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Experience based reading of Pleistocene human footprints in Pech-Merle

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A B S T R A C T

Human footprints in the painted cave of Pech-Merle, France, have been investigated by archaeologists since the 1920s with state-of-the-art methods of the given time. Science always provided tool kits to analyse the information about individuals imprinted into the ground. However, the old human method of expert track reading has first been employed on these tracks in 2013 (as in some other caves with preserved human tracks from the Pleistocene). This special knowledge was deployed by three trackers from the Ju/'hoansi-San in Namibia who enriched our knowledge on the tracks in Pech-Merle in two significant ways: five individuals were identified, aged from 9–10 to over 50 years, from both sexes and some footprints were found that hitherto had been overlooked. It turned out that the features crucial for their interpretation are congruent with those of morpho-metric measurements but their experience based interpretation is more fine-grained than an interpretation based on the available statistics alone. Accordingly it seems justified to introduce the two methods as complementary tools for archaeology, i.e. the established morpho-metric approach flanked by morpho-classificatory track reading.

1. Introduction

Human hand- and footprints are the most personal, non-substance-based traces left by our Pleistocene ancestors. When there is good preservation, such an imprint in a plastic surface 'freezes' information about a short period of time in the life of a single person. No other findings in archaeology are so rich in information about a brief individual moment.

Prehistoric foot- and handprints are known from different continents and periods (Lockley et al., 2008; Pasda, 2013). Well known and among the most spectacular are footprints from early hominids in Laetoli and Koobi Fora in East Africa (Leakey and Harris, 1987; Raichlen et al., 2008), the early Pleistocene ones recently discovered at Happisburgh on the English east coast (Ashton et al., 2014) and the late Pleistocene footprints from Willandra, south-eastern Australia (Webb et al., 2006).

Even richer in number and no less fascinating are footprints left by late Pleistocene modern humans in decorated caves in South-western France (Vallois, 1931; Pales, 1976; Duday and García, 1985). Pech-Merle, as one of the most spectacular of these decorated caves, contains a small area with Pleistocene human footprints. They were studied repeatedly during the last century, eventually even by three professional trackers from the Ju/'hoansi-San from Tsumkwe (Namibia), Ciqae, Kxunta and Thao. Traditionally the Ju/'hoan lived as hunter–gatherers and much of the scientific knowledge on forager societies is based on research conducted in their home area (e.g. Lee and DeVore, 1976; Marshall, 1976). Each investigation of the tracks in Pech-Merle was accompanied by appropriate state-of-the-art documentation, including imaging technology with a structured light scanner in 2014.

This unique variety of recordings offers the possibility to plot the different approaches, the results obtained and documentations of

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different authors in order to synthesize a comprehensive result from the apparently separate analytical systems of morpho-metric studies and what we call the morpho-classificatory study (i.e. track reading based on lifelong learning and experiences (Pastoors et al., 2015)).

2. Material

On the long list of Palaeolithic masterpieces of decorated caves in the Midi-Pyrénées region, Pech-Merle is without doubt one of the most exceptional ones (see Fig. 1). The cave is situated at the confluence of the Sagne and Célé rivers at the foot of the Rochecourbe cliffs. It was discovered in 1922 by two young speleologists (A. David and H. Dutertre) accompanied by Reverend Amédée Lemozi from the adjacent community of Cabrerets. Lemozi published the first rock art drawings from Pech-Merle in 1929 (Lemozi, 1929). Since 1974 Michel Lorblanchet has been conducting intensive research in Pech-Merle. The cumulative results of his work were published in 2010 and give profound insight into, among other things, the technical process of producing rock paintings (Lorblanchet, 2010).

The cave is formed by 2 km of galleries on two different levels. The upper one reveals no archaeological findings. By contrast, the huge lower galleries house a rich body of rock art. The main halls are labelled 'l'Ossuaire', 'Salle Préhistorique', 'Galerie des Disques' and 'Galerie de l'Ours'. In the 'Galerie des Disques' Lemozi discovered a small surface of around 9 sqm with some human footprints roughly 100 m from the collapsed late Pleistocene entrance (Lemozi, 1929). Even if the old surface with the footprints has not been affected in modern times, its original state is concealed by a thin layer of calcite that has formed on it in the course of time. Nevertheless enough details of the imprints are still discernible to permit in-depth studies.

In Pech-Merle the prehistoric remains are considered to belong to three phases between 25 and 15 ka based on iconographic arguments. Only the single radiocarbon date of 29,447 ± 633 calBP (24,640 ± 390 BP – Gifa 95357; date calibrated with CalPal-2007$_{\mathrm{Hulu}}$: Weninger et al., 2009) obtained from charcoal in the black colour on one of the two famous spotted horses fits in this timeframe. Other existing dates are considered to be contaminated (Lorblanchet, 2010). In consequence, there is no certainty about the precise dating of the human footprints.

3. Methods

Existing documentation of the footprints in Pech-Merle is incomplete and outdated. In order to generate a state-of-the-art record, the entire surface was scanned with a structured light scanner (Aicon smart*SCAN*^{3D}). Considering that the footprints are covered with a thin layer of calcite and dust, the finest details of the footprints are masked. Therefore 1 mm per pixel seemed to be the appropriate resolution to generate a 3D model of the footprints and their surroundings. The advantage of this kind of documentation lies certainly in its relative objectivity; every point of the surface was recorded with the same intensity and metric precision. This allows comparative assessment of the existing documents and interpretations from morpho-metric as well as morpho-classificatory analyses (Pastoors et al., 2015).

In 2013 three professional trackers from the Ju/'hoansi-San from Tsumkwe (Namibia), Ciqae, Kxunta and Thao, inspected the original footprints in Pech-Merle and three other French decorated caves (Pastoors et al., 2015). Thus indigenous knowledge was a methodologically integrated part of archaeological data-gathering without the detour of ethnographic analogy or as mere validation of previously acquired results (Webb et al., 2006; Webb, 2007).

Integrating indigenous knowledge (IK) of tracking into the research procedure is not a matter of romanticism and it is not aimed at getting an exotic view on tracks from another world-view. Rather we seek alternative interpretation of data on the same empirical base that is available to everyone (Liebenberg, 1990; Lockley, 1999) (see Table 1). Indigenous knowledge of tracks is not based in different rationality, logic or causalities as may be the case with Traditional Ecological Knowledge (TEK) at least in part (Berkes, 2008, p. 8). Expert tracking, for hunting purposes in particular, aims to produce a narrative of a real incident that is irrevocably past on the basis of in-depth knowledge of the entire ecosystem acquired through thorough experience (Liebenberg, 1990). Tracking knowledge of hunter–gatherers has wide overlaps with the knowledge of western-trained zoologists or trophy hunters (Blurton Jones and Konner, 1976). The capabilities of hunter–gatherers in reading tracks are legendary throughout various types of literature (e.g. Marshall Thomas, 1988; Liebenberg, 1990; Biesele and Barclay, 2001); and were verified under western scientific test conditions (Stander et al., 1997; Wong et al., 2011). But despite the presence of prehistoric tracks on all continents

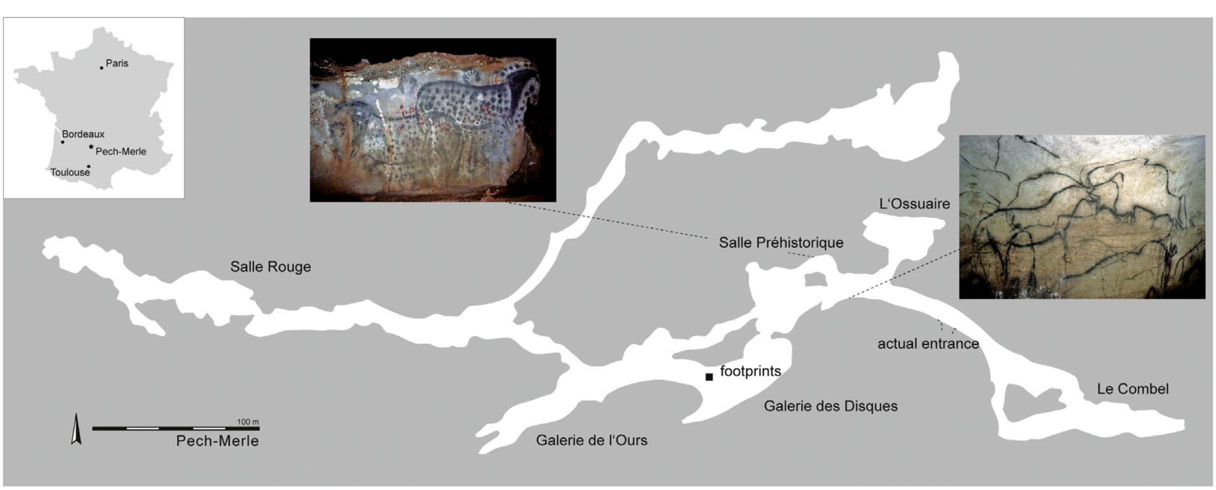

Fig. 1. Pech-Merle: topographical map of the cave with indication of the main localities – Photos Heinrich Wendel (The Wendel Collection, Neanderthal Museum).

(Lockley et al., 2008; Pasda, 2013) only very little, rather anecdotal use has been made of it in archaeological contexts (Webb et al., 2006; Franklin and Habgood, 2009).

Table 1
Methodological base: morpho-metric versus morpho-classificatory approach (*refers largely to animal spoor, but most can be transferred to human spoor as well; studies of Stander et al. (1997) and Wong et al. (2011) refer only to animal spoor).

	Morpho-metric approach (Western science)	Morpho-classificatory approach (San trackers)*
Epistemological method	induction	abduction (Liebenberg, 1990) hypothetico-deductive method
Knowledge from different sources	anatomy; statistics; prehistory; ethnography	anatomy; zoological details on behavior, seasonal changes, reproduction, diet and feeding habits – concerning the prey as well as 'contextual' animals; biosphere; geosphere; pedology; climate; memory of recent weather conditions; knowledge of place; absolute orientation
Acquisition of relevant knowledge	reception of empirical studies on adult male persons from South and Central Africa, Madagascar, South Asia, South Pacific Islands and Middle Europe (Vallois, 1931; Pales, 1976)	lifelong learning and practice of skills, using it in constant discourse with others
Detection depth	species; size; speed of movement; sometimes sex (Pales, 1976)	species; individual; age; sex; way and speed of movement; behavior; body posture; weight; handicap; age of spoor
Contextual frame	controlled, rigid	flexible
Preconditions for interpretation	controlled substrate matrix, requires optimum conditions (Vallois, 1931; Duday and García, 1983)	flexible, works also under adverse conditions
Data source	complete foot	partial footprint suffices
Body posture of subject	requires controlled upright posture and steady movement for analysis	irrelevant since anybody posture can be read from the spoor
Body height	foot length* 6.67 = body height (foot length = 15% of body height) (Vallois, 1931; Pales, 1976)	no statement except implications from age indication
Precondition for height estimates	compliance with empirical studies (see above)	–
Age estimates	rough categorization: child–adolescent–adult	narrowly approximated age in years
Sex indication	only in exceptional cases	definite
General reliability	no test studies	95% (Stander et al., 1997) 74% (Wong et al., 2011)

If the method of tracking is analysed epistemologically it is linked to the concept of abduction (after C.S. Peirce, cf. Liebenberg, 1990). Upon thorough study of the character of tracking, some authors have no doubt of its status as analogous to science or as its forerunner (Blurton Jones and Konner, 1976; Liebenberg, 1990; Chamberlin, 2002). Ciqae, Kxunta and Thao assert that decisions of trackers who hunt together and their interpretation of spoor are based on intense communication and consensus (see Blurton Jones and Konner, 1976; Liebenberg, 1990; Biesele and Barclay, 2001 for corroboration). Moreover, in hunter–gatherer societies, skills in tracking are not the exclusive knowledge of adult male hunters and they are not restricted to animal tracks but also include human spoor (cf. Marshall Thomas, 1988, p. 26; Biesele and Barclay, 2001, p. 79).

"*While species can be identified by characteristic features, there also exist individual variations within a species. These variations make it possible for an experienced tracker to determine the sex as well as an approximate estimation of the animal's age, size and mass. A tracker may also be able to identify a specific individual animal by its spoor.*" (Liebenberg, 1990, pp. 122–123)

In fact, the interpretations of human footprints by Ciqae, Kxunta and Thao are of an equally high precision as those noted by Liebenberg. This fact prompts questions as to which features of the footprints are significant for such detailed information. Liebenberg compiles different features which serve as a base for the determination of age and sex: size, depth, and way of movement, body structure and association with other footprints. Furthermore he noted that the exact shape of every individual is unique and therefore it is possible to identify individual animals and also humans.

Most features used by Ciqae, Kxunta and Thao show clear similarities with the landmark and measurement systems for human footprints used for morpho-metric analysis (see Fig. 2): foot length, ball-of-foot breadth and footprint angle (Mauch et al., 2008b), or Clark angle, ball width, heel width and instep width (Bennett and Morse, 2014, p. 33, Fig. 2.12).

The interpretations of Ciqae, Kxunta and Thao consist of a broad spectrum of details which cover different features: sex, age, foot position, gait, body posture, and pace. All are embraced by the individual subject determination, which is based on all aforementioned features but most importantly the shape of the forefoot and here especially the toes.

For sex determination all above listed measurements of the footprint are relevant (male > female), even the Clark angle (male > female) and the relation of heel width to instep width (male < female).

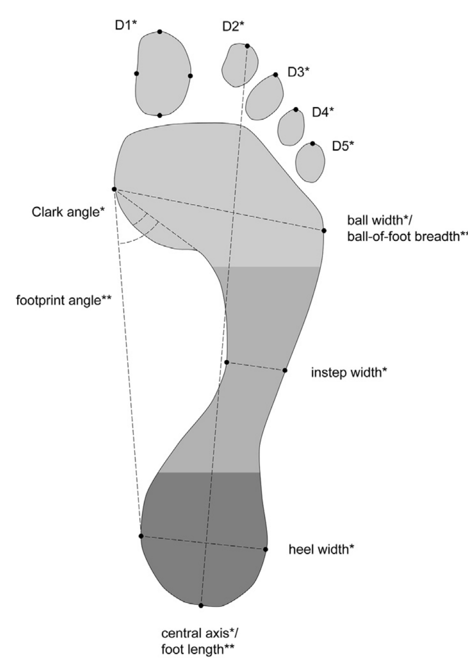

Fig. 2. Basic landmark and measurement systems for human footprints used for morpho-metric analysis according to Bennett and Morse* (2014, Fig. 2.12c and 12d) and Mauch et al.** (2008b, Table 2).

For the age estimation all features listed under sex determination are relevant, too. Furthermore the flexibility of the toes (young > old) and the presence of cracks in the skin (young < old) are taken into account in tracking.

Ciqae, Kxunta and Thao differentiate among five foot postures: parallel (!o), light outward twist (//xa//xa), developed outward twist (n!gwi), light inward twist (gaba), and developed inward twist (ton!gwi).

During the track-reading process all features undergo a holistic assessment and are reviewed against the contextual information. When a tracker gives an interpretation of a spoor there are several fields of basic information (sex, age, foot position, gait, body posture, and pace). But he does not describe or explain the discriminating attributes which he analysed. Yet this list of fields of basic information shows that a detailed inventory of distinctive features is being analysed by the trackers and this overlaps in large parts with the morpho-metric landmark and measurement systems (see above). Nevertheless the epistemological procedure cannot easily be determined in the same way as Liebenberg has done for the entire tracking process (Liebenberg, 1990, pp. 29–30) and as would be expected in a western scientific environment. In general two principal approaches exist in following a spoor, an inductive–deductive one which Liebenberg labels systematic tracking, and a hypothetico-deductive (or abductive) one, termed speculative tracking. To understand the concrete reading of a single imprint one needs a time-consuming process of interviews and practical exercises in order to develop and spell out the methodological *chaîne opératoire*. Further research is necessary to determine the epistemological characteristics of the methodology applied by Ciqae, Kxunta and Thao to each single imprint.

4. Results

The number of human footprints identified by previous researchers in Pech-Merle ranges from only four (Vallois, 1931) up to twelve (Duday and García, 1983). By discovering five hitherto unknown footprints Ciqae, Kxunta and Thao increased the number to 17, without being able to interpret all footprints (see Fig. 3). Unclear ones were not commented upon because in Ju/'hoan language the subjunctive does not exist, and precision in the determination of spoor is essential for hunter–gatherers. Consequentially such imprints were not integrated into the process of reading and interpretation.

In the Pech-Merle footprints the trackers saw five subjects walking barefoot. These are concentrated on the western part of the preserved area in the ‘Galerie des Disques’ (see Fig. 4 and Table 2).

The first subject (n°1) is a man of about 34–35 years old (adultus) who left a single right footprint at the eastern edge of the area. The movement points in a west-northerly direction. It has been recognized already by Lemozi (1929) and Duday and García (1983) without further descriptions.

In contrast subject n°2, a 25 year old young woman (adultus), is represented by two left footprints leading in a north-westerly direction. They are preserved at the eastern and northern part of the clayish area. Between the two left footprints the right one is missing due to the hard surface in this place. Ciqae, Kxunta and Thao interpret a slow pace which is proved by the short step size of around 42 cm (when reconstructing the missing right footprint in the middle of the two left footprints). While the footprint at the eastern edge (footprint n°2.1) was already documented and studied by Lemozi (1929) and Duday and García (1983), the corresponding second one (footprint n°2.2) in the northern part of the area has only now been discovered by Ciqae, Kxunta and Thao.

Based on the maximum length (Lmax = 199 mm) of the hitherto known footprint from subject n°2, Duday and García (1983; footprint n°4) reconstruct a body size of 1326 m. For them this footprint does not reflect the bio-mechanical schema of normal walking. “Le basculement du pied et la faiblesse de la phase propulsive trouvent leur explication la plus plausible dans le contact – sans doute douloureux – de la portion antérointerne de la voûte sur cet objet dur qui semble être un caillou ou un fragment de concrétion (?).” (Duday and García, 1983, p. 212)

Subject n°3 has left three footprints (right–left–right) in the eastern and central part of the preserved area. According to Ciqae, Kxunta and Thao they belong to a 9–10 years old boy (infans II) who was walking first in a westerly direction, turning later towards the west-north and accelerating the pace. The increasing step distance from 27 cm to 42 cm suggests this interpretation. The first footprint (footprint n°3.1) of this little series was already analysed by Lemozi (1929) and Duday and García (1983). Both saw it pointing towards the east. While the second footprint (footprint n°3.2) was only documented without further comments by Duday and García (1983), the third one (footprint n°3.3) was discovered by Ciqae, Kxunta and Thao in 2013.

Based on the maximum length (Lmax = 212 mm) of the first right footprint from subject n°3 Duday and García (1983; footprint n°2) reconstruct a body size of 1413 m. Duday and Garcia described the footprint as follows: “L'ensemble de la voûte est parfaitement marqué; la portion médio-plantaire s'inscrit même en double contour, témoin manifeste de la cambrure du pied. L'appui des orteils est par contre à peine perceptible: la première phalange de l'hallux s'est plus profondément imprimée que la pulpe. L'appui antérieur semble donc n'avoir été qu'esquissé.” (Duday and García, 1983, p. 212)

A man (subject n°4) with an age older than 50 years (maturus/senilis) crossed the area in a westerly direction. He left two footprints (left–right) in the eastern edge and in the central part. That his pace was fast is known by the step size of around 60 cm. While the left footprint (footprint n°4.1) was already analysed by Lemozi

Table 2
Comparison of different interpretations available for Pech-Merle footprints: (*) refers to Ciqae, Kxunta and Thao (Pastoors et al., 2015) and (**) refers to Duday and Garcia (Duday and García, 1983). (***) Added with the age estimation according to Anderson et al. (1956) and based on the measurements from Duday and García (1983).

Footprint*	Side	Direction	Age	Age-group	Sex	Footprint**	Lmax** (mm)	Body size** (m)	Age***
1.1	right	Galerie Préhistorique	34–35	adultus	male	9	–		
2.1	left	Galerie Préhistorique	25	adultus	female	4	199	1.3	7–9 boy/girl
2.2	left					–	–		
3.1	right	Galerie Préhistorique	9–10	infans II	male	2	212	1.4	8–10 boy/8–11 girl
3.2	left					–	–		
3.3	right					–	–		
4.1	left	Galerie Préhistorique	>50	matures/senilis	male	6	225	1.5	9–12 boy/girl
4.2	right					–	–		
5.1	right	Galerie de l'Ours	30	adultus	female	–	–		
5.2	left					11	239	1.6	11–14 boy/11–18 girl

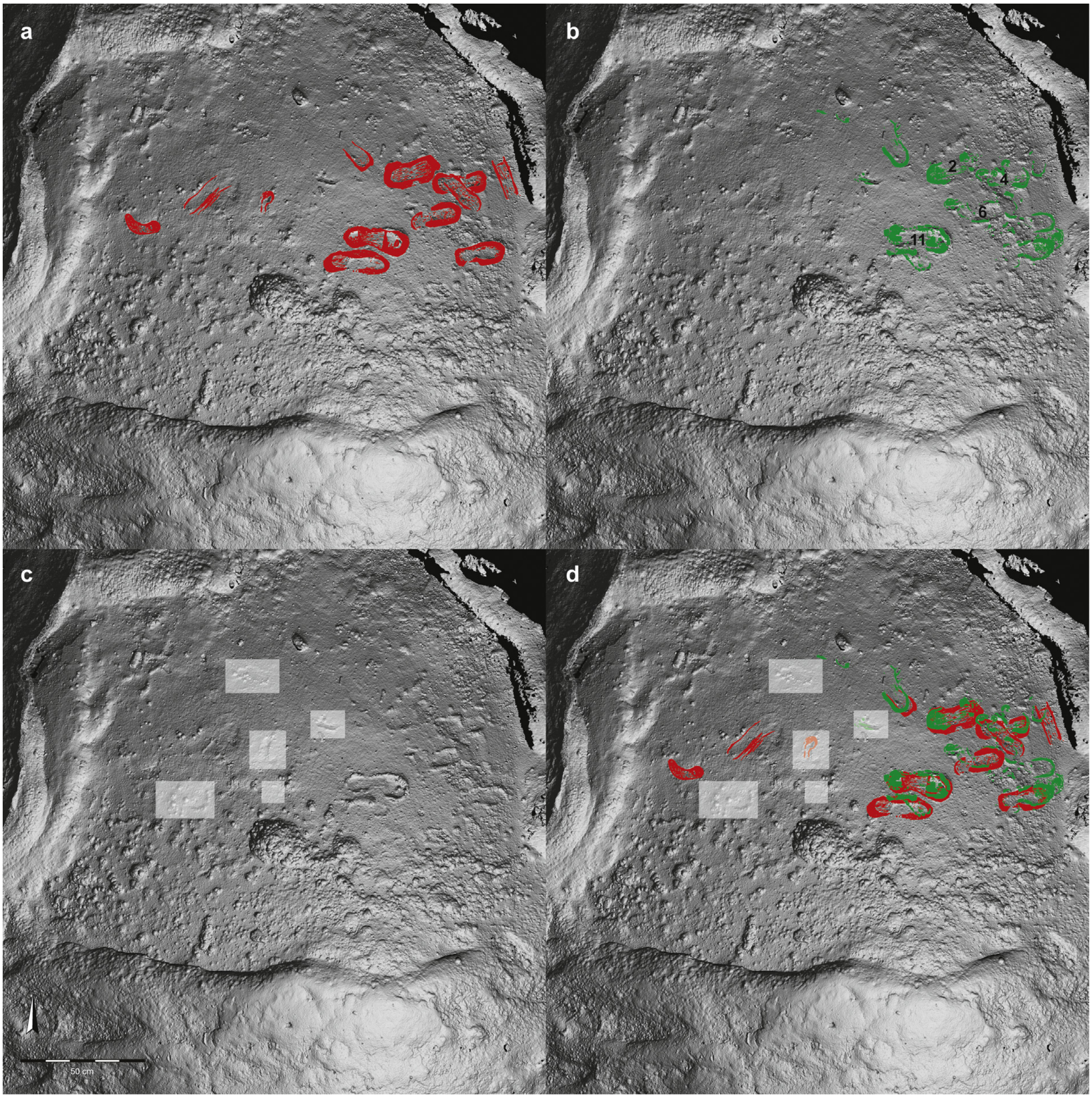

Fig. 3. Pech-Merle: history of documentation and discoveries: a) Lemozi, 1929, b) Duday and García, 1983, c) Pastoors et al., 2015, while rectangles indicate new discoveries, and d) compilation of all three investigations.

(1929) and Duday and García (1983), the corresponding right one (footprint n°4.2) was discovered by Ciqae, Kxunta and Thao.

Based on the maximum length (Lmax = 225 mm) of the left footprint from subject n°4, Duday and García (1983; footprint n°6) reconstruct a body size of 1.50 m. For Duday and García this footprint "est certainement la plus harmonieuse. Tous les reliefs plantaires y sont inscrits, et les bourrelets d'argile qui la cernent indiquent un déroulement normal." (Duday and García, 1983, pp. 211–212)

Subject n°5 has left certainly the most often cited prehistoric footprint. According to Ciqae, Kxunta and Thao it represents a 30 year old women (adultus) who has left two footprints (right–left) while walking in a fast pace over this area (step width around 83 cm). They are located in the central part, and her walking direction was east. Due to the relatively deep imprint, the trackers deduce that the woman was carrying additional load. The left footprint (footprint n°5.2) is the most visible one, it has been analysed by Lemozi (1929) and Duday and García (1983). The corresponding right one (footprint n°5.1) was hitherto unknown. It was discovered again by Ciqae, Kxunta and Thao in 2013.

Based on the maximum length (Lmax = 239 mm) of the left footprint from subject n°5 Duday and García (1983; footprint n°11) reconstruct a body size of 1593 m. Duday and García summarize that the foot "s'est enfoncé dans l'argile fluide qui a fusé tout autour, s'insinuant même entre les deux premiers orteils. [...] La prédominance du premier rayon dans la phase terminale de l'appui se trouve donc exagérée, et il est clair qu'il s'agit là d'une empreinte dynamique, très évocatrice d'un élan propulsé accentué, (pied d'appel d'un saut ?)." (Duday and García, 1983, p. 213)

In summary, Ciqae, Kxunta and Thao see in these footprints five individuals, ranging from age group (following Martin, 1928) infans II over adultus to maturus/senilis (see Table 2). Two men, two women and one boy crossed this area at a normal and fast pace. While the young boy (n°3) changed his direction of movement to

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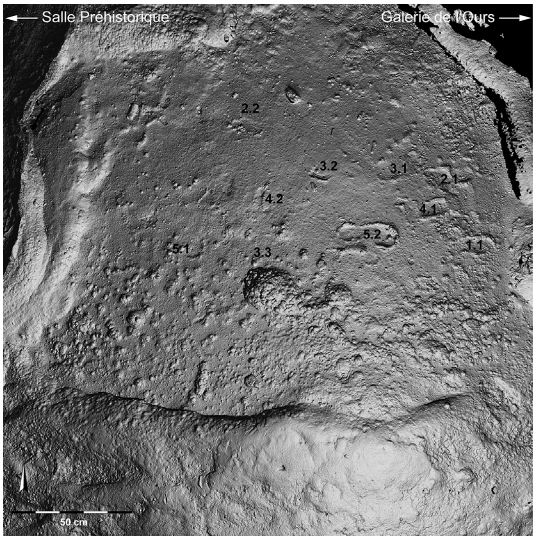

Fig. 4. Pech-Merle: distribution of footprints of five subjects.

the left, the 30 year old woman (n°5) was carrying an additional load. The footprints are concentrated in the eastern part of the preserved area; this is certainly due to the softness of the soil. Apart from subject n°5 all other movement directions are facing towards the west; subject n°5 was walking in an easterly direction.

The footprints are located in a shallow depression of the rocky surface in the ‘Galerie des Disques’, in which some mud accumulated. When approaching this area today from the actual artificial entrance and coming from the 'Salle Préhistorique', one has some space to move but after the muddy area the path narrows into an ascending balcony that has to be negotiated with prudence in order to avoid dropping down. The path to which the area with footprints belongs connects the ‘Salle Préhistorique’ with the back part of the ‘Galerie de l'Ours’. Coming from this back part of the ‘Galerie de l'Ours’, the ‘Galerie des Disques’ presents its extension on a lower level. The immediate prolongation of the natural path follows the wall on a sort of balcony and leads directly to the ‘Salle Préhistorique’. To reach the other parts of the ‘Galerie des Disques’, climbing was necessary. The area of footprints is so far in a crucial position: coming from the deeper part of the cave, facing to the ‘Salle Préhistorique’ with its rock art, after a long secure passage attention is necessary to reach the balcony safely. If however coming from the opposite direction, from the ‘Salle Préhistorique’, and moving beyond the area with tracks, less attention is needed as the ground gets safer. In the immediate surroundings of the tracks no other archaeological remains have been found. The next rock art is located in the narrow part of the ‘Galerie de l'Ours’ and in the ‘Salle Préhistorique’ (Ministère de la Culture, 1984, p. 467).

To conclude: the footprints of four subjects are faced towards the ‘Salle Préhistorique’, the footprints of only one subject are oriented in the opposite direction to the ‘Galerie de l'Ours’. Subject n°3, the 9–10 years old boy, changed the walking direction 45° to the left and accelerated the pace simultaneously. Due to this action, the young boy steers clear of the nearby profound abyss towards the safe cave wall.

5. Discussion

The non-destructive imaging technology used for a complete state-of-the-art documentation of the entire area containing human footprints in Pech-Merle improves our understanding of the entire configuration. For the first time a complete view of all footprints discovered during the last 90 years is available, and this view includes the immediate surroundings. With new image-processing technology the drawings at scale made by Lemozi (1929) and later Duday and García (1983) are brought together in a single document, along with the recent discoveries of Ciqae, Kxunta and Thao. It becomes obvious that new discoveries are concentrated in the western part of the area and it remains unclear why they were overlooked or ignored by the preceding researchers. Once pointed out by Ciqae, Kxunta and Thao, they were distinctly visible.

The interpretations of the trackers go far beyond the published ones: both Lemozi and Vallois saw two individuals only (Lemozi, 1929; Vallois, 1931). While Lemozi assumes a woman walking with an adolescent (her child), Vallois hypothesizes about an adult and a child without further precise base.

A closer look at the analysis of Duday and García (1983) reveals some progress compared to their predecessors since they provide details of singular footprints, but on the other hand they subsume all footprints as the result of one single person's activity. “Leurs différences portent essentiellement sur des dimensions longitudinales; mais nous avons montré qu'elles sont davantage dues à des incidents de la marche qu'à de véritables variations morphologiques. En définitive, nous pensons que toutes ces empreintes peuvent être rapportées à un seul et même individu.” (Duday and García, 1983, p. 214) Based on the well-formed footprint n°6 in their recording (footprint n°4.1), they reconstruct a shoe size (‘pointure parisienne’) of 33.5–34 and conclude. “Ces traces peuvent donc être attribuées à un grand enfant, un adolescent ou même, à l'extrême rigueur, à un adulte au pied particulièrement gracile.” (Duday and García, 1983, p. 214) This cautious interpretation contradicts partly the one given by Ciqae, Kxunta and Thao, who counted one infans II (subject n°3), three adulti (subjects n°1, n°2 and n°5) and one maturus/senilis (subject n°4).

In the recently published analysis of the hominids footprints from Happisburgh (Ashton et al., 2014), the authors used for age determination the study conducted by Anderson et al. (1956). They analysed the foot length of 512 male and female subjects of an age between 1 and 18 years, which have been measured for 5–12 consecutive years (Anderson et al., 1956). According to Anderson et al. (1956) and based on the measurements from Duday and García (1983) the footprints from Pech-Merle belong to a 7–9 year old boy or girl (subject n°2, footprint n°4), a 8–10 years old boy or a 8–11 years old girl (subject n°3, footprint n°2), a 9–12 years old boy or girl (subject n°4, footprint n°6), and a 11–14 years old boy or 11–18 years old girl (subject n°5, footprint n°11) (Table 2). Despite the possibility to interpret the variety of their data in such a disparity, Duday and Garcia attributed all footprints to one single person. It becomes obvious that age estimation based on measurements only is limited, because foot growth ends with an age of around 16 years (see Anderson et al., 1956). Therefore the extending investigations on other features which are preserved in footprints – as was realised by Ciqae, Kxunta and Thao – is more successful than the limited interpretation made possible by morpho-metric data.

The observation that most of the hand negatives, finger drawings and fingerprints in Pech-Merle belong to adulti is interesting, but it is impossible to link both phenomena with actual scientific methods, postulating that hand negatives and footprints belong to the same persons. Singular exceptions prove also the presence of younger subjects: these include finger drawings at the edge of the panel C of the ‘Plafond’, one little red hand negative near the ‘Femmes-bisons’, and the flexed finger negatives on the panel of the spotted horses (Lorblanchet, 2010, p. 177). The latter two representations are interpreted by Lorblanchet as female fingers.

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Finally the interpretations of Ciqae, Kxunta and Thao support the rejection of the first published reading by Lemozi, who was certainly influenced by the general interpretation of cave art as embedded in ceremonial activities: “Cet ensemble d'éléments fait penser à une femme, artiste ou prêtresse, venue là peut-être pour quelque cérémonie et accompagnée de son enfant. Celui-ci, peut-être un jeune initié, tournait timidement autour d'elle dans tous les sens, sans s'écarter de plus de cinquante centimètres.” (Lemozi, 1929, p. 154)

In view of the fact that the area with the footprints is but a random excerpt of one of the natural travel routes inside the cave, the readings of Ciqae, Kxunta and Thao would seem to be most ‘down to earth’. Not only do they see people walking along in a pace adapted to the surroundings – including a young boy who seemingly preferred the safer nearness to the cave wall when stepping onto the slanting balcony – but they also see that these people just passed by once. This stands in contrast to Duday and Garcia – notwithstanding that they refrain from insinuating any ritual activity – according to whom a single person would have had to either step to and from on this spot in an erratic manner, or the person would have had to return more than once to this spot from one side.

6. Conclusions

It turns out that Pech-Merle is an ideal case study to plot morpho-metric and morpho-classificatory approaches against each other in order to discuss and to synthesize the obtained results. It can thus be demonstrated that both approaches make use of comparable features like foot length, ball-of-foot breadth and footprint angle (Mauch et al., 2008b), or Clark angle, ball width, heel width and instep width (Bennett and Morse, 2014, p. 33, Fig. 2.12). The pivotal difference between morpho-metric and morpho-classificatory approaches is the *chaîne opératoire*. Whereas morpho-metric analysis uses for all determinations every single footprint as a closed set of data, morpho-classificatory analyses summarize morphological information on every single footprint together with its contextual associations. The morpho-classificatory approach integrates all available information mirroring human behaviour. Related footprints are ascribed to a particular subject, which only thus reveal details of behaviour like the gait, step width and pace of movement as important additional information to age and sex determination. The reading process starts with the identification of subjects, which subsequently are studied in detail. Unclear footprints are recognized but not included in the final interpretation. Taking all readable footprints into account and integrating them into a holistic picture enables the trackers to summarize the story of the area of footprints.

In view of this wealth of information the restricted data of morpho-metric analyses allow only a reduced depth of interpretation and does not fully exploit the information potential of the human footprints. Taking into account only the maximum length of a footprint, as was done in Pech-Merle in the works of Lemozi, Vallois, Duday and Garcia in their exemplary application of the morpho-metric method, inevitably results in an interpretation that cannot go beyond a certain basic level of an extrapolated stature and a rough age determination. For Duday and García (1983) the morpho-metric analysis results in subsuming all footprints into the product of one single human's activity. A problematic muddy substrate and fragmented preservation introduce further fuzziness.

At other sites with Pleistocene footprints, like Happisburgh, Niaux and Tuc d'Audoubert, research is conducted in a comparable way, i.e. it is founded on the measurement techniques available (Vallois, 1928, 1931; Pales, 1976; Ashton et al., 2014).

The morpho-metric approach should use the results of the morpho-classificatory approach to sharpen its method, thus broadening the catalogues of features to be included in data capturing. The reading of footprints results from the shared knowledge of the observers and cannot completely be captured by metric analysis. Therefore and for the time being, the morpho-classificatory approach is able to produce a broader spectrum of information about human behaviour based on footprints than the morpho-metric method.

This problem was already mentioned by Martin (1928) in his general description of anthropological research. According to him measurements were taken to highlight fine differences, which neither human eye can detect nor our language is able to describe. As the derived statistics is important for anthropological research, it is not advisable “blindlings darauflos zu messen, eine Unsumme von Messungen auszuführen und ebenso viele Zahlenwerte anzusammeln, die nicht imstande sind, morphologische Vorstellungen zu vermitteln. […] Jedes Maß hat einer bestimmten Fragestellung zu genügen und muß für sich allein oder in Beziehung zu anderen Maßen ein wichtiges körperliches Merkmal oder Verhältnis möglichst genau zum Ausdruck bringen. (…to keep on measuring blindly, execute an abundance of measurements and accumulate an equal mass of figures that are incapable of invoking a morphological notion. […] Every measurement has to comply with a specific question and by itself or in relation to other measurements it has to express a significant bodily feature or proportion.) (Translation by TLE)” (Martin, 1928, pp. 62–63).

Bibliographic research regarding the years 2009–2013 counts 2083 articles published in four highly cited journals worldwide (Journal of Foot and Ankle Research, Foot & Ankle International, Journal of Foot & Ankle Surgery and Foot and Ankle Clinics) (Luo et al., 2015) and evinces a wide field of research around foot anatomy and morphology. They cover a wide spectrum of different topics relevant for shoe production, medicinal and forensic research: age estimation (Hackman et al., 2013), sexual dimorphism and sex determination (Fessler et al., 2005; Atamturk, 2010; Krauss et al., 2011a, 2011b; Kautilya et al., 2013; Kanchan et al., 2014; Keme Ebimobo et al., 2014; Rahman et al., 2014), body size estimation (Mohanty et al., 2012), and uniqueness (see Bennett and Morse, 2014, pp. 180ff) as well as anthropological basics (growth of foot) (Davenport, 1932; Meredith, 1944; Anderson et al., 1956; Mauch et al., 2008a). The cited studies evince the variability of interpretations and reflect the high informational potential of human feet and footprints. Consensus exists about sexual dimorphism at the arch, the lateral side of the foot, the first toe and the ball of the foot. Males have longer and broader feet than females for a given stature (Wunderlich and Cavanagh, 2001), while females tend to have a narrower heel in relation to the forefoot and have narrower feet than males in general relative to length (Frey, 2000). These facts in turn underline the validity and relevance of the interpretation made by Ciqae, Kxunta and Thao in their morpho-classificatory approach which addresses exactly these relations and measures in a footprint.

The study of human footprints in Pech-Merle cave presented here has to be seen as a further step towards the understanding of differences and overlaps of morpho-metric and morpho-classificatory approaches. Both imply unique analytical means which, if combined, may enrich the reading of human footprints. Future research should focus on sharpening morpho-metric approaches as well as determining the epistemological procedure of the morpho-classificatory tracking approach.

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References

Anderson, M., Blais, M., Green, W.T., 1956. Growth of the normal foot during childhood and adolescence: length of the foot and interrelations of foot, stature, and lower extremity as seen in serial records of children between 1–18 years of age. American Journal of Physical Anthropology 14, 287–308.
Ashton, N., Lewis, S.G., Groote, I.d., Duffy, S.M., Bates, M., Bates, R., Hoare, P., Lewis, M., Parfitt, S.A., Peglar, S., Williams, C., Stringer, C.B., 2014. Hominin footprints from early Pleistocene deposits at Happisburgh, UK. PLoS One 9 (2).
Atamturk, D., 2010. Estimation of sex from the dimension of foot, footprints, and shoe. Anthropologischer Anzeiger 68, 21–29.
Bennett, M.R., Morse, S.A., 2014. Human Footprints: Fossilised Locomotion? Springer International Publishing, Cham, s.l.
Berkes, F., 2008. Sacred Ecology: Traditional Ecological Knowledge and Resource Management. Routledge, New York.
Biesele, M., Barclay, S., 2001. Ju/'hoan Women's tracking knowledge and its contribution to their husbands' hunting success. African Study Monographs (Suppl. 26), 67–84.
Blurton Jones, N., Konner, M.J., 1976. !Kung knowledge of animal behavior: or: the proper study of mankind is animals. In: Lee, R.B., DeVore, I. (Eds.), Kalahari Hunter-Gathreers. Harvard University Press, Cambridge, Mass, pp. 325–348.
Chamberlin, J.E., 2002. Hunting, tracking and reading. In: Brockmeier, J., Wang, M., Olson, D.R. (Eds.), Literacy, Narrative and Culture. Curzon, Richmond, Surrey, pp. 67–85.
Davenport, C.B., 1932. The growth of the human foot. American Journal of Physical Anthropology 17, 167–211.
Duday, H., García, M.A., 1983. Les empreintes de l'Homme préhistorique. La grotte du Pech-Merle à Cabrerets (Lot): une relecture significative des traces de pieds humains. Bulletin de la Société Préhistorique Française 80, 208–215.
Duday, H., García, M.A., 1985. L'homme et la caverne. Histoire et Archéologie 90, 35–39.
Fessler, D.M., Haley, K.J., Lal, R.D., 2005. Sexual dimorphism in foot lenght proportionate to stature. Annals of Human Biology 32, 44–59.
Franklin, N.R., Habgood, P.J., 2009. Finger markings and the Willandra Lakes footprint site, South-Eastern Australia. Rock Art Research 26 (2), 199–203.
Frey, C., 2000. Foot health and shoe wear for women. Clinical Orthopaedics 372, 32–44.
Hackman, L., Davies, C.M., Black, S., 2013. Age estimation using foot radiographs from a modern Scottish population. Journal of Forensic Sciences 58, 146–150.
Kanchan, T., Krishan, K., Prusty, D., Mechado, M., 2014. Heel–Ball index: an analysis of footprint dimensions for determination of sex. Egyptian Journal of Forensic Sciences 4, 29–33.
Kautilya, V., Bodkha, P., Poothanathan, P., 2013. Determination of stature and sex from anthropometry of the foot among south Indians. International Journal of Review in Life Sciences 3, 22–26.
Keme Ebimobo, T., Mukoro Duke, G., Vitalis, E., Baxter-Grillo, D., 2014. Sexual dimorphism of correlations of feet anthropometric parameters and height (stature) among undergraduate students of a university, western Nigeria. Journal of Dental and Medical Sciences 13, 46–53.
Krauss, I., Grau, S., Mauch, M., Maiwald, C., Horstmann, T., 2011a. Sex-related differences in foot shape. Ergonomics 51, 1693–1709.
Krauss, I., Langbein, C., Horstmann, T., Grau, S., 2011b. Sex-related differences in foot shape of adult Caucasians – a follow-up study focusing on long and short feet. Ergonomics 54, 294–300.
Leakey, M.D., Harris, J.M. (Eds.), 1987. Laetoli: a Pliocene Site in Northern Tanzania. Clarendon, Oxford.
Lee, R.B., DeVore, I. (Eds.), 1976. Kalahari Hunter-Gatherers. Harvard University Press, Cambridge, Mass.
Lemozi, A., 1929. La grotte-temple du Pech-Merle: Un nouveau sanctuarie préhistorique. Picard, Paris.
Liebenberg, L.W., 1990. The Art of Tracking: the Origin of Science. David Philip, Cape Town.
Lockley, M., 1999. The eternal trail: a tracker looks at evolution. Perseus Books, Reading, Mass.
Lockley, M., Roberts, G., Yul Kim, J., 2008. In the footprints of our ancestors: an overview of the hominid track record. Ichnos 15, 106–125.
Lorblanchet, M., 2010. Art pariétal: Grottes ornées du Quercy. Éditions du Rouergue, Rodez.
Luo, X., Liang, Z., Gong, F., Bao, H., Huang, L., Jia, Zhiwei, 2015. Worldwide productivity in the field of foot and ankle research from 2009–2013: a bibliometric analysis of highly cited journals. Journal of Foot and Ankle Research 8, 1–6.
Marshall, L., 1976. The !Kung of Nyae Nyae. Harvard University Press, Cambridge.
Marshall Thomas, E., 1988. The Harmless People. David Philip Publishers, Cape Town.
Martin, R., 1928. Lehrbuch der Anthropologie: in systematischer Darstellung mit besonderer Berücksichtigung der anthropologischen Methoden, second ed. Fischer, Jena.
Mauch, M., Grau, S., Krauss, I., Maiwald, C., Horstmann, T., 2008a. Foot morphology of normal, underweight and overweight children. International Journal of Obesity 32, 1068–1075.
Mauch, M., Mickle, K.J., Munro, B.J., Dowling, A.M., Grau, S., Steele, J.R., 2008b. Do the feet of German and Australian children differ in structure? Implications for children's shoe design. Ergonomics 51, 527–539.
Meredith, H.V., 1944. Human foot length from embryo to adult. Human Biology 16, 207–282.
Ministère de la Culture (Ed.), 1984. L'art des cavernes: Atlas des grottes ornées paléolithiques francaises. Imprimerie national, Paris.
Mohanty, B.B., Agrawal, D., Mishra, K., Samantsinghar, P., Chinara, P.K., 2012. Estimation of height of an individual from foot length: a study on the population of Odisha. International Journal of Review in Life Sciences 2, 69–74.
Pales, L., 1976. Les empreintes de pieds humains dans les cavernes: Les empreintes du résau nord de la caverne de Niaux (Ariège). In: Archives de l'Institut de Paléontologie Humaine, vol. 36. Masson, Paris.
Pasda, C., 2013. Zu Fuss – Spurenfossilien des eiszeitlichen Menschen. In: Pastoors, A., Auffermann, B. (Eds.), Pleistocene Foragers: Their Culture and Environment. Festschrift in Honour of Gerd-Christian Weniger for His Sixtieth Birthday, Wissenschaftliche Schriften des Neanderthal Museums, vol. 6. Neanderthal Museum, Mettmann, pp. 51–70.
Pastoors, A., Lenssen-Erz, T., Ciqae, T., Kxunta, U., Thao, T., Bégouën, R., Biesele, M., Clottes, J., 2015. Tracking in Caves: experience based reading of Pleistocene human footprints in French caves. Cambridge Archaeological Journal. http://dx.doi.org/10.1017/S0959774315000050. Available on CJO2015.
Rahman, M.A., Mahajan, A.A., Shroff, A.G., 2014. Sexual dimorphism in foot print ratio. Journal of Dental and Medical Sciences 13, 1–4.
Raichlen, D.A., Pontzer, H., Sockol, M.D., 2008. The Laetoli footprints and early hominin locomotor kinematics. Journal of Human Evolution 54, 112–117.
Stander, P.E., Ghau, //., Tsisaba, D., #Oma, //., /Ui, /., 1997. Tracking and the interpretation of spoor: a scientifically sound method in ecology. Journal of Zoology 242, 329–341.
Vallois, H.V., 1928. Etude des empreintes des pieds humains du Tuc d'Audoubert, de Cabrerets et de Ganties. In: Congrès International d'Anthropologie et d'Archéologie Préhistorique III, pp. 328–335. Amsterdam.
Vallois, H.V., 1931. Les empreintes de pieds humains des grottes préhistoriques du Midi de la France. Palaeobiologica 4, 79–98.
Webb, S., 2007. Further research of the Willandra Lake fossil footprint site, southeastern Australia. Journal of Human Evolution 52, 711–715.
Webb, S., Cupper, M.L., Robins, R., 2006. Pleistocene human footprints from the Willandra Lakes, southeastern Australia. Journal of Human Evolution 50 (4), 405–413.
Weninger, B., Jöris, O., 2008. A ^{14}C age calibration curve for the last 60 ka: the Greenland-Hulu U/Th timescale and its impact on understanding the Middle to Upper Paleolithic transition in Western Eurasia. Journal of Human Evolution 55, 772–781.
Weninger, B., Joris, O., Danzeglocke, U., 2009. CalPal-2007. Cologne Radiocarbon Calibration & Palaeoclimate Research Package, calpal.de, using CalPal-2007Hulu calibration data set published in Weninger and Jöris (2008).
Wong, P.B.Y., de Van Coeverden Groot, P., Fekken, C., Smith, H., Pages, M., Boag, P.T., 2011. Interpretation of Polar Bear (*Ursus maritimus*) tracks by Inuit Hunters: inter-rater reliability and inferences concerning accuracy. The Canadian Field-Naturalist 125, 140–153.
Wunderlich, R.E., Cavanagh, P.R., 2001. Gender differences in adult foot shape: implications for shoe design. Medicine & Science in Sports & Exercise 33, 605–611.