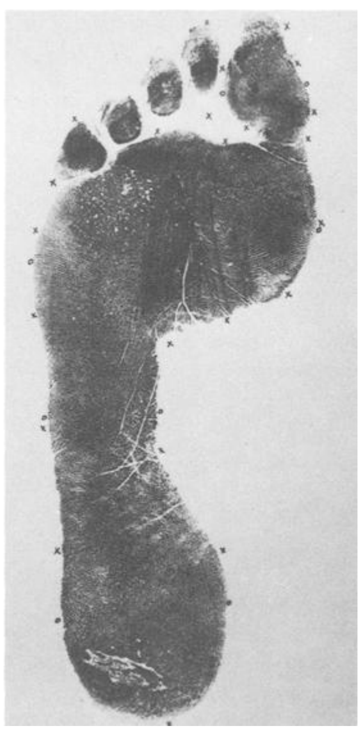

FIG. 2—*Basic morphological* (X) *and measurement* (o) *landmarks for analysis of plantar footprint.*

example, a big toe pad may have a circular, oval, parallel-sided, or some other shape. The grid enables one to identify the points along the pad where curvature occurs as well as how much curvature is present.

Results

Analysis of footprints from living and prehistoric individuals has yielded a broad array of data. Major results of the analysis have been summarized.

Unless bare footprints are impressed in a soft substance, like moist soil, their dimensions are representative of the plantar portion of the foot, not the size of the actual foot; that seeming discrepancy will be addressed further along in the report. Footprints of different individuals may have comparable foot lengths and ball, arch, and heel width, that is, to within 5 mm of each other, but the morphological contours of the footprints are quite different. Some subjects, both prehistoric and contemporary, may exhibit similar morphological contours in one region of the footprint, such as the heel, but have different contours in other regions, such as the ball or arch.

Dimensional or morphological similarities may occur in the footprints of members from the same family, but significant morphological differences still are present in one or more regions of the footprint. Footprints of dizygotic twins (Fig. 4) are no more alike in morphology or in measurements than are single-birth individuals in a family; similarities occur, but so do differences.

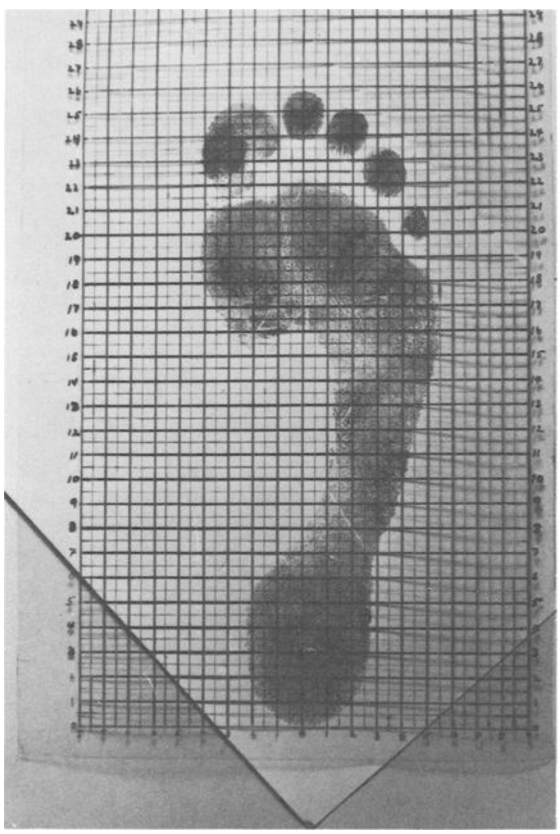

FIG. 3—*Centimetre grid overlying footprint for qualitative and quantitative analyses of footprint morphology.*

As one might suspect, the footprints of monozygotic twins contain many points of similarity in both measurements and morphological contours (Fig. 5). Dimensional differences are minimal (within a few millimetres) in foot length, ball, arch, and heel widths, and even in lengths and width of toe pads. At first glance, the morphological contours of the footprints may appear identical, but subtle differences can be observed (by using the grid overlay), often occurring in the posterior contours of the ball, ball-arch juncture, or arch-heel juncture.

When stationary and walking (or sliding) footprints of an individual are compared, individualistic traits may be identified (Fig. 6). The morphology of the heel, ball, and arch exhibit minimal contour change when account is taken of the weight shift in the body; overall dimensional changes occur, but sectional dimensions are fairly stable. The toes curve to grip the ground or floor in stationary footprints and especially so in walking or sliding footprints. Distribution of body weight along the walking footprint is reflected in the particular pressure areas on the heel, arch, ball, and toes, and unless pathology or a genetic anomaly is involved, only the pads of the toes are impressed on the ground.

The foot outline is the intermediate foot form between the bare footprint (plantar footprint) and the sandal or shoe print. The outline provides dimensional and morphological information of the foot relative to its plantar surface (Fig. 7), except in the medial arch and medially posterior ball areas. Other than in the two areas noted, the outline usually is a 5- to 10-mm enlargement per area of the bare footprint; less than a 5-mm enlargement is found among linear individuals with minimal flesh padding on the foot.

In relating the foot outline of an individual to his or her sandal or shoe print, cultural factors, like types, styles, differentials in brand size, and materials of the footgear, must be considered along with the biological features of the foot. Whatever the footgear, the foot outline is a reduction of the sandal or shoe print. In sandals of soft material, and without soles, like the prehistoric fibers, cloths, or moccasin-type leathers, the outline dimensions are a reduction of 5 to 10 mm (or less) per area from the sandal impressions. Morphological contours of the foot often are visible in sandal (or moccasin) impressions, but they are masked in most shoe prints. Some dimensions (like foot length) of the foot outline may be 20 to 30 mm less than suggested by the shoe print.

FIG. 4—*Footprints of adult female dizygotic twins; note morphological dissimilarity.*

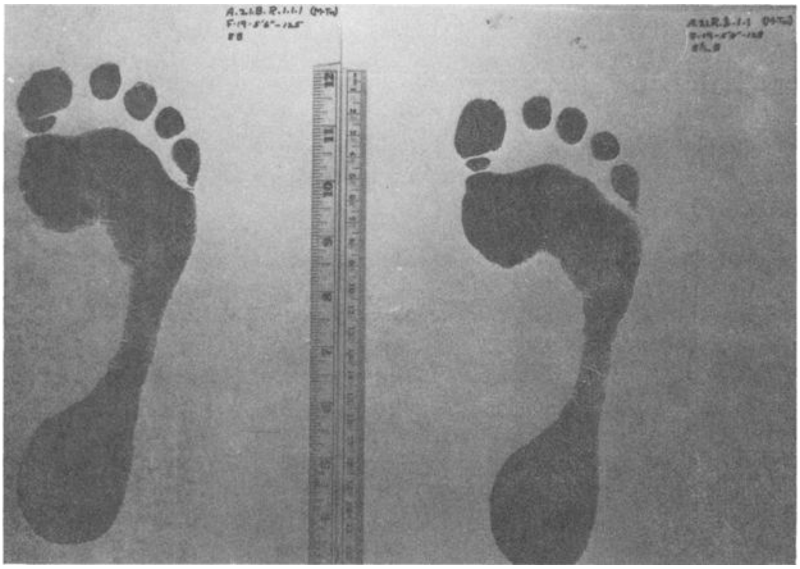

FIG. 5—*Footprints of adult female monozygotic twins; note subtle morphological differences in the big toe, its juncture with the ball, and the juncture of the ball with the arch.*

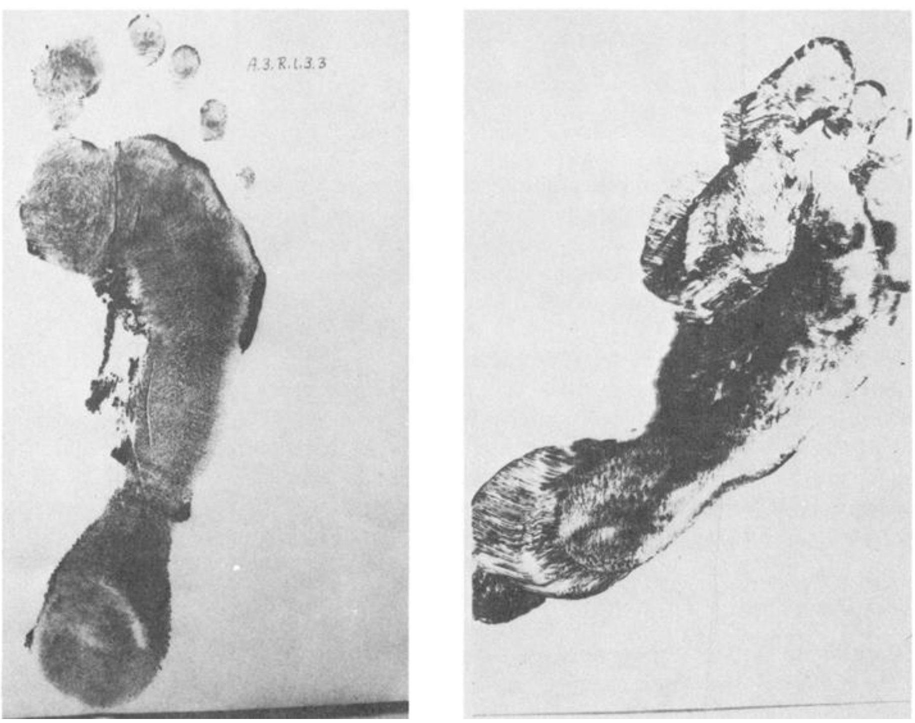

FIG. 6—(left) *Stationary footprint of adult male and* (right) *sliding footprint of the same person as he slipped and regained balance. Stability of morphological contours is visible in the big toe, ball, and arch (lightened area); lateral arch contour is exaggerated from the pressure of shifted body weight.*

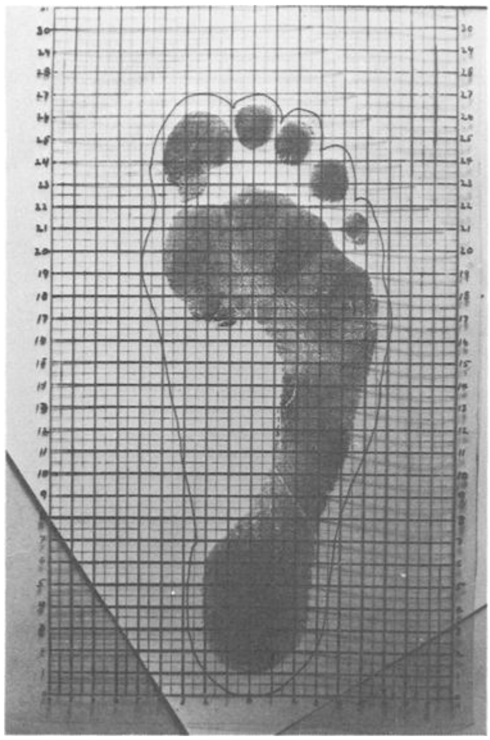

FIG. 7—*Foot outline of plantar footprint of adult male. Note that except for the medially posterior ball and medial arch areas, the outline is a 5- to 10-mm enlargement of the footprint.*

An intervening variable provides indirect information on the foot outline, the shoe print, and even the bare footprint (the plantar one). The wear pattern on the bottom of a sandal or shoe reflects the weight-bearing pressure areas of the foot. Thus, size and shape of the worn areas enable one to predict probable dimensional correlations between shoe print and foot outline and possible morphological correlations between shoe print and bare (plantar) footprint.

A knowledge of the human skeletal structure, body form, and ranges of human variation is imperative in assessing the probable age, sex, height, and weight of a person who made a footprint. The size and robustness of foot bones, such as the calcaneus and phalanges of the big toe, or particular parts of the bones, such as distal metatarsals and proximal fifth metatarsal, provide information on age (mature/immature) and sex. The total length of the bones (foot length) has a positive correlation with stature, and a positive correlation also is found between fully rounded morphological contours of the foot and body weight.

Conclusions

From the analysis of the footprints, definitive information on many physical characteristics of the individuals who made them was retrieved. The information on footprint (and foot) morphology is especially significant because it elucidates the individuality of each person's footprints. That the shape, or form, of an individual's foot is uniquely his or her own should come as no surprise to physical anthropologists. The combined effects of heredity and life experiences are operative in determining the size and shape of our feet; and for each of us, the manifestation of those effects is uniquely our own.

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