RECONSTRUCTION OF THE SPY II NEANDERTAL WITH BIOMECHANICAL ANALYSIS

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SUMMARY
A major problem of fossil hominid biomechanical analysis is a lack of complete specimens in the fossil record with many individual fossil specimens damaged by the impact of diagenesis and excavation. Significant advances in the field of three dimensional image processing (3D) and extensive digitization of Neandertals fossils have enabled the creation of accurately scaled reconstructions of individual fossil bones although no single individual in the Neandertal fossil record preserves all the skeletal elements of an entire specimen. This is a project to create a complete three dimensional (3D) virtual model of the Spy II Neandertal using different Neandertal skeletal remains (Spy II, Kebara 2 and La Ferrassie 1 and 2, Neandertal 1). Models were created using a software programme called lhpFusionBox (developed at the Laboratory of Anatomy, Biomechanics and Organogenesis, Université Libre de Bruxelles). Novel reconstruction techniques available from lhpFusionBox enabled the entire process to be performed according to a scientifically-sound and controlled methods. Several biomechanical studies have also been performed on the model, including muscle moment arms and gait analysis.

INTRODUCTION
Neandertal skeletal morphology is commonly viewed as ‘hyperpolar’ and the robustness of the skeleton, relatively short stature and low cranial indices, follow Bergmann’s and Allen’s rule of a cold-climate adaptation, traits also found in cold-climate adapted modern humans [1].This differential skeletal morphology has also been interpreted as an adaptation for frequently elevated levels of biomechanical stress, consistent with higher mechanical loads or simply as genetic baggage [1]. This study aimed to test why Neandertals were so robust by analysing if this was linked to locomotion. Analysis of locomotion in fossil hominids is difficult as motion data of fossil hominids is not available. A further major problem of fossil hominid analysis in all studies is the lack of complete specimens in the fossil record. The Spy II skeleton is well preserved and has relatively complete lower and upper limbs and cranium. The first aim in this study was to create a complete three dimensional (3D) virtual model of a Neandertal using the Spy II Neandertal as a base and different Neandertal skeletal remains where Spy II bones were missing or damaged. Two biomechanical feasibility studies were then conducted on the model: a squatting motion data from an anatomically modern human (AMH) was applied to the lower limb of this virtual model and an analysis of the knee flexor moment arms (i.e., hamstring muscles) was performed.

METHODS
Spy II material and casts of bones were obtained from the Royal Belgian Institute of Natural Sciences and included: Spy II skeleton (cranium, knee, tibia, almost complete femur, talus, calcaneus, ulnae and partial sacrum, hemerus, scapula, clavicles and hand and feet bones), Neandertal 1 skeleton casts (iliac bone, femur, hemerus), La Ferrassie 1 (scapula, foot bones, talus) and Kebara 2 skeleton cast (iliac, thorax). All available bones and casts were processed by Computerized Tomography (CT) [2]. 3D models of bones were created using AMIRA, Meshlab and lhpFusionbox. lhpFusionBox is a software system partly developed at ULB [3], from the open-source library MAF [4]. It is currently being designed for biomechanical and clinical studies related to the musculoskeletal system of modern humans. lhpFusionBox has recently been adapted for paleoanthropological analysis and all 3D models with ALs were mirrored to create a full lower limb.

Scaling the skeleton. Anatomical landmarks (ALs) were virtually palpated on all 3D models using strict definitions [5]. Missing or incomplete Spy II bone models were then created by registering the Neandertal bones to the Spy II dimensions using their respective AL lists in singular value decomposition (SVD) algorithms [6]. Information of the transformation was given by the root mean square (RMS) error of the various ALs processed by the algorithm [6]. The majority of scaling was straightforward and utilized affine or similarity scaling [7]. There is no common element between the Kebara 2 pelvis and the Spy lower skeleton so there is no way to scale the Kebara 2 pelvis to the Spy II skeleton directly. LhpFusionBox was therefore adapted to process objects of a different nature (i.e., in this study for example, scaling a pelvis to the dimensions of a particular femur via an intermediate pelvis and femur) [8].

Biomechanical analysis. The reconstructed lower limb model was registered to an in-vivo human motion squatting model [9] via anatomical landmarks. The same method was also applied to a comparative AMH human model and a bonobo (Pan paniscus) skeleton and motion data of flexion/extension internal/external rotation was analysed on all models. On the AMH and Neandertal model, origins and insertions of the hamstring muscles were located on the 3D models and processed to estimate muscles’ line of actions. Hamstring knee moment arms were then processed from the distance between the hamstring muscle line of actions and the knee instantaneous helical axis (Figure 1).
Figure 1: Neandertal model obtained in this study and fused to a squatting motion of a modern human (screen snapshot from lhpFusionBox with data graph and 3D display) [2]. On the left: the model. White bones = Neandertal fossil remains, pink bones = AMH. Anatomical reference frames were built on the hip, knee and ankle joint according to international recommendations. Knee motion axis is displayed. Line-of-action of the long head of the biceps cruralis m. is also visible. On the right: biomechanical graph from data obtained from the model. Motion representation are displayed (see caption in the figure; Add = adduction; Abd = abduction; Ext = extension; Flex = flexion; IntRot = internal rotation; ExtRot = external rotation). The long head of the biceps cruralis m. moment arm is given by a full line. Similar results were obtained for the semi-membranosus m., semi-tendinosus m. and short head of the biceps cruralis m. (not displayed here).

RESULTS AND DISCUSSION
The visualisation of the reconstructed Neandertal skeleton registered to human motion data (Fig. 1) and associated RMS errors [8] indicated that the presented scaling paradigm led to a satisfactory result. Motion analysis on the knee joint allowed further quantification of morphological differences (Fig.1). The Neandertal bones demonstrated slightly more internal/external rotation than AMH and slightly less abduction/adduction although differences were small and may also be related to experimental artefacts and errors (e.g., during the registration process) [8]. Visualisation of motion reconstruction for the Bonobo showed serious discrepancies between joint surface and motion in full extension. Comparison of the muscle moment arms obtained from the Neandertal model and modern human model seem to demonstrate that the available Neandertal specimen show hamstring mechanical advantages compared to a modern human of the same size [2].

CONCLUSIONS
The Neandertal model integrated with the motion data of a human enabled visualisation, creation of anatomical axes, motion representation and the processing of specific biomechanical parameters with graphic output, e.g., related to muscle moment arms (Fig. 1). Neandertals were shown to perform a similar same bipedal motion as anatomically modern humans. The bonobo data showed major differences. The analysis of the hamstring muscles showed that the Neandertal may have had a mechanical advantage in comparison to modern day humans (Fig 1) and [2]. Further studies will concentrate on developing a full muscular skeletal analysis of the Neandertal.

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