Title :

Categorization of occupation in documented skeletal collections: Its relevance for the interpretation of activity-related osseous changes

Short title :
Categorization of occupation in documented skeletal collections

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Abstract :

Studies on identified skeletal collections yield discordant results about the association between osseous changes and activity. These dissonances can be ascribed to several factors: the variability of the osseous changes selected for observation, the inconsistency of their interpretative criteria and the inhomogeneous classification of occupation, here used as synonym of profession, within each study. The need to standardize the concept of occupation in its biomechanical and socio-cultural expression is currently addressed by the authors, as members of a working group created after the workshop "*Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns*" (Coimbra University, 2009). Within this framework, the authors reviewed the literature dedicated to entheseal changes and functional adaptation of long bones, focusing their research on studies based on European identified skeletal collections and on the criteria used in each study to classify occupations. The aim of this research was to (a) assess agreements and disagreements between authors with regard to the criteria used to categorize occupation, and (b) highlight the steps needed to build a classification system permitting future comparisons between collections of different chronological and geographical contexts. Data from the literature was exported to a table including the assessment criteria used to classify the occupation for each profession and the assignment of specific occupations to occupational categories. Overall, our results revealed two main issues: an ambiguous historical interpretation of occupation, and a marked influence of the researcher's perspective on the criteria used to classify occupations. Therefore, although the table allows basic comparisons between collections, further research is needed in order to obtain shared classifications based on each profession's specifics.

Key words :

entheseal changes, functional adaptation, identified collections, Europe

Introduction

According to the World Health Organization (WHO), the musculoskeletal system is the most common target of occupational diseases (Luttmann *et al*., 2003; Nelson *et al*., 2005). The generally accepted link between biomechanical stimuli and skeletal changes at the level of joints and entheses has been widely used for biocultural reconstructions (for a review see Jurmain *et al*., 2011). This approach, largely based on untested assumptions about the prominence of environmental (i.e. biomechanical) factors on shaping skeletal morphology has, however, been challenged by studies conducted over the last 10 years on European identified collections (Cunha & Umbelino, 1995; Mariotti *et al*., 2004, 2007, 2009; Alves Cardoso, 2008; Perréard Lopreno, 2009; Villotte, 2008, 2009; Villotte *et al*., 2010; Milella, 2010; Milella *et al*., 2012, Alves Cardoso & Henderson, 2010; Niinimäki, 2011).

Identified skeletal collections permit comparisons of the relative role played by different factors on skeletal changes. Information such as sex, age, date of birth and death, place of birth and death and profession of each subject are known. Moreover, such samples typically show homogeneous profiles, with the subjects sharing the same ancestry and representing the same geo-chronological context (Cox, 1996; Rocha, 1995; Perréard Lopreno & Eades, 2003).

The value of human skeletal collections and anatomical specimens is undeniably interlinked with the growth of medical knowledge, the history of physical anthropology, and, most recently, with the development of forensic anthropology (Walker, 2008). Anatomists and anthropologists from the 20th century realized early the importance of collecting skeletons from individuals of known age, sex, population affinity, occupation and cause of death for use in anthropological and forensic research (Walker, 2008). Most of the methods used these days to ascertain biological and health profiles and the morphological variability of past and modern populations, were developed and/or tested in documented skeletal collections (Komar & Grivas, 2008; Walker, 2008).

Though entheseal changes are the most used proxy of biomechanical stress, geometric proprieties of long bones are also regularly investigated (Perréard Lopreno 2007). Biomechanical approaches share a well-informed theoretical basis (i.e. Trinkaus *et al.,* 1994; Ruff *et al*., 2006; Ruff, 2008) and are increasingly adopted for biocultural reconstructions (i.e. Wescott & Cuningham, 2006; Marchi *et al*., 2006; Sládek *et al*., 2007). However, the specificity of bone response to biomechanical stress is still not fully understood (Pearson & Lieberman, 2004).

Biomechanical studies share relevant theoretical issues with entheseal changes: (a) the problem of reliability of specific skeletal changes in reconstructing specific activities or lifestyles and (b) the degree of reliability of comparative approaches applying modern kinesiological data to past populations (Dutour, 1992; Stirland, 1998; Wilczak & Kennedy, 2000; Knüsel, 2000; Jurmain *et al*., 2011).

Studies on identified collections generally share a common research design, i.e. attempting to use data on specific occupations and professional classes to emphasize possible correlations between skeletal changes and *in vivo* physical strains (after controlling for both sex and age). While a general agreement exists about the importance of age influencing the expression of the studied skeletal features (Cunha & Umbelino, 1995; Mariotti, 2004, 2007; Villotte, 2009; Alves Cardoso & Henderson, 2010; Milella, 2010; Villotte *et al.*, 2010; Milella *et al*., 2012), attempts to define the role played by physical activity on those features reflect a high degree of inconsistency. Some studies reveal little or no correlation between skeletal changes and the assumed biomechanical stress experienced during life (Cunha & Umbelino, 1995; Alves Cardoso, 2008; Alves Cardoso & Henderson, 2010; Milella, 2010; Milella *et al*., 2012; Niinimäki, 2011). Others obtain positive results, mostly considering occupational groups rather than specific activities (Perréard Lopreno, 2007; Villotte, 2009, 2010).

Several factors may be considered to explain these discrepancies:

- the focus on different skeletal features (e.g. entheseal changes, joint changes, geometric properties of long bones),
- the use of different methodologies for data collection and analysis,
- the adoption of different criteria to group the subjects on the basis of their documented profession.

The described issues, and the problems surrounding the concept of occupation with its multiple facets, was highlighted during the workshop "*Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns*" (Coimbra University, 2009: http://www.uc.pt/en/cia/msm/). This workshop addressed the progress and limitations of research on entheseal changes (Santos *et al.*, 2011). One of its major contributions was the creation of several working groups to specifically address the questions of entheseal changes terminology (Jurmain &Villotte, 2010), recording methods (Henderson *et al.*, 2010; 2012), and the concept and classification of occupation (Perréard Lopreno *et al.*, 2012). This paper presents the results obtained by the working group on occupation, three years after its foundation. Our aim is to introduce, after reviewing the pertinent literature, a set of criteria for the interpretation, classification and grouping of documented professions. Such criteria would represent a useful reference and framework for future studies seeking to explore activity-related changes in identified collections.

Materials and Methods

To conduct the research, eight case studies, based on seven identified European skeletal collections, were chosen for analysis (Fig. 1; Table 1). Only European collections were selected as they were specifically studied by the authors. Furthermore, they share a similar chronological setting, and, based on the authors previous research, also some cultural settings which facilitate comparisons.

The studies were selected based on the following criteria: (1) European identified skeletal collections; (2) the researchers should present a clear hypothesis or research question; (3) the research should have well-defined criteria in the classification of occupations at time of death, in accordance to the occupational category created by the authors themselves. We conducted a review of the available literature dedicated to entheseal changes by considering both published and unpublished (e.g. PhD theses) material. The sample was maximized by applying a broad range of keywords (e.g. "entheseal", "enthesis", "enthesopathy", "enthesopathies", "musculoskeletal stress markers", "MSM", "activity stress markers", "markers of occupational stress", "activity and occupation"). Following the steps taken for the selection of references (Fig. 2), a total of eight case studies were considered for this analysis (Table 1).

To allow comparisons, all definitions of the criteria and categories used in the original case studies were investigated and described, and specific occupations common to all studies were searched for. The data recorded in each study were tabulated by author and research question. With regard to specific occupations, and to test the effectiveness of criteria defined and used in the original studies, the data was cross-tabulated by occupational grouping.

Results

The data presented below represents a synthetic description of the results obtained by this review. A detailed database, including the complete categorization established by Perréard Lopreno (2007), Villotte (2009), Milella (2010), Milella *et al.* (2012) on five European identified collections and illustrating in more detail the variability of the collections' occupational profile, is available on the website of the workshop of Coimbra 2009, in a preliminary version (http://www.uc.pt/en/cia/msm/MSM_Occupation).

A marked bias affects the frequencies of specific professions in all examined cases. In the Sassari collection, for instance, half of the sample is composed of farmers, which leads to other professions being rather underrepresented (Milella, 2010). In order to tackle such issues and to obtain suitable subsamples to be further analyzed statistically, several strategies were proposed, overall referable to two types of classifying criteria: biomechanical (Table 2) and socio-cultural.

Biomechanical criteria

Biomechanical criteria focus on the expected biomechanical stress due to the performance of occupation-related tasks. Occupations are dichotomously grouped according to (a) historical-ethnographic data (Perréard Lopreno, 2007; Alves Cardoso & Henderson, 2010; Niinimäki, 2011), or (b) data from studies in occupational medicine (Villotte, 2009). Table 2 shows, in order of increasing complexity, the applied criteria and definitions by author, as identified in the present review.

The distinction between manual (M) and non-manual activities (see Table 2 for explanation of the abbreviations) represents the more general and shared approach, with a relatively low discrepancy between authors. More specific criteria consider the level of biomechanical stress involved in the performance of a profession and its possible association with the carrying of heavy loads. This approach is the basis of a set of rather overlapping subsamples (L, I, H). The last two grouping criteria (R, S) take into account: (a) the performance of professions characterized by iterated physical tasks associated to another risk factor such as the repeated use of tools causing shocks to the body (R), and (b) the performance of professions involving a lateralized use of the upper limb (S). The specificity and different theoretical background of R and S is demonstrated by a lower degree of overlapping between such classification systems (for detailed definitions, see Table 2).

Overall, even if the range of biological description is considerable, a general agreement is observable between different authors about the way to subdivide physical activities. However, one issue shared by such approaches is their reliance on documentary/clinical data, which leads to significant shortcomings when this information is not available (i.e. for females and unspecific professions such as employee or assistant).

Socio-cultural criteria

Socio-cultural criteria were used by Alves Cardoso (2008) in order to infer *gender*, a social and cultural construct, from occupational information. The author, assuming a link between sexual division of labour and gender constructs, tested the possible correlation between differential patterns of entheseal changes and sex-specific activities. The adopted criteria, described as social and cultural, are intimately related with the research objective. The criteria are based on historical data of known occupations, and the manner in which these were representative of the socio-economic status. The grouping by profession is done using the 1951 Registrar General (Armstrong, 1972) and the categories employed by João Roque (1988). The resulting categories are: Government administration / Services; Commerce / Transport; Skilled workers / Artisans; Farmers / Servants; Unskilled workers; Army / Navy; and Doméstica ("housewife"). Even if some of these categories share similar biological and physical criteria, their socio-cultural interpretation differs markedly.

Occupational grouping

Our review demonstrates to the role played by the original research hypotheses with regard to the adopted criteria (i.e. categorization) and the level of comparability between different

studies. Table 3 shows the distribution of studies on identified collections subdivided by research hypothesis and classifying criteria. Most of the studies are biologically oriented, with the exception of Cunha and Umbelino (1995), Alves Cardoso (2008), and Alves Cardoso and Henderson (2010). Of these, only Alves Cardoso (2008) includes social-culturally orientated research that takes into account biological and biomechanical factors.
Another issue is the proposition by some authors of additional activity groups based on the merging of several physical criteria (e.g. manual, intense, *and* lateralized activities). Figure 3 schematically illustrates this approach, while Table 4 shows its negative effect on the comparability of studies on three different professions (shoemakers, farmers and barbers/ hairdresser). Even if authors agree with regard to the description of the activity, there are discrepancies with regard to the occupational groupings, despite equivalent categories based on biomechanical criteria.

Discussion

Over the last decades, identified skeletal collections were widely used as "windows of opportunity" to reconstruct past human occupations, as well as key sources for the development of methodological bases for research on activity-related osseous changes (Mariotti *et al.*, 2004, 2007; Villotte, 2009). Unfortunately, in most cases, the inherent limitation of the identified collections, such as the representativeness of the samples, the criteria used in the assemblage collection, the source and completeness of the documentation available for each individual (Komar & Grivas, 2008), and the difficulty of deconstructing the documented occupation into testable physical components, were not taken into account by researchers.
The problem of the representativeness of the skeletal samples has been widely discussed in palaeodemographic and palaeopathological literature (e.g. Wood *et al*., 1992; Waldron, 1994; 2007; Dutour, 2008; Milner *et al*., 2008; Pinhasi & Bourbou, 2008; Jackes, 2011; Ortner, 2011), for both archaeological and documented samples. According to Komar and Grivas (2008: 224), a recurrent pitfall in the use of identified collections is the tendency to confound "documented" with "representative", which are not equivalent. The method by which the collection was assembled, the criteria used in the selection of the individuals, or the osteological material available at that time renders the identified collections unrepresentative of the original population and produces a possible source of bias (Komar & Grivas, 2008), namely in occupational studies. Hunt and Albanese (2005) clearly discuss this problem, addressing the history and demographic composition of the Terry Anatomical Collection.
An incomplete or unclear documentary record for each individual may also affect the interpretation of the biological and socio-cultural data (Henderson *et al.*, 2012). This problem is significant in the study of past occupations, being one of the major concerns targeted in the case studies analysed. For example, Villotte (2009) observed that 86% (214/248) of the women studied were recorded as housewives, which does not sufficiently clarify the type of activities they performed throughout life, nor the respective biomechanical impact upon the musculoskeletal system. Alves Cardoso (2008) made a similar observation, emphasizing that much of the activity performed and corresponding biomechanical impacts bear little to no relation to the description of occupation at time of death. Consequently, a large part of the investigation conducted by the authors was restricted to the male sample. These limitations can be partially overcome through indirect information retrieved from archives with: (1) the father's profession, if sufficient historical information was available about the role of the individual as a child in the household activities, assuming that an essential part of the bone structure is developed during puberty (Kontulainen *et al*., 2001, 2002; Bass *et al*., 2002; Daly *et al*., 2004; Nanyan *et al*., 2005); and (2) the husband's occupation in cases where the socio-

professional category reflects the woman's condition. The places and conditions in which the individuals lived as a child and as an adult (e.g. city versus country) are also useful parameters to consider in the description of the socio-economic background, as well as in other aspects of their daily lives. Swedlund and Herring (2003) point out that archives may provide multiple lines of enquiry for the physical anthropologist with regard to demography, health, nutrition and genetics of historical populations. For instance, an attempt to link documentary sources collected from the historiography of a asylum for mentally ill that operated during the second half of the nineteenth century (Oneida County Asylum, New York, USA) with surviving skeletal records of its patients, is described by Phillips (2003). In this study, the biomechanical effects of the "labour therapy" prescribed to long-term inmates was explored by evaluating particular skeletal traits such as robusticity indices, measures of cortical maintenance, and vertebral burst fractures, concluding that the asylum inmates were engaged in heavier workloads when compared with their cohorts in the general population (Phillips, 2003: 126). In spite of the importance of the archival research, in most cases this methodological option is difficult to combine with the data from identified skeletal collections, not only because of the time-consuming nature of the search, but also due to the lack of additional records that allow the complete reconstruction of the individual's historiography in terms of health status and long-term occupational profiles. Consequently, the physical components of the activity cannot directly be evaluated; aspects of the daily life may be questioned.

Another aspect frequently neglected by researchers and highlighted in this study is the difficulty of deconstructing the documented occupation into meaningful physical components. To know the occupation is one thing, to understand the intricacies of the actual activities associated with that occupation is another. It is recognized from clinical studies that the risk of developing musculoskeletal changes through occupation not only depends on the physiological characteristics of the individuals, including the tissue response to load and age, but also on other variables such as the psychological and/or socio-cultural environment and the type of exposure to external mechanical stimuli (National Research Council, 2001). If it is already difficult to ascertain the real significance of each variable on the living for occupations with well-known tasks and performances, this constraint significantly increases significantly in the study of past populations. More specifically, the lack of knowledge about the specific types and levels of biomechanical stress characterizing occupations performed in the past should be stressed. This issue represents a relevant bias when trying to build interpretative hypotheses on the basis of the observed osseous changes.

Finally, two levels of subjectivity were pinpointed in the present discussion: the uncertainty with regard to the knowledge about the historical background of samples concerning occupation, and the specific research design and author's interpretation. It is now understood that occupation groups may be reorganized based on working hypotheses, and that there are multiple possible combinations of groupings (Alves Cardoso and Henderson, 2012). However, by highlighting the criteria of biomechanical or sociocultural categorization, we noticed that the questions, and the respective answers, that can be set from these samples are limited. This fact, in addition to unsolved methodological constraints and particular subjectivities inherent to each study limits the categorization of occupation based on identified collections even more. Despite the importance of the characterization or documentation of historical periods, the use of identified skeletal collections to corroborate a link between morphological changes and underlying mechanical factors is difficult. The testing of hypotheses about the link between skeletal changes and occupations will only be possible through a better understanding of bone responses to the amount, duration, frequency, intensity, and severity of certain activities (Meyer *et al*., 2011).

Conclusion

One line of research, which has developed over the last ten years and aims to identify morphological adaptations of the skeleton to activity, is based on the study of individuals with known occupations, sex and age-at death, from European identified skeletal collections. The criteria and the manner of how occupations are grouped, which vary according to the case studies, constrain the comparison of results, and limit the interpretation of the relative importance of factors analysed. Bearing this in mind, the aim of this paper was to identify the classification criteria used in eight recent studies and establish a framework for future reference.

This study has identified two major criteria for categorizing occupations: one biomechanical and another socio-economical. The diversity of occupations represented in the collections have led researchers to identify the physical characteristics of activities, permitting the regrouping into dichotomous categories (e.g. manual vs. non-manual), in order to perform statistical analysis of sub-samples and test hypotheses relating biomechanical aspects of the skeletons to activity. It is revealed that biomechanical criteria of categorization show high levels of agreement between the studies. A list of occupations and their deconstruction into biomechanical categories was summarized in a database in order to be used as a reference in future studies permitting a certain level of comparison between studies to be conducted.

Considering the research hypotheses in each of the studies explored, the formation of activity groups varied from one study to another. In some cases there was a combination of physical parameters, in others the use of socio-economic categories. These groupings are not comparable at all. Moreover, at present, it seems that socio-cultural categorizations are not suitable for a correlation with activity-related changes to the skeleton.

Therefore, after considering the overall analysis of the studies explored, and the results obtained, we recommend that occupations are categorized based on biomechanical criteria. These can be found online at: www.uc.pt/en/cia/msm/MSM_Occupation.

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Authors' contribution:

All authors contributed equally to the preparation of this paper

References

Alves Cardoso F. 2008. *A portrait of gender in two 19th and 20th Portuguese populations: a paleopathology perspective.* PhD thesis, Department of Archaeology, Durham University.

Alves Cardoso F, Henderson CY. 2010. Enthesopathy formation in the humerus : data from known age-at-death and known occupation skeletal collections. *American Journal of Physical Anthropology* **141**: 550-560. DOI: 10.1002/ajpa.21171

Alves Cardoso C. and Henderson C. Y. 2012. The Categorisation of Occupation in Identified Skeletal Collections: A Source of Bias? *International Journal of Osteoarchaeology*. DOI: 10.1002/oa.2285.

Armstrong WA. 1972. The use of information about occupation. In *Nineteenth-century Society. Essays in the Use of Quantitative Methods for the Study of Social Data*, Wrigley EA. (ed.). Cambridge University Press: Cambridge; 191-310.

Bass SL, Saxon L, Daly RM, Turner CH, Robling AG, Seeman E, Stuckey S. 2002. The effect of mechanical loading on the size and shape of bone in pre-, peri, and post-pubertal girls: a study in tennis players. *Journal of Bone and Mineral Research* **17**: 2274-2280. DOI: 10.1359/jbmr.2002.17.12.2274

Cox MJ. 1996. *Life and death in Spitalfields, 1700 to 1850*. Council for British Archaeology: York.

Cunha E, Umbelino C. 1995. What can bones tell about labour and occupation: the analysis of skeletal markers of occupational stress in the Identified Skeletal Collection of the Anthropological Museum of the University of Coimbra (preliminary results). *Antropologia Portuguesa* **13**: 49-68.

Daly RM, Saxon L, Turner CH, Robling AG, Bass SL. 2004. The relationship between muscle size and bone geometry during growth and in response to exercise. *Bone* **34**: 281-287. DOI:10.1016/j.bone.2003.11.009

Dutour O. 1992. Activités physiques et squelette humain: le difficile passage de l'actuel au fossile. *Bulletins et Mémoires de la Société d'Anthropologie de Paris* **4**: 233-241.

Dutour O. 2008. Archaeology of human pathogens: palaeopathological appraisal of palaeoepidemiology. In *Paleomicrobiology: past human infections*, Raoult, D; Drancourt, M (eds). Springer-Verlag: Berlin Heidelberg; 125-144.

Henderson C, Mariotti V, Pany-Kucera D, Perréard Lopreno G, Villotte S, Wilczak C. 2010. *Scoring entheseal changes: proposal of a new standardized method for fibrocartilaginous entheses*. [Online]. Poster presented at the 18th European Meeting of the Paleopathology Association, Vienna, Austria 23rd–26th of August 2010. [Consulted in 16/10/2012]. Available from: https://www.uc.pt/en/cia/msm/Vienna2010.pdf.

Henderson CY, Mariotti V, Pany-Kucera D, Perréard Lopreno G, Villotte S, Wilczak C. 2012. The effect of age on entheseal changes at some fibrocartilaginous entheses. *American Journal of Physical Anthropology* 144: 163-164. DOI : 10.1002/ajpa.22033.

Henderson CY, Caffell AC, Craps DD, Millard AR, and Gowland R. 2012. Occupational mobility in nineteenth century rural England: the interpretation of entheseal changes. *International Journal of Osteoarchaeology*. DOI: 10.1002/oa.2286.

Hunt D, Albanese J. 2005. History and demographic composition of the Robert J. Terry Anatomical Collection. *American Journal of Physical Anthropology* **127**: 406-417. DOI: 10.1002/ajpa.20135

Jackes M. 2011. Representativeness and bias in archaeological skeletal samples. In *Social Bioarchaeology*, Agarwal S, Glencross B (eds). Blackwell Publishing, Ltd.: Malden; 107-146.

Jurmain R, Alves Cardoso F, Henderson CY, Villotte S. 2011. Bioarchaeology's holy grail: the reconstruction of activity. In *A companion to paleopathology*, Grauer AL. (ed.). Wiley-Blackwell: Chichester; 531-552.

Jurmain R, Villotte S. 2010. *Terminology. Entheses in medical literature and physical anthropology: a brief review* [Online]. Document published online in 4th February following the Workshop in Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns, University of Coimbra, July 2-3, 2009. Coimbra, CIAS – Centro de Investigação em Antropologia e Saúde. [Consulted in 16/10/2012]. Available from: http://www.uc.pt/en/cia/msm/MSM_terminology.

Knüsel CJ. 2000. Bone adaptation and its relationship to physical activity in the past. In *Human osteology in archaeology and forensic science*, Cox M, Mays S. (eds). GMM: London; 381-401.

Komar D, Grivas C. 2008. Manufactured populations: what do contemporary reference skeletal collections represent? A comparative study using the Maxwell Museum documented collection. *American Journal of Physical Anthropology* **137**: 224-233. DOI: 10.1002/ajpa.20858

Kontulainen S, Kannus P, Haapasalo H, Sievanen H, Pasanen M, Heinonen A, Oja P, Vuori I. 2001. Good maintenance of exercise-induced bone gain with decreased training of female tennis and squash players: a prospective 5-year follow-up study of young and old starters and controls. *Journal of Bone and Mineral Research* **16**: 195-201. DOI: 10.1359/jbmr.2001.16.2.195

Kontulainen S, Sievanen H, Kannus P, Pasanen M, Vuori I. 2002. Effect of long-term impact-loading on mass, size, and estimated strength of humerus and radius of female racquet-sports players: a peripheral quantitative computed tomography study between young and old starters and controls. *Journal of Bone and Mineral Research* **17**: 2281-2289. DOI: 10.1359/jbmr.2002.17.12.2281

Luttmann A, Jäger I, Griefahn B, Caffier G, Liebers F, Steinberg F. 2003. Preventing musculoskeletal disorders in the workplace. *Protecting Workers' Health Series*, 5. World Health Organization: Geneva.

Marchi D, Sparacello V, Holt B, Formicola V. 2006. Biomechanical approach to the reconstruction of activity patterns in neolithic western Liguria, Italy. *American Journal of Physical Anthropology* **131**: 447-455. DOI: 10.1002/ajpa.20449

Mariotti V, Facchini F, Belcastro MG. 2004. Enthesopathies; proposal of a standardized scoring method and applications. *Collegium Antropologicum* **28**: 145–159.

Mariotti V, Facchini F, Belcastro MG. 2007. The study of entheses: proposal of a standardised scoring method for twenty-three entheses of the postcranial skeleton. *Collegium Antropologicum* **31**: 291–313.

Mariotti V, Milella M, Belcastro MG. 2009. Musculoskeletal stress markers (MSM): methodological reflection. In *Program – Abstract Book: Workshop in Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns*, Santos AL., Alves Cardoso F., Assis S., Villotte S. (eds). CIAS: Coimbra; 28.

Meyer C. Nicklisch N, Held P, Fritsch B, Alt K. 2011. Tracing patterns of activity in the human skeleton: An overview of methods, problems, and limits of interpretation. *Homo-Journal of Comparative Human Biology* **62**: 202-217. DOI: 10.1016/j.jchb.2011.03.003

Milella M. 2010. *Skeletal markers of activity: methodological and interpretative reflections after the study of the whole Frassetto Sassari identified skeletal collections*. Ph.D. Dissertation, University of Bologna.

Milella M, Belcastro MG, Zollikofer CP, Mariotti V. 2012. The effect of age, sex, and physical activity on entheseal morphology in a contemporary Italian skeletal collection. *American Journal of Physical Anthropology* ***148***: 379-388. DOI 10.1002/ajpa.22060

Milner G, Wood J, Boldsen J. 2008. Advances in Paleodemography. In *Biological Anthropology of the Human Skeleton*. Katzenberg, A, Saunders, S. (eds). John Wiley & Sons, Inc.: New Jersey; 561-600.

Nanyan P, Prouteau S, Jaffre C, Benhamou L, Courteix D. 2005. Thicker radial cortex in physically active prepubertal girls compared to controls. *International Journal of Sports Medicine* **26**: 110-115. DOI: 10.1055/s-2004-817859

National Research Council. 2001.*Musculoskeletal disorders at the workplace: low back and upper extremities.* National Academy Press: *Washington*, D.C.

Nelson D, Concha-Barrientos M, Driscoll T, Steenland K, Fingerhut M, Punnett L, Prüss-Ustün A, Leigh J, Corvalan C. 2005. The global burden of selected occupational diseases and injury risks: methodology and summary. *American Journal of Industrial Medicine* **48**: 400-418. DOI 10.1002/ajim.20211.

Niinimäki S. 2011. What do Muscle Marker Ruggedness Scores Actually Tell us? *International Journal of Osteoarchaeology* **21**: 292-299. DOI: 10.1002/oa.1134

Ortner D. 2011. Human skeletal paleopathology. *International Journal of Paleopathology* **1**: 4-11. DOI: 10.1016/j.ijpp.2011.01.002

Pearson OM, Lieberrman DE. 2004. The aging of Wolff's « law »: ontogeny and responses to mechanical loading in cortical bone. *Yearbook of Physical Anthropology* **47**: 63-99. DOI: 10.1002/ajpa.20155

Perréard Lopreno G. 2007. *Adaptation structurelle des os du membre supérieur et de la clavicule à l'activité : analyse de l'asymétrie des propriétés géométriques de sections transverses et de mesures linéaires dans une population identifiée (collection SIMON)*. Université de Genève (PhD, archives ouvertes*).*

Perréard Lopreno, G. 2009. The morphology of clavicular entheses observed on a sample of identified skeletons (SIMON collection, Switzerland): methodological discussion. In *Program – Abstract Book: Workshop in Musculoskeletal Stress Markers (MSM): limitations and achievements in the reconstruction of past activity patterns*, Santos, A. L, Alves Cardoso, F, Assis, S, Villotte, S. (eds). CIAS: Coimbra; 35.

Perréard Lopreno G, Alves Cardoso F, Assis S, Milella M, Speith N. 2012. Working activities or workload ? Categorization of occupation in identified skeletal series for the analysis of activity-related osseous changes. *American Journal of Physical Anthropology* **147**, no S54: 236. DOI: 10.1002/ajpa.22033

Perréard-Lopreno, G.; Alves Cardoso, F.; Assis, S.; Milella, M.; Speith, N. 2012. *Working activities or workload? Categorization of occupation in identified skeletal series for the analysis of activity-related osseous changes*. [Online]. Invited poster presentation at the 81th Annual Meeting of the American Association of Physical Anthropologists, Portland, Oregon, 11th – 14th of April, 2012. [Consulted 16/10/2012]. Available from: http://www.uc.pt/en/cia/msm/MSMWorkingGroup_Occupation_AAPA2012.

Perréard Lopreno G, Eades S. 2003. Une démarche actualiste en paléoanthropologie: la collection de squelettes de référence. In *ConstellaSion: hommage à Alain Gallay*. Besse M, Stahl Gretsch LI, Curdy P. (eds). Cahiers d'archéologie romande: Lausanne; **95**; 463-472.

Phillips S. 2003. Worked to the bone: the biomechanical consequences of "labor therapy" at a nineteenth century asylum. In *Human Biologists in the archives*, Herring A, Sweedlund A. (eds). Cambridge University Press: Cambridge; 96-129.

Pinhasi R, Bourbou C. 2008. How representative are human skeletal assemblages for population analysis? In *Advances in Human Paleopathology*, Pinhasi R, Mays S. (eds). John Wiley & Sons, Ltd: Chichester; 31-44.

Rocha MA. 1995. Les Collections Ostéologiques Humaines Identifiées du Musée Anthropologique de l'Université de Coimbra. *Antropologia Portuguesa* **13**: 7-38.

Roque JL. 1988. *A população da freguesia da sé de Coimbra (1820-1849): breve estudo socio-económico*. Gabinete de Publicações da Faculdade de Letras: Coimbra.

Ruff C, Holt B, Trinkaus E. 2006. Who's afraid of the big bad Wolff ? : « Wolff's law » and bone functional adaptation. *American Journal of Physical Anthropology* **129**: 484-498. DOI: 10.1002/ajpa.20371

Ruff CB. 2008. Biomechanical analyses of archaeological human skeletons. In *Biological anthropology of the human skeleton*, Katzenberg MA, Saunders RS. (eds). Wiley-Liss: New York; 183-206.

Santos AL, Alves Cardoso, F, Assis S, Villotte S. 2011. The Coimbra Workshop in Musculoskeletal Stress Markers (MSM): an annotated review. *Antropologia Portuguesa* **28:** 135-161.

Sládek V, Berner M, Sosna D, Sailer R. 2007. Human manipulative behavior in the Central European Late Eneolithic and Early Bronze Age: Humeral bilateral asymmetry. *American Journal of Physical Anthropology* **133**: 669-681. DOI: 10.1002/ajpa.20551

Stirland AJ. 1998. Musculoskeletal evidence for activity: problems of evaluation. *International Journal of Osteoarchaeology* **8**: 354-362.
DOI: 10.1002/(SICI)1099-1212(1998090)8:5<354::AID-OA432>3.0.CO;2-3

Swedlund A, Herring A. 2003. Human biologists in the archives: demography, nutrition and genetics in historical populations. In *Human Biologists in the archives*, Herring A, Sweedlund A. (eds). Cambridge University Press: Cambridge; 1-10.

Trinkaus E, Churchill SE, Ruff CB. 1994. Postcranial robusticity in Homo. II: humeral bilateral asymmetry and bone plasticity. *American Journal of Physical Anthropology* **93**: 1-34. DOI: 10.1002/ajpa.1330930102

Villotte S. 2008. *Enthésopathies et activités des hommes préhistoriques: recherche méthodologique et application aux fossiles européens du Paléolithique supérieur et du Mésolithique.* Ecole doctorale Sciences et Environnement, Université de Bordeaux I: Bordeaux. (Thèse, non publiée).

Villotte S. 2009. *Enthésopathies et activités des hommes préhistoriques : recherche méthodologique et application aux fossiles européens du Paléolithique supérieur et du Mésolithique*. BAR International Series 1992. Archaeopress: Oxford.

Villotte S, Castex D, Couallier V, Dutour O, Knüsel CJ, Henry-Gambier D. 2010. Enthesopathies as occupational stress markers: evidence from the upper limb. *American Journal of Physical Anthropology* **142**: 224-234. DOI: 10.1002/ajpa.21217

Waldron T. 1994. *Counting the dead: the epidemiology of skeletal populations*. John Wiley & Sons: Chichester.

Waldron T. 2007. *Palaeoepidemiology: the measure of disease in the human past*. Left Coast Press Inc.: Walnut Creek CA.

Walker P. L. 2008. Bioarchaeological ethics: a historical perspective on the value of human remains. In *Biological Anthropology of the Human Skeleton*, Katzenberg, M, Saunders, S. (eds). Wiley-Liss: New York; 3-40.

Wescott DJ, Cunningham DL. 2006. Temporal changes in Arikara humeral and femoral cross-sectional geometry associated with horticultural intensification. *Journal of Archaeological Science* **33**: 1022-1036. DOI: 10.1016/j.jas.2005.11.007

Wilczak CA, Kennedy KAR. 2000. Mostly MOS: technical aspects of identification of skeletal markers of occupational stress. In *Forensic osteology: advances in the identification of human remains* (second edition), Reichs KJ. (ed.). Charles C Thomas: Springfield, Illinois; 461-490.

Wood J, Milner G, Harpending H, Weiss K, Cohen M, Eisenberg L, Hutchinson D, Jankauskas R, Česnys G, Katzenberg, A, Lukacs J, McGrath J, Roth E, Ubelaker D, Wilkinson R. 1992. The osteological paradox: problems of inferring prehistoric health from skeletal samples [and comments and reply]. *Current Anthropology* **33**: 343-370.

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Table 1: Descriptive summary of the case studies selected.

Collection	Country	Housed	Burial Period*	n° of Skeletons*	Acquisition	Case Study
(1) Collections of Bologna, Bologna	Italy	Museum of Anthropology / University of Bologna	1898 - 1937	433	1st half of 20th century	Villotte 2009
(2) Collections of Bologna, Sassari			1918 - 1932	606		Milella 2010; Milella *et al.* 2012 Villotte 2009
(3) Luis Lopes Skeletal Collection	Portugal	Museum of Natural History, Lisbon	1805 - 1975	1692	1980 - 1991 and from 2000	Alves Cardoso 2008; Alves Cardoso & Henderson 2010
(4) Identified Skeleton of Coimbra Collection		Museum of Anthropology / University of Coimbra	1826 - 1938	505	1915 - 1942	Cunha & Umbelino 1995; Alves Cardoso 2008; Villotte 2009; Alves Cardoso & Henderson 2010
(5) Spitalfields Skeletal Collection, London	United Kingdom	Natural History Museum	1729 - 1852	383	1984 - 1986	Villotte 2009
(6) Collection SIMON	Switzerland	Laboratory of Prehistoric Archaeology and Anthropology / University of Geneva	1910 - 1960	495	1991 - 1993 and 1998 - 2003	Perréard Lopreno 2007
(7) Natural History Collection Museum	Finland	University of Helsinki	early 20^{th} century	108	c. 1920 - 1940	Niinimäki 2011

***** there is varied information about the burial period and the number of skeletons according to authors.

Table 2. Biomechanical criteria and definitions used in the case studies.

Biomechanical criteria	**Abbreviation used in this text**	**Definitions**	**Authors**
Manual versus non-manual	M	"One corresponds to those professions considered as manual, which imply an important solicitation of the whole body or part of it, the other professions considered as non manual".	Villotte 2008: 120.
		"(...) to decide the entire professional sample using as criteria: 1) the practice of manual activities, (…)"	Milella 2010: 26.
		"The grouping of the occupations as being manual or non-manual was performed based on historical evidence for the activities performed".	Alves Cardoso & Henderson 2010: 552.
		"non-manuals: (...) we assume that the subjects practiced professions which were not physically demanding, (…) without important or specific functional loads".	Perréard Lopreno 2007: 37.
Carrying of heavy loads	L	"(…) the risk that an occupational lesion will happen is proportional to the load born by the tissue (…)"	Villotte 2008: 124.
		"(...) to divide the entire professional sample using as criteria: (...), 2) the practice of activities related with load bearing (…)"	Milella 2010: 26.
Intensity	I	"(…) intense physical activities comprising the carrying of loads, the use of heavy tools requiring a lot of strength (…)"	Perréard Lopreno 2007: 37.
Hard work	H	"Two groups according to labour intensity (heavy and light); labour was considered heavy if it included a lot of lifting, moving, heavy loads or getting short of breath"	Niinimäki 2011: 294.
		"(...) hard workers (HW) are associated with generalized, high exposure to biomechanical stimuli, while light workers (LW) had professions and occupations that, even if physically demanding, involved highly specialized tasks"	Milella *et al.* 2012: 2.
Repetitive movements of the upper limbs	R	"(...) when repetitiveness is associated to another risk factor, such as the repeated use of tools causing shocks to the body (hammers or similar tools, axes) (…)"	Villotte 2008: 124.
Specialization	S	"The *specialist* group is formed of various professions, but those subjects do have in common the practice of a manual activity and the fact that they are not farmers"	Perréard Lopreno 2007: 37.

Table 3. Distribution of the studies by research hypothesis and biomechanical criteria (M = manual versus non-manual; L = carrying heavy loads; H = hard work; I = intensity; R = repetitive movement of the upper limbs; S = specialization).

		Biomechanical criteria						**Socio-cultural criteria**
Studies	**Research question**	**M**	**L**	**H**	**I**	**R**	**S**	
Alves Cardoso & Henderson 2010	Use of some of the attachment sites on the humerus to explore the relationship between enthesopathy formation, activity, and the ageing process.	X						X
Alves Cardoso 2008	Can gender (social construct) be inferred via analysis of entheseal changes supposedly related with activity?							X
Cunha & Umbelino 1995	Attempt to find a correlation between osseous markers and activity in order to test their reliability.							X
Milella 2010; Milella *et al*., 2012	Are entheseal changes influenced by sex, age and activity?	X	X	X				
Niinimäki 2011	Explore the nature and effects of labour intensity, age and size on MSM.				X			
Perréard Lopreno 2007	Biomechanical analysis of the upper limbs: differences of asymmetry between mostly bi-manual versus more uni-manual occupations ?	X			X		X	
Villotte 2009	What is an enthesis and how can its study on dry bones help to obtain information on behaviour and daily life of past populations?	X	X			X		

Table 4. Distribution of specific occupations according to biomechanical criteria (M = manual versus non-manual; L = carrying heavy loads; H = hard work; I = intensity; R = repetitive movements of the upper limbs; S = specialization) and corresponding occupational groupings following the authors' information groups.

	Biomechanical criteria						
Shoemaker	**M**	**L**	**H**	**I**	**R**	**S**	**occupational groupings**
AC & H	1*						Manual
AC						1	Skilled workers /Artisans
M	1	0					Manual and Not load bearing
M & al.	1		0				Light worker
PL	1			0		1	Light specialist
V	1	0			1		Manual and Repetitive movements
Farmer / Day labourer	**M**	**L**	**H**	**I**	**R**	**S**	**occupational groupings**
AC	1	1					Farmers / Servants
M	1	1					Manual and Load bearing
M & al.	1		1				Heavy worker
PL	1			1		0	Farmers
V	1	1				1	Manual and Heavy load bearing and Repetitive movements
Barber / Hairdresser	**M**	**L**	**H**	**I**	**R**	**S**	**occupational groupings**
AC						1	Skilled workers / Artisans
M	1	0					Manual and Not load bearing
M & al.	1		0				Light worker
PL	0			0		0	Non-manual
V	1	0			1		Manual and Repetitive movements

Abbreviations: AC & H: Alves Cardoso & Henderson 2010; AC: Alves Cardoso 2008; M: Milella 2010; M & al.: Milella *et al.* 2012; PL: Perréard Lopreno 2007; V: Villotte 2009.

* Dichotomous classification: (1) the occupation corresponds to the biomechanical criteria; (0) the occupation does not correspond to the biomechanical criteria; (empty cell) biomechanical criteria not considered by the authors.