12. RECONSTRUCTING THE MANUAL ACTIVITIES OF A FULLY DOCUMENTED INDIVIDUAL OF ADVANCED AGE

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ABSTRACT

Reconstructing habitual physical activities in the past constitutes a fundamental objective of anthropological sciences. The morphology of muscle attachment sites (entheses) is widely utilized for this purpose, but their reliability has been previously questioned due to important methodological downsides of traditional methodological approaches. Recently, one of us (the first author) has put forth a novel methodology relying on the multivariate analysis of precisely obtained three-dimensional measurements. The accuracy of this method in reconstructing activity using hand entheses was demonstrated using a mid-19th century sample with uniquely detailed long-term occupational documentation (Basel Collection, Basel, Switzerland). Nevertheless, all individuals used in our previous research were relatively young (below 48 years old or less), while the extensive effects of old age on entheseal morphology are widely demonstrated in the literature. Consequently, the applicability of entheseal methods on individuals whose age is either advanced or uncertain is currently questionable. This pilot case study focuses on an old individual originating from the same population (STJ-1734) as our comparative sample from Basel, in order to evaluate the efficiency of our method for old individuals. Even though the resulting entheseal patterns were in agreement with the individual's lifestyle, they also seemed influenced by the presence of arthritic lesions in the thumb's metacarpophalangeal joint. The results of this pilot case-study suggest that the activities

of an old individual can potentially be accurately reconstructed using our novel 3D methodology. Nevertheless, researchers should always take into consideration that the resulting patterns may be biased by pathological conditions which may also not always be traceable on skeletal remains.

12.1 INTRODUCTION

One of the major objectives of anthropological sciences involves the reconstruction of physical activity in past human societies and/or species (Foster et al., 2012; Wilczak et al., 2016). One of the main bone traits used for this purpose are entheses, the areas of the bones where muscles attach (Foster et al., 2012; Karakostis et). Nevertheless, past approaches for analyzing entheses present severe methodological downsides and limitations (Wilczak et al., 2016; Henderson et al., 2017; see detailed Discussion in Karakostis et al., 2014; 2018a; 2018b), while some studies have openly questioned the usefulness of entheses as indicators of occupational stress. For this purpose, one of us (FAK) has developed a new method for analyzing entheses relying on the morphometric analysis of high-definition three-dimensional (3D) models, precise measuring protocols, and multivariate statistical analyses (Karakostis and Lorenzo, 2016). This is the first entheseal method for reconstructing physical activity that has been validated based on controlled experimental research on different laboratory animals, following blind analytical procedures (Karakostis et al., 2019a; 2019b). Based on this new method combined with a reference skeletal series curated at the Natural History Museum of Basel comprising specimens from the mid-19th century with unique lifelong occupational documentation (Hotz et al., 2012; see also Karakostis et al., 2017; Karakostis and Hotz, 2023), we identified a clear association between hand entheseal multivariate patterns reflecting habitual grasping performance (i.e., power versus precision grasping) and the nature of long-term occupational activity (Karakostis et al., 2017). The same method was subsequently used on a case study of a famous unidentified individual from Basel, “Theo the Pipesmoker”, for which it provided new information that helped on the reconstruction of its identity (Hotz et al., 2017).

In these previous studies, one of the main criteria used to select individuals for the analysis was the condition of being less than 50 years old. This is because biological age comprises a fundamental factor of variation in entheses, with its effects maximizing after the age of 50 to 60 years (e.g., Milella et al., 2012). Particularly, entheseal size and robusticity changes with old age, probably as a consequence of degeneration in combination with lifelong accumulation of stress (see Milella et al., 2012; Noldner and Edgar, 2013; see also Karakostis et al., 2017; 2018a). In fact, age is known to affect all structures and mechanisms surrounding entheseal development, such as bone remodeling, muscle architecture, or even the levels of physical activity typically expected in individuals of an old age (Maimoun and Sultan, 2011). The effect of age on entheseal robusticity was also confirmed by the results of our studies on different populations (Karakostis and Lorenzo, 2016; Karakostis et al., 2017; Karakostis and Hotz, 2023), which demonstrated how the size of hand entheses was strongly and positively correlated with age. By contrast, multivariate patterns of entheses explaining differences in long-term occupational activity was not correlated with biological age (between 18 and 48 years of age).

The fact that old age affects occupational stress markers (including entheses) has led to the inability of anthropologists to investigate physical activity in old individuals. Importantly, biological age is often not diagnosable either due to low preservation of specific important elements of the pelvis or simply because the bones in question represent extinct species whose biology can only be speculated. In these cases, the uncertainty of this individual’s age prevents any accurate assessment of its physical activities. In this framework, developing methods of entheseal analysis which are not affected by age would be extremely beneficial for reconstructing the occupational profile of unidentified skeletal remains. This pilot study aims at addressing this issue by applying our novel methodological approach (Karakostis et al., 2016; 2017; 2018a) on a case study of an individual of 68 years 7 month and 25 days old along with 45 other thoroughly documented individuals from the same geo-chronological context (for more information, see Materials and Methods below). This individual also belongs to the well-known reference collection of Basel-Spitalfriehof. Given that our method seems to control for factors of interindividual variability including age (Karakostis et al., 2017, Karakostis and Hotz, 2023), we hypothesize that the hand bones of this individual will present a distinctive power or precision grasping entheseal pattern. Theoretically, this pattern will be consistent with the fact that the occupational activities of this individual did not involve heavy manual work over multiple years before death.

12.2 MATERIALS AND METHODS

Our previous research focused on 45 adult males from the mid-19th century, belonging also to the Basel-Spitalfriedhof collection (Karakostis et al., 2017). These specimens were selected based on the high preservation status of their hand bones, lack of medical pathologies affecting their hand movement (based on official medical records), absence of direct relatedness in the sample, same sex (males), relatively young age (less than 50 years old), similar socioeconomic status, and similar population of origin. Individuals whose long-term activities involved heavy manual labor presented an entheseal pattern reflecting power-grasping (involving muscles of the thumb and the fifth finger). By contrast, individuals with lifelong occupations of lower intensity showed a precision-grasping pattern of entheses (involving the thumb and the index finger). Our statistical analyses showed that these patterns were not significantly correlated with age (until 48 years old), estimated body height, weight, or bone length (Karakostis et al., 2017). Even though only bones of the right anatomical side were initially used (Karakostis et al., 2017) we thoroughly demonstrated that bilateral asymmetry does not considerably affect these results in a more recently published study (Karakostis et al., 2018a).

This study will use the same comparative sample of 45 male specimens for assessing the entheseal patterns of individual “STJ-1734”, or –during his lifetime- Mr. Balthasar Fischer (Figs. 1 and 2), who belongs to the same popu-lation group (mid-19th century Basel).

The town archives of the city of Basel have provided highly detailed information on the life history of the individual under study (Hotz et al., 2012; see also Karakostis et al., 2017, Karakostis and Hotz, 2023). The skeleton STJ-1734 belongs to Mr. Balthasar Fischer, originating from the city of Basel, who lived between the years 1785 and 1854 (i.e., 68 years 7 months and 24 days old), mostly within the urban premises of Basel (Switzerland). His cause of death was dropsy (Hydrops universalis). His main occupation in life involved the trading of flour, without active participation in physically demanding tasks surrounding the production and mass transportation of the material. On the 11th February of 1847, his spouse Mrs. Ursula Muggli-Fischer died at the old age of 67 years 10 months and 3 days. Almost two years later, on the 6th October 1848, Balthasar Fischer entered the retiring residence of the Citizen Hospital.

Mr. Fischer spent the last six years of his life in that establishment as a pensioner of the 1st degree (i.e., with a relatively high income), who could afford a relatively expensive accommodation at the citizen hospital (Bürgerspital), in Basel. Therefore, his final lifestyle was not physically demanding for several years before death. Nevertheless, he is also reported to have spent part of his young adult life as a soldier in Naples, but his bones do not show any sign of endured trauma. Based on the archived information on this individual’s long-term occupational profile as well as his lifestyle before death, we hypothesize that its hand entheseal pattern will not reflect habitual power grasping and will more closely align with the hand morphology of individ-

Figure 1: Skeleton of Mr. Balthasar Fischer, who died in April, 25th, and was buried April 27th 1854 in the grave 708 of the cemetery of the Citizen Hospital (Photography by courtesy of the "Archäologischen Bodenforschung Basel-Stadt").

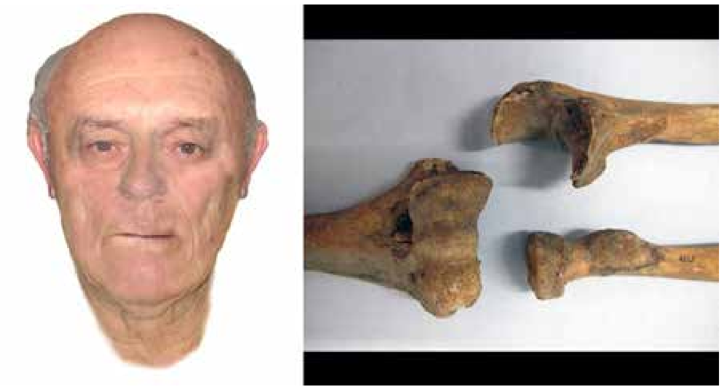

Figure 2: Left side: Facial reconstruction of Mr. Balthasar Fischer at the age of 67 years (courtesy of Pierre Ingold). Right side: Manifestation of arthrosis in the elbow joint including slight signs of eburnation.

uals with lifelong activities involving lower physical intensity and/or semi-mechanized tasks.

In accordance with the methodology established in our previous research (Karakostis and Lorenzo, 2016; Karakostis et al., 2017; 2018a; Hotz et al., 2017), we focused on nine muscle attachments located on six particular hand bones (all three thumb bones, index proximal phalanx, fifth metacarpal, and fifth proximal phalanx) (Table 1). These entheses correspond to eleven manual muscles. The exact location of these areas has been both described and depicted in different previous publications (Karakostis and Hotz, 2023; Karakostis and Lorenzo, 2016; Karakostis et al., 2017; 2018a; Hotz et al., 2012). Given that previous research on the same sample showed consistent results between the left and the right anatomical side (Karakostis et al., 2018a), we focused on the right-hand bones due to their better preservation. In the skeleton of Mr. Balthasar Fischer, all six right hand bone elements and nine entheseal areas were preserved. However, it should be emphasized that the proximal articular surface of the pollical proximal phalanx (metacarpophalangeal joint) presents large exostoses along the margins of the articular surface (Fig. 3). These traits, in combination with slight eburnation on the articular surface of the first proximal phalanx, might be related to the occurrence of monarticular osteoarthritis (Byers, 2011). Alternatively, it could be related to a reaction of the bone to intense joint injury (Byers, 2011). It should be mentioned that the same individual presented osteoarthritis also in his corresponding elbow joint, whose use is fundamental in most manual activities involving elbow flexion or extension (Fig. 2). Given that the exostoses are not located directly on the muscle attachments of the pollical proximal phalanx (Fig. 3), the latter will be included in our entheseal analysis. Nevertheless, our interpretations will take these pathological manifestations of the hand into con-sideration (see Discussion).

Based on our established methodology (Karakostis and Lorenzo, 2016; Karakostis et al., 2017), the surfaces of these bones were 3D scanned using a Breuckmann Smartscan scanner (Hexagon Inc., Baden, Germany) with 125 mm FOV, an automatic turntable, and the accompanying Optocat software package (Hexagon Inc.). This scan-

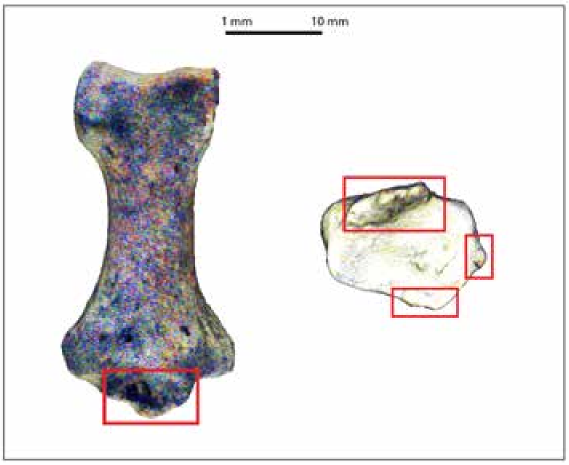

Figure 3: Palmar (left) and proximal (right) views of the right thumb proximal phalanx. The red rectangles indicate the presence of pathological exostoses. In the depicted 3D models, the color histogram was equalized to fit all possible colors (see Karakostis et al., 2017).

ner uses structured-light technology providing a measuring accuracy of nine microns. For each hand bone element, 20 scans were taken from different angles along an arc of 360 degrees. These scans were aligned and merged into 3D models. In accordance with a methodology developed by one of us (FAK; Karakostis and Lorenzo, 2016; Karakostis, 2023), which was recently named the Validated Entheses-based Reconstruction of Activity (V.E.R.A.) method (Karakostis and Harvati, 2021), we focused on nine muscle attachment sites. Entheseal areas were delineated and their 3D areas were measured in square mm, using the Meshlab software package version 1.3.3 (CNR-INC, Rome, Italy). Subsequently, these measurements were size adjusted using the geometric mean (Karakostis et al., 2017; 2018a) and subjected to principal component analysis (PCA) based on a correlation matrix (Field, 2013), using the software package IBM SPSS (IBM Inc., Armonk, NY; version 24 for Windows). The PCs plotted were those with eigenvalues values over 1 (Field, 2013). The PCAs did not rely on prior occupational group classification and they were categorized (i.e., colored) a posteriori following Karakostis et al. (2017) and based on the detailed archived information on the nature of their lifelong occupational activities.

12.3 RESULTS

The descriptive statistics for the comparative sample used are already thoroughly reported in previous work (Karakostis et al., 2017) both for raw and size-adjusted variables. Moreover, Karakostis et al. (2017) have demonstrated that all statistical assumptions for PCA are met for this sample.

MUSCLES	MAIN ACTION	ENTHESIS STUDIED
Abductor pollicis	Abducts the thumb	Radial base of the first proximal phalanx
Flexor pollicis brevis	Flexes the first metacarpophalangeal joint	Radial base of the first proximal phalanx
Adductor pollicis	Adducts the thumb	Ulnar base of the first proximal phalanx
First dorsal interosseous	Abducts the second finger	Radial base of the second proximal phalanx
First palmar interosseous	Draws second finger towards the 3rd finger	Ulnar base of the second proximal phalanx
Oponnens pollicis	Abducts, rotates, and flexes the thumb	Radial diaphysis of the first metacarpal
Extensor carpi ulnaris	Extends the wrist, adducts hand	Ulnar base of the fifth metacarpal
Flexor pollicis longus	Flexes the first distal phalanx	Palmar diaphysis of the first distal phalanx
Extensor pollicis brevis	Extends the thumb	Dorsal base of the first proximal phalanx
Abductor digiti minimi	Abducts the fifth finger	Ulnar base of the fifth proximal phalanx
Flexor digiti minimi	Flexes the fifth finger	Ulnar base of the fifth proximal phalanx

Table 1: The eleven muscles associated with the nine entheses analyzed.

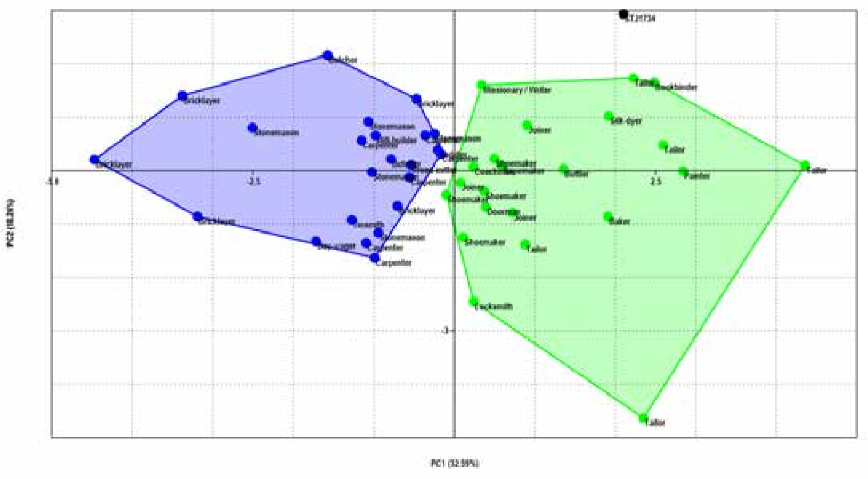

Figure 4: Results of size-adjusted PCA on a correlation matrix: PC1 and PC2. No a priori group classification was performed. Colors indicate heavy manual laborers (in blue) and precision workers (in green).

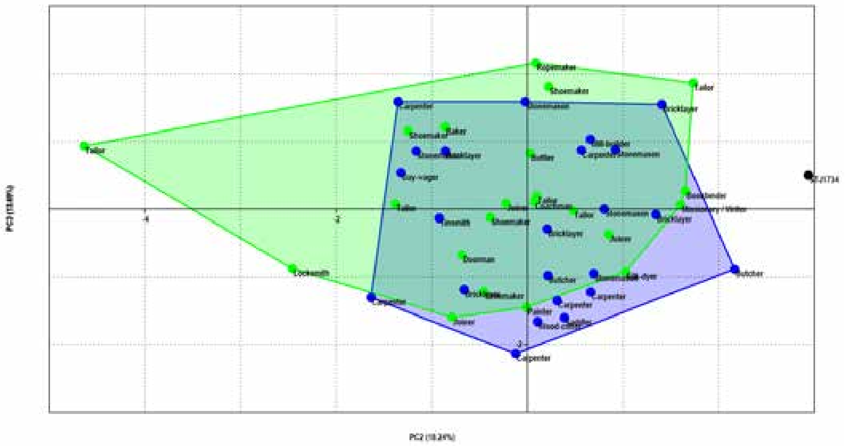

Figure 5: : Results of size-adjusted PCA on a correlation matrix: PC2 and PC3. No a priori group classification was performed. Colors indicate heavy manual laborers (in blue) and precision workers (in green).

In the PCA, the first three PCs were plotted (Figs. 4 and 5), representing the 64.52% of total variation in the sample. The major axis of variation (PC1; 32.59%) separated lifelong heavy manual laborers (blue) from long-term precision workers (for more details, see Karakostis et al., 2017). The factor loadings for this PC (Fig. 6) mirrors the results of our previous research on the same sample (Karakostis et al., 2017), according to which precision workers presented an entheseal pattern corresponding to a muscle group coordinated for thumb-index finger precision grasping, whereas heavy manual workers showed a pattern consistent with the application of maximum grip force (e.g., Marzke et al., 1998; Clarkson, 2000). On PC1 (Fig. 4), STJ-1734 plots together with fine workers of low intensity and/or semi-mechanized activity (see Karakostis et al., 2017), in consistency with the long-term occupational profile of this individual which did not involve heavy manual tasks.

By contrast, on PC2 (18.24%) and PC3 (13.69%), there is extensive overlapping between the two occupational tendencies (Fig. 5). Nevertheless, the high PC2 score of individual STJ-1734 causes it to plots outside the range of variation of both occupational tendencies (Figs. 3 and 4). Its high PC2 value mainly reflects its proportionally large enthesis of the first dorsal interosseous and the common insertion tubercle of abductor digiti minimi and flexor digiti minimi (Fig. 7) in combination with a relatively small attachment for the flexor pollicis longus (thumb distal phalanx). Finally, on PC3, which does not seem to be associated with the nature of occupational activities (Figs. 5 and 8), STJ-1734 overlaps with both occupational categories.

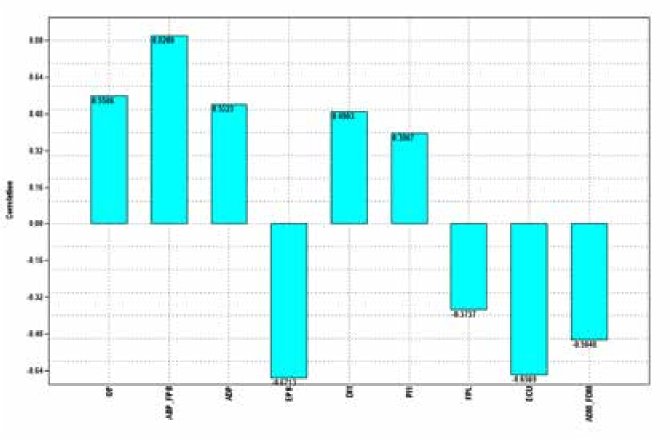

Figure 6: Factor loadings of PC1. Abbreviations: abductor pollicis brevis: ABP; Abductor digiti minimi: ADM; adductor pollicis brevis: ADP; first dorsal interosseous: DI1; extensor carpi ulnaris: ECU; extensor pollicis brevis: EPB; flexor digiti minimi: FDM; flexor pollicis brevis: FPB; flexor pollicis longus: FPL; opponens pollicis: OP; first palmar interosseous: PI1.

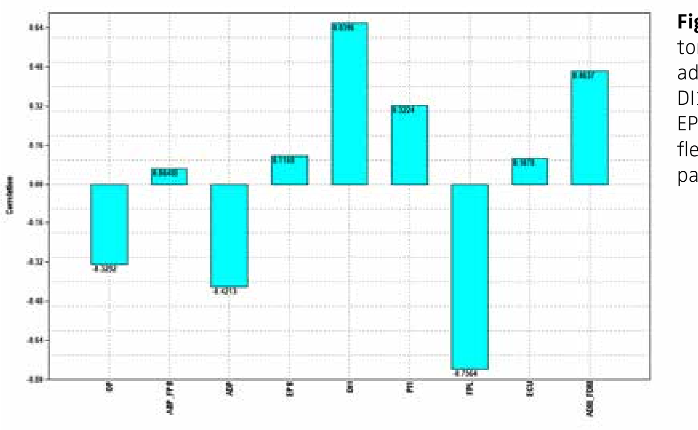

Figure 7: Factor loadings of PC2. Abbreviations: abductor pollicis brevis: ABP; Abductor digiti minimi: ADM; adductor pollicis brevis: ADP; first dorsal interosseous: DI1; extensor carpi ulnaris: ECU; extensor pollicis brevis: EPB; flexor digiti minimi: FDM; flexor pollicis brevis: FPB; flexor pollicis longus: FPL; opponens pollicis: OP; first palmar interosseous: PI1.

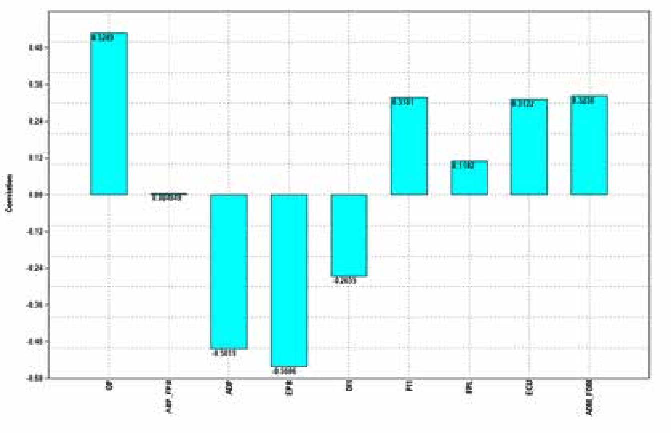

Figure 8: Factor loadings of PC3. Abbreviations: abductor pollicis brevis: ABP; Abductor digiti minimi: ADM; adductor pollicis brevis: ADP; first dorsal interosseous: DI1; extensor carpi ulnaris: ECU; extensor pollicis brevis: EPB; flexor digiti minimi: FDM; flexor pollicis brevis: FPB; flexor pollicis longus: FPL; opponens pollicis: OP; first palmar interosseous: PI1.

12.4 DISCUSSION

The results of this analysis verify that it is possible for an old individual to present distinctive entheseal patterns. In the case study of STJ-1734, its pattern on PC1 involves a grasping behavior that relies more on precision movements rather than high grip force (power grasping). This causes this individual to overlap with lifelong precision workers on PC1, associated with fine activities of low intensity and/or semi-mechanized tasks involving the thumb and the index finger muscles. This result is consistent with the detailed historical archives on this old individual's main occupation and lifestyle before death.

However, the analysis also revealed that the second axis of variation in the sample (PC2) separates STJ-1734 from all other younger individuals of both occupational tendencies (aged between 18 and 48 years old) (Fig. 4). As indicated by the corresponding factor loadings (Fig. 7), STJ-1734's high PC2 score primarily reflects the combined occurrence of a relatively large enthesis for the first dorsal interosseous (index finger; correlation coefficient r = 0.66) and a relatively small attachment for the flexor pollicis longus (thumb; correlation coefficient r = - 0.76). In general, the former muscle is associated more with precision grasping movements, whereas the latter plays a fundamental role in sustained power grasping.

In this regard, STJ-1734's value on PC2 does not necessarily contradict its entheseal pattern on PC1. Nonetheless, if factor loadings with moderate strength in that particular PC (0.30 to 0.59; see Field, 2013) are also taken into consideration, then the resulting patterns (Fig. 7) do not clearly represent either power or precision grasping movements, but still seem to carry a biomechanical signal. This is because the negative loadings involve three muscles which act closely together for forceful movement of the thumb involving opposition, adduction, and pollical distal flexion, whereas the positive loadings reflect an interaction between the index finger (adduction and abduction) and the fifth finger (abduction and flexion). In this context, the extreme positive PC2 score of specimen STJ-1734 (indicating intense interactions between the second and the fifth finger) might be explainable by the pronounced lesions at the metacar-pophalangeal joint of the thumb (Fig. 3) in combination with the occurrence of elbow osteoarthritis (Fig. 2). Such a pronounced arthritic condition would have probably affected the thumb's movability and biomechanical efficiency, leading to a reduced capacity for sustaining objects in the palm. As a consequence, STJ-1734 might perhaps have been forced to adopt an alternative grasping behavior for securing objecting in the palm, which would have necessarily involved the synergistic coordination of the lateral and medial borders of the fingers, formed respectively by the index (abduction and adduction) and the fifth finger (abduction and flexion).

Overall, the above observations suggest that, in spite of the extensive effects of advanced age on entheses, entheseal multivariate patterns are still observable in old individuals and can potentially carry a functional signal (as indicated by our observations for PC1). Therefore, if future research further verifies these conclusions using increased sample sizes comprising fully documented old individuals, it will become possible to assess the manual activities of old individuals based on the 3D multivariate patterns of their hand entheses. Nevertheless, it must be highlighted that these patterns are substantially affected by pathological conditions affecting biomechanical efficiency, such as arthritis or trauma. Given that age-related degeneration is a major factor of such lesions, entheseal analyses of old individuals presenting pathological traits may likely be biased. In fact, provided that many pathological conditions affecting body movement do not clearly -or always- manifest on the external morphology of the bones (e.g., fibromyalgia or many tendinopathies), any biomechanical assessments involving old individuals should be treated with caution.

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