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Multivariate assessments of activity-related skeletal changes: Interpreting Bell Beaker specialized male archery and social organization in Central Europe

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Abstract

Objectives: The Bell Beaker period witnessed the rise of individual inhumations with "wealthy" burial contexts containing archery-related grave goods, leading archaeologists to label the individuals in these tombs as "archers." This study looks to (1) compare the skeletons from male "archer" burials with those from male "non-archer" burials—those not having archery-related grave goods—in order to assess a possible link between burial context and physical activity, and (2) apply a biomechanics profile to evaluate whether the individuals associated with these "archer" burials practiced specialized archer activity.

Materials and Methods: The corpus (males only) included 46 "archers" and 40 "non-archers" from Bell Beaker individual inhumations. Osteological data included measurements, scores of entheseal changes, and a diagnosis of certain pathologies. Data analyses involved visual observations, hypothesis tests, dimension reduction, and MANOVA, with approaches aimed at exploring the treatment of data missingness.

Results: Measurement data revealed no differences between the two groups. Evaluations of entheseal changes found that "non-archers" had consistently more instances of bone surface modifications than "archers." Individual assessments of specialized archer occupation identified 11 possible specialized archers.

Discussion: These findings indicate a possible labor differentiation represented through the presence of a probably prestigious "archer" burial context. This suggests a link between grave good presence and labor, but not between a Bell Beaker archery occupation and an "archer" burial context. Data analyses support the application of biomechanics to osteological analyses in order to assess specialized activity on the skeleton.

KEYWORDS
archery, Bell Beaker, biomechanics, entheseal changes

1 | INTRODUCTION

The Bell Beaker period (third millennium BCE) acts as a transition from the end of the Neolithic to the beginning of the Bronze Age in Europe and North Africa (Besse, 2014; Furholt, 2020; Gallay, 1979; Harrison, 1980; Müller & van Willigen, 2001; Nicolis, 2001). This period, so-called for its distinctive pottery, presents a gradual eastward expansion over a vast geographic area while maintaining a largely uniform material culture, in particular with regard to ceramics (Figure 1) (Bailly & Salanova, 1999; Czebreszuk, 2014; Salanova, 2016). These findings originally signaled the presence of a large migration of the Bell Beaker peoples; however, archaeological analyses have found subtle regional differences as well as evidence for local material production (Besse, 2003, 2014, 2015; Czebreszuk, 2014; Harrison, 1980). This evidence for a prominent local tradition combined with the vast geographic reach of the Bell Beakers has raised the question as to how these cultural traditions spread, even leading many archaeologists to refer to this period as a "phenomenon" (Besse, 2014; Czebreszuk, 2014; Lemercier, 1998). Recent analyses examining aDNA have found clear genetic differences between the Bell Beaker peoples of the West and those of the East (modern-day Central Europe), indicating that material similarities were not the result of human migration but rather of ideas (Olalde et al., 2018). At the same time, Bell Beaker genome studies in Britain identified telling similarities with samples from Central Europe, showing that, at least for part of the expansion, migration did play a role (Olalde et al., 2018; Reich, 2019). This complex relationship between migration patterns, local production, and a vast geographic area at such a pivotal time of European prehistory has inspired researchers to explore the daily lives and functioning of the Bell Beaker peoples.

1.1 | Evidence for Bell Beaker social organization

Wealth inequality is a strong indicator for social stratification, and, in archaeology, this is commonly illustrated through funerary traditions, in particular grave goods and tomb architecture. Throughout the Bell Beaker period, burials exhibit skewed distributions of wealth between

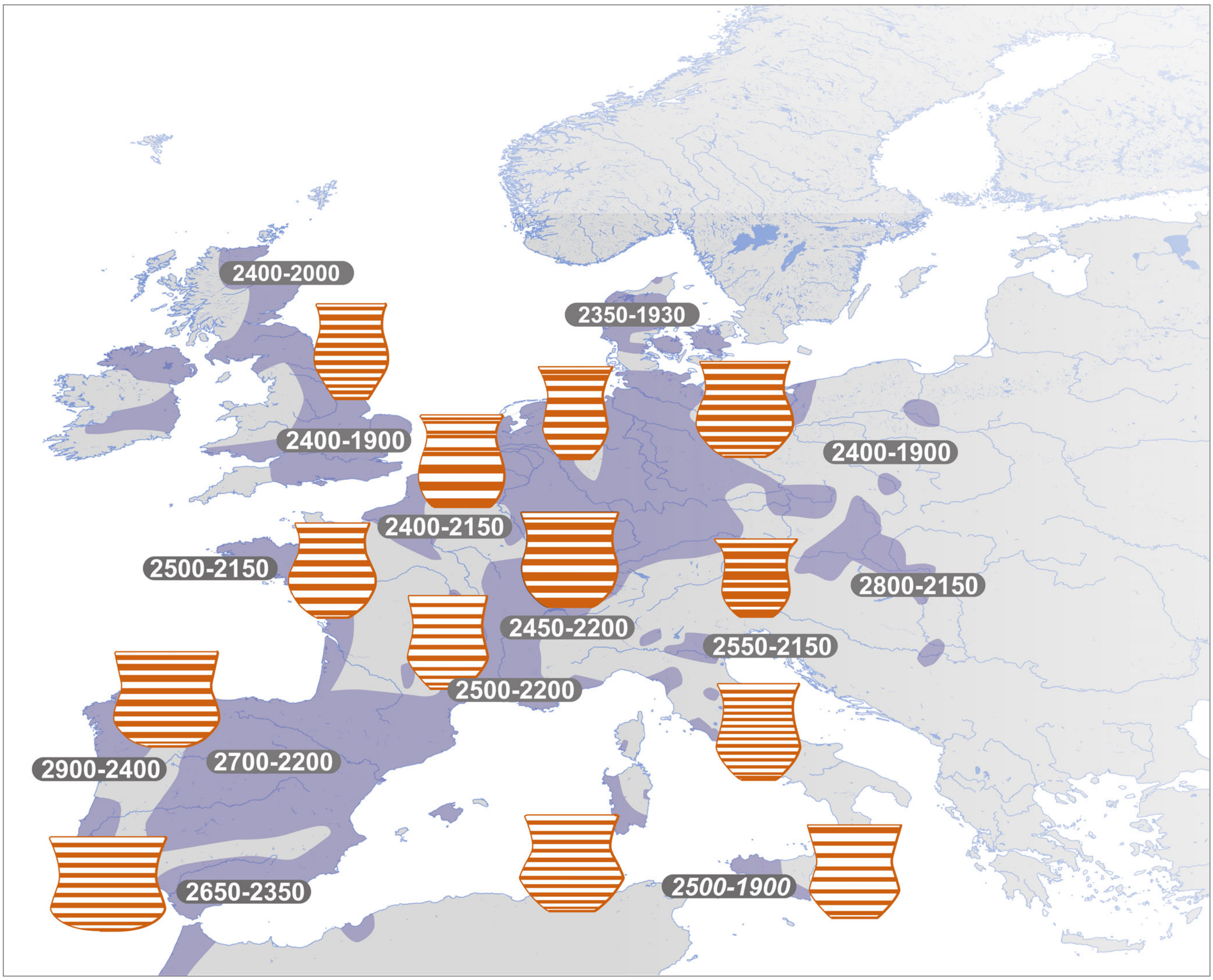


FIGURE 1 A distribution map showing the spread and regional variation of bell beakers throughout Europe, from Besse (2014), Figure 1).

individuals, both in terms of item quantity and quality (e.g., the Bell Beaker cemeteries of Hoštice, Pavlov, and Hulín) (Binford, 1972; Chapman, 2015; Drozdová et al., 2011; Heyd, 2001, 2007; Ryan-Despraz, 2022). Many such goods, for example ornaments and gold decoration, are purely symbolic and show evidence of trade, a practice strongly linked to a centralized economy reminiscent of a complex social organization (Abegg et al., 2022). In addition to grave goods, Bell Beaker monumental tombs also exist, such as the dolmens of Sion "Petit-Chasseur" (Switzerland) and "Saint-Martin-de-Corléans" (Italy), though they are rare (Bocksberger, 1976; Corboud, 2009; De Gattis et al., 2018). Most monumental tombs were only for select individuals; however, their construction would still have required the coordination of multiple people—a level of organization consistent with the presence of leadership roles. Isotopic and genetic analyses also contribute to the assumption of Bell Beaker social stratification. Numerous studies have found evidence for a reduced male geographic mobility (i.e., male sedentarism) together with high maternal genetic diversity, indicating a level of female exogamy demonstrative of patriarchal societies (Fitzpatrick, 2011; Grupe et al., 1997; Sjögren et al., 2019). Lastly, it is worthwhile to consider child burials presenting numerous and "rich" burial items (e.g., ornamental objects, especially those made of metal or carved stone). Children could not yet have held specialized roles in a society, such as artisan or warrior; however, the Bell Beaker period witnessed the presence of "wealthy" child burials, including some instances where these were the most prominent in the cemetery (e.g., Popůvky (Czechia)) (Bálek et al., 1999; Bedáňová, 2023; Heyd, 2000; Matějíčková, 2007; Turek & Černý, 2001). Many of these cases also contained archery-related items, and these "prestigious" burials could indicate the presence of important traditions linked to inheritance (Bedáňová, 2023; Sjögren et al., 2019).

1.2 | Bell Beaker funerary tradition

Investigations classify two general Bell Beaker funerary traditions in continental Europe: the Western Complex (modern-day Western Europe—e.g., France, Spain, and Portugal) characterized most commonly by the presence of collective burials in tombs erected by preceding cultures, and the Eastern Complex (modern-day Central Europe—e.g., Czechia, Hungary, and Poland) marked by the widespread presence of individual inhumations (Heyd, 2001; Müller, 2001; Vander Linden, 2015). However, it is important to note that this classification represents trends rather than a strict dichotomy between funerary complexes; an undefined border and multiple exceptions attest to the complexity of the overall funerary traditions (Lemercier et al., 2022; Salanova, 2022; Tchérémissinoff et al., 2022).

During this time, stone wristguards associated with archery began to appear, most notably in select individual burials of the Eastern Complex, and this has often led archaeologists to interpret these graves as having belonged to archers (Heyd, 2007; Turek, 2017). Indeed, combined with the presence of arrowheads, bow-shaped pendants, and artistic depictions, the Bell Beaker period saw a rise in archery representations, which has prompted hypotheses asserting an archery prominence in social functioning and organization (Corboud, 2009; Nicolas, 2019, 2020; Ryan-Despraz, 2022; Ryan-Despraz & Nicolas, 2022). Additionally, "archer" burials tend to be more wealthy, in terms of both grave good quality and item quantity, while also being relatively uncommon (Fitzpatrick, 2011; Heyd, 2007). The question then arises as to who were these "archers" and what their role could have been in Bell Beaker society.

1.3 | Activity-related skeletal changes

Since the beginning of the 20th century, biological anthropologists have attempted to study daily life and behavior through analyses of activity-related skeletal changes (Capasso et al., 1999; Kennedy, 1998; Larsen, 1997; Merbs, 1983; Villotte, 2023). The principle is based on the idea that bone can adapt, or sometimes alter pathologically, to its external environment, for example to biomechanical constraints (Acosta et al., 2017; Deymier et al., 2019; Nikita et al., 2019; Weiss, 2003; Wolff, 1892). The form and morphology of entheses, which are the insertions on bone for tendons, ligaments, and articular capsules, could reflect such changes (Benjamin et al., 2002, 2004; Benjamin & McGonagle, 2001), and modifications at these points, entheseal changes (EC), are commonly linked to human biomechanics (Cashmore & Zakrzewski, 2013; Dutour, 1992; Havelková et al., 2011; Pálfi & Dutour, 1996; Perreard Lopreno, 2007; Schrader, 2019). In addition to EC, other skeletal changes used to identify activity and behavior have included degenerative joint disease (DJD) and diaphyseal dimensions and geometry (Bridges, 1991; Hawkey & Merbs, 1995; Jones et al., 1977; Jurmain et al., 2012; Rhodes & Knüsel, 2005; Ruff et al., 1994; Walker & Holliman, 1989). Like EC, DJD is also linked to mechanics as the degeneration of the articular cartilage leads to direct bone-on-bone contact through movement, although other important factors such as age and genetics could exacerbate the issue (Chen et al., 2017; Goodman & Martin, 2002; Rogers & Waldron, 1995; Salter., 2002; White, 2000). While the etiologies for DJD are numerous, its appearance in younger individuals is more commonly associated with biomechanics, especially when expressed asymmetrically (Capasso et al., 1999; Mann & Hunt, 2005; Merbs, 1983; Schwartz, 2007; Tainter, 1980). Lastly, metric analyses can also be useful for assessing biomechanical loading. Traditionally, this has specifically included cross-sectional geometry (Becker, 2019; Cowgill, 2018; Honda et al., 2015; Lieberman et al., 2004; Macintosh et al., 2013; Maggiano et al., 2008; Niinimäki et al., 2016; Nikita et al., 2011; Ogilvie & Hilton, 2011), however external measurements could also serve as a cheaper proxy to such techniques. For example, the calculation of bone dimensions (e.g., a "robusticity index") and overall size comparisons could provide developmental insight when comparing populations.

1.4 | Objectives

This study applied non-destructive, macro-observations of external measurements, EC, and DJD to assess a collection of Bell Beaker individuals, organized into two groups based on the presence of archery-related grave goods, for indications of physical activity in general and of specialized archery in particular. While ideally this study would have included both males and females, a lack of female "archer" burials necessitated a males-only focus. The goals of this study were two-fold: (1) to observe any morphological differences between the two groups, which could draw a cultural link between burial context and manual activity, and (2) to test the theory that "archer" burials belonged to specialized archers. This study will additionally evaluate the dependability of activity determinations from the skeleton as well as how data analyses could help improve the reliability of interpretations.

While this study focuses on "archer" burials with respect to daily life and social organization, assessments as to the function of archery, such as for hunting or warfare, are outside the scope of this study; however, related works provide a thorough discussion of this question (see Ryan-Despraz, 2021, 2022). This study also controls for a possible link between archaeological identity ("archer" burial) and biological identity (archer occupation). While "non-archer" burials could have also belonged to specialized archers, this study relies on the archaeological context to drive the hypothesis of occupation. For this reason, individual analyses of specialization do not include "non-archers".

2 | MATERIALS AND METHODS

2.1 | Skeletal collection

This study examined 86 male skeletons from individual inhumations of the Bell Beaker Eastern Complex (modern-day Central Europe), specifically the regions of Lower and Upper Austria, Bavaria (Germany), Bohemia (Czechia), and Moravia (Czechia) (Supplementary Information Figures S1–S3). This focus on individual burials was essential because of the direct relationship between the individual and the burial context. The decision to group individuals from such a large geographic area was based on three reasons: (1) Bell Beaker attribution—archaeological analyses all confidently classified these individuals as "Bell Beaker", (2) distribution—many inhumations are single finds not belonging to a cemetery, and (3) adequate sample size—"archer" burials are not prevalent and this study requires a level of bone surface preservation not common in prehistoric collections, therefore the research required an expanded geographic scope in order to ensure an adequate sample size.

The skeletal sample was organized into two groups: "archers" (group A, $n = 46$) (Table 1) and "non-archers" (group N, $n = 40$) (Table 2). The "archer" burials contained at least one object related to archery (i.e., stone wristguard, arrowhead, or bow-shaped pendant) (Figure 2), whereas the "non-archers" did not have any goods associated with archery.

2.2 | Sex, age, and measurements

This study controlled each skeleton for sex and age. The primary method of sex determination was DSP 2 (Brůžek et al., 2017), which uses the discriminant analysis principle to compare pelvis measurements to an established worldwide reference sample. When preservation did not allow for DSP 2 analyses, additional methods involved morphological observations of the coxal bone, skull, and burial orientation, two of which were required for a sex determination (Acsádi & Nemeskéri, 1970; Bruzek, 2002; Brůžek, 1991; Buikstra & Ubelaker, 1994; Murail et al., 2005; Stevenson et al., 2009; Walker, 2008). Burial orientation for the Bell Beaker period is exceedingly consistent and reliable, especially for male burials; indeed, a study by Müller (2001) only found inconsistencies between biological sex and archaeological grave orientation 4.6–5.6% of the time (Heyd, 2001; Vander Linden, 2015). This study was not able to determine the sex of one group A individual, Lochenice 3, and they were therefore not included in the population analyses. However, this individual's seemingly "rich" burial context (i.e., multiple items, with many examples of carved stone) remained of interest, therefore the skeleton was still included in individual analyses for specialized archer activity.

Age determinations included four methods adapted to specific age groups. For adolescents and young adults, fusion stages were classified for the ischial tuberosity (Coqueugniot & Weaver, 2007) as well as for the sternal epiphysis of the clavicle, annular epiphysis of the thoracic vertebrae, annular epiphysis of the lumbar vertebrae, the iliac crest, and the inferior angle of the scapula (Schaefer et al., 2009). For individuals >35 years, evaluations of the sacro-pelvic iliac surface, including development scores for the auricular surface and modifications of the apical surface and iliac tuberosity, were implemented (Schmitt, 2001, 2005). Lastly, the Brooks and Suchey (1990) method for the os pubis served to classify individuals into one of six age groups throughout adulthood. As a final verification, individuals demonstrating tooth wear consistent with advanced aging were excluded (Faillace et al., 2017; Mays, 1998, 2002). Any individual for whom age was not confidently <60 years was not included in the study.

An upper and lower age limit was necessary for two main reasons: (1) studies have shown that both EC and DJD appear much more commonly with age (Alves Cardoso & Henderson, 2010; Jurmain et al., 2012; Pearson & Lieberman, 2004), and (2) children could not yet have been "specialized" in terms of physical development. For these reasons, this study implemented an age range of ~15 to 60 years. However, analyses do not differentiate between age groups due to an already relatively low sample size and the fact that determinations are often quite broad.

When preservation allowed, this study additionally gathered 56 measurements (per side) on the clavicle ($n = 4$), scapula ($n = 9$), humerus ($n = 12$), radius ($n = 6$), ulna ($n = 6$), femur ($n = 11$), tibia ($n = 6$), and fibula ($n = 2$) and calculated two bone proportion index ratios. The two ratios, calculated from the measurements, include

Type 1:

$$\frac{Right - Left}{Average}.$$

The resulting value then further provides indications for left-versus right-handed bone-size dominance trends.

TABLE 1 The suspected "archers" (Group A) used in the study.

Site	Region	Grave/Inventory Number	Sex	Age	Grave context
Altenmarkt	Bavaria (DE)	gr. 6, obj. 25	Male[d]	30–60	Wristguard (left), arrowheads, dagger, bell beaker, hematite, flint, and boar's tooth (Schmotz, 1990)
Brandýsek	Bohemia (CZ)	71	Male	<60	Four flint arrowheads, copper dagger, bowl, jug, and two flint fragments (Kytlicová, 1960; Hájek, 1968a, 1968b)
Franzhausen	Lower Austria (AT)	230	Male	30–40	Wristguard, spherical cup, bowl, bronze, copper, and pearl rings/beads near the neck (Neugebauer & Gattringer, 1982)
Gemeinlebarn	Lower Austria (AT)	2071	Male[d]	30–50	Wristguard, two bell beakers, cup, handled pot, copper awl, dagger, and two metal spiral rings (Neugebauer & Neugebauer, 1997; Neugebauer & Neugebauer-Maresch, 2001)
Hoštice 1, za Hanou	Moravia (CZ)	821	Male[d]	20–27	Bow-shaped pendant, pitcher, bowl, small container, worked stone tip, animal bones (domesticated), and worked bone (Drozdová et al., 2011; Růžičková, 2008, 2009)
Hoštice 1, za Hanou	Moravia (CZ)	862	Male[d]	30–50	Wristguard, copper dagger, bell beaker, pitcher, bowl, bone button (unsure if v-shaped), and animal bones (Olivik, 2009a, 2009b; Drozdová et al., 2011)
Hoštice 1, za Hanou	Moravia (CZ)	863	Male[d]	30–50	Seven arrowheads, gold and silver fragments, and animal bones (Drozdová et al., 2011; Olivik, 2009a, 2009b; Peška, 2013a; Sosna, 2012)
Hoštice 1, za Hanou	Moravia (CZ)	864	Male[d]	30–50	Bow-shaped pendant, four arrowheads, bell beaker, pitcher, and animal bones (domesticated) (Drozdová et al., 2011; Olivik, 2009a, 2009b; Růžičková, 2009; Sosna, 2012)
Hoštice 1, za Hanou	Moravia (CZ)	884	Male[d]	<50	Wristguard, copper dagger, three pitchers, bowl, and animal bones (Drozdová et al., 2011; Olivik, 2009a, 2009b)
Hoštice 1, za Hanou	Moravia (CZ)	915	Male[d]	<50	Wristguard, arrowheads, copper dagger, two bell beakers, lithic blade, polishing stone, and animal bones (domestic) (Olivik et al., 2009a, 2009b; Drozdová et al., 2011; Sosna, 2012)
Hoštice 1, za Hanou	Moravia (CZ)	949	Male	30–60	Wristguard, four arrowheads, two pitchers, bowl, two silver spirals, three gold spirals, bone object (ring?), animal bones (domestic) (Olivik et al., 2009a, 2009b; Drozdová et al., 2011; Sosna, 2012; Peška, 2013a)
Hulín1	Moravia (CZ)	66	Male[d]	<60	Wristguard, boar tusk (Peška, 2013b)
Hulín1	Moravia (CZ)	73	Male[d]	<60	Two arrowheads, anvils, hammers (smith equipment), bowl, and decorated bell beakers (Peška, 2013b)
Hulín1	Moravia (CZ)	85	Male[d]	30–50	Wristguard (Peška, 2013b)
Ivanovice	Moravia (CZ)	812	Male	<60	Wristguard, two arrowheads, copper dagger, two mugs, and bowl with animal bones (Tkáč, 2008)
Ivanovice	Moravia (CZ)	814	Male	<60	Arrowheads (Tkáč, 2008)
Landau (Dingolfing, 1981)	Bavaria (DE)	2118/24, 22/1193	Male	>19	Wristguard, two arrowheads, daggers, and amber pearls (Heyd, 2000)
Ledce II	Moravia (CZ)	1/52	Male[d]	<60	Wristguard (left association), stone arrowhead, two decorated beakers, boar tusk, bone clasp, and bone object (Dvořák, 1992)
Lhánice	Moravia (CZ)	8	Male[d]	<60	Wristguard, copper dagger, cup, pitcher (Moucha, 2005)
Lochenice	Bohemia (CZ)	3	ND[a]	30–40	Two arrowheads, quartzite blade, bowl, jug, bone pendant, and flint fragments (Hájek, 1968a, 1968b)
Oberstimm II/1982	Bavaria (DE)	2	Male	<60	Wristguard, arrowheads, copper dagger, lithics, bowl, and bell beaker (Rieder, 1983)

(Continues)

TABLE 1 (Continued)

Site	Region	Grave/Inventory Number	Sex	Age	Grave context
Osterhofen-Altenmarkt	Bavaria (DE)	2	Male[d]	30–50	Five wristguards, three arrowheads, three daggers, four small cups, one large cup, and flint (Schmotz, 1994)
Osterhofen-Altenmarkt	Bavaria (DE)	10	Male	<60	One wristguard, bow-shaped pendant fragments, two copper objects, several small pots, and five bowls (Schmotz, 1994)
Osterhofen-Altenmarkt	Bavaria (DE)	11	Male[d]	<60	Arrowhead, copper objects, decorated bow-shaped pendants, flint fragments, and nine cups (Kern, 2016a; Schmotz, 1994)
Ostopovice	Moravia (CZ)	14	Male[d]	30–60	Five arrowheads, four-footed bowl, small jug, and animal bones (Dvořák, 1992)
Pavlov	Bohemia (CZ)	500	Male	17–21	Two bow-shaped pendants (boar's tusk), copper dagger, jug, and pottery shard (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	502	Male	16–34	Bow-shaped pendant (boar's tooth), two arrowheads, jug, bowl, and animal bones (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	519	Male	15–20	Wristguard, arrowheads, bowl and jug fragments, and animal bones (Dvořák et al., 1996)
Praha 8-Kobylisy	Bohemia (CZ)	36,749	Male[d]	<50	Arrowhead, bow-shaped pendant, copper dagger, and ceramics (Fridrichová et al., 1995; Soudský, 1954)
Radovesice	Bohemia (CZ)	53/80-I	Male[d]	20–29	Found in the same burial group as cremated child 53/80-II and grave goods more associated with child than this adult male; however they include wristguard, arrowheads, bow-shaped pendant, bell beaker, jug, ceramic fragments, v-shaped buttons[b] (Muška, 1981; Turek & Černý, 2001); Turek, 2004, 2006; Shbat, 2013)
Radovesice	Bohemia (CZ)	59/80-II	Male	20–29	Found in the same burial group as cremated child 53/80-II; grave goods more associated with child than this adult male; however, they include wristguard, bow-shaped pendant, arrowheads, and v-shaped buttons[c] (Muška, 1981; Shbat, 2013)
Radovesice	Bohemia (CZ)	116/78	Male	<34	Wristguard, arrowhead, copper dagger, bell beaker, jug, antler, boar's tooth, lithics, beaver tooth, and flint fragments (Muška, 1981; Shbat, 2013; Turek, 2003)
Rosnice	Bohemia (CZ)	I/59	Male[d]	19–34	Wristguard (left association), copper dagger, flint dagger, bow-shaped pendant, bell beaker, small jug, and copper ring (Hájek, 1968a, 1968b; Vokolek, 1965)
Rousínov	Bohemia (CZ)	19/2	Male	20–29	Double burial, second individual a male child; wristguard, arrowheads, sharpening stone, bow-shaped pendant, bell beaker, bowl, cup, and flint (Geisler, 1990)
Stehelčeves	Bohemia (CZ)	1	Male	<60	Two wristguards, two bell beakers, bell beaker shards, jug, copper dagger, copper awl, boar tooth fragment, grindstone, stone anvil, and stone hammer (Hájek, 1966, Hájek, 1968a, 1968b)
Stehelčeves	Bohemia (CZ)	2	Male	<60	Wristguard, stone arrowheads, three bell beakers, copper dagger, metal hammer, flint scraper, antler ax, and flint bevels (Hájek, 1966, Hájek, 1968a, 1968b)
Straubing Stadttäcker	Bavaria (DE)	1	Male	30–50	Wristguard, bow-shaped pendant, and cup (Christlein, 1982; Prammer, 1981)
Sulejovice	Bohemia (CZ)	3	Male	<60	Wristguard, three arrowheads, two bell beakers, and two jugs, and chunk of amber (Hájek, 1962; Hájek, 1968a, 1968b)
Tödling	Upper Austria (AT)	4	Male	17–20	Bowl with animal bones (pig), dagger tip, three bow-shaped pendants, bit (horse) cross-section, orientation ENE-WSW (Kern, 2016b; Kern & Wiltschke-Schrotta, in press)

TABLE 1 (Continued)

Site	Region	Grave/Inventory Number	Sex	Age	Grave context
Tödling	Upper Austria (AT)	5	Male	20–35	Two handled bowls, five bow-shaped pendants, flint (blade fragment?), pebble (worked), orientation ENE-WSW (Kern and Wiltschke-Schrotta, in press)
Trieching	Bavaria (DE)	670, 22/1193	Male	30–50	Excavation grave 1; wristguard, arrowheads, lithic scraper, copper dagger, amber bead, and beaker (Kreiner, 1991)
Velké Přilepy	Bohemia (CZ)	2	Male	16–24	Flint arrowhead, bowl, and pitcher (Skružný et al., 2000)
Veselí na Moravě	Moravia (CZ)	XVII, 158	Male[d]	16–24	Wristguard (left), jug, bowl, pebbles, and boar's tooth (Staňa, 1960)
Vykáň	Bohemia (CZ)	1	Male[d]	<60	Wristguard, bow-shaped pendant, 2 jugs, bowl, flint dagger, pot, and leg device (Hájek, 1968a, 1968b)
Weichering	Bavaria (DE)	17	Male[d]	30–60	Bow-shaped pendant, cup, bowl, and ceramic fragments (Weinig, 1992)
Žabovřesky	Bohemia (CZ)	32,293	Male	<60	Wristguard, bell beaker, pot, jug, and bowl (Blajerová, 1962; Zápotocký, 1962)

Abbreviation: ND, not determined.
[a]The biological sex determinations were not consistent. Even with the DSP2 method, one os coxal identified as male and the other as female. The Walker method revealed rather female characteristics, but the burial orientation was male (lying on the left side).
[b]The grave goods are seemingly more associated with the child burial. Therefore this individual's classification as A is debatable; however because the general burial context still included archery-related items, 53/80-I maintains an A status.
[c]As with 53/80-II, the grave goods are seemingly more associated with the child burial, therefore this individual's classification as A is debatable.
[d]A sex determination using the DSP 2 method.

Type 2:

$$\frac{\textit{Circumference}}{\textit{Maximum Length}}.$$

This ratio could allow for a comparison of midshaft "robusticity" differences between the two groups.

Tables 3 and 4 provide a complete list of the measurements and ratios, all of which follow the criteria established in Martin and Saller (1957).

2.3 | Biomechanics

This study examined each individual with respect to a biomechanics profile. This profile involved a literature review and had three main objectives: (1) determine the precise movements and corresponding muscles activated in archery, (2) examine modern archery reports for common injuries, and (3) assess previous anthropological research on the skeletons of suspected archers. Establishing the biomechanics and common injuries in archery comprised organizing the findings of multiple sources into one complete overview of archery science. This overview identified 39 primary muscles activated during archery, and these muscles served as the basis of this study's assessment of EC. Table 5 lists these muscles, their side distribution (draw arm, bow arm, or both arms), and the corresponding source. The literature review for injuries found that they most commonly occur from overuse and are located on the draw arm shoulder, with prominent secondary locations at the elbow (Table 6). Lastly, this study is not the first to examine specialized archery in the archaeological record (though it is the first for the Bell Beaker period); therefore, findings from seven previous studies were also considered. Primary observations from those works include the presence of os acromiale (Stirland, 2013), DJD of the glenoid cavity and humeroradial joint (Merbs, 1983; Ryan et al., 2018), larger upper limb measurements (Stirland, 2013; Thomas, 2014), overall greater levels of EC in archer populations when compared with non-archer populations (Ryan et al., 2018; Thomas, 2014; Tihanyi et al., 2015), and upper limb asymmetries in likely archers (Dutour, 1986; Molnar, 2006; Ryan et al., 2018; Stirland, 2013; Thomas, 2014; Tihanyi et al., 2015).

2.4 | Analyses of entheseal changes (EC)

The entheses chosen for evaluation were those linked to the muscles established by the biomechanics review. EC analyses included four different methods according to the type of enthesis (mainly, fibrous or fibrocartilaginous), with each enthesis matched to the method best able to encapsulate its surface appearance. Those methods included the Coimbra method, the Mariotti et al. method, the Villotte method, and an absence/presence method (Henderson et al., 2013, 2016; Mariotti et al., 2004, 2007; Villotte, 2006). The Coimbra method requires eight different scores for a single enthesis as it differentiates between the contour and the center. The Mariotti et al. method provides a score based on whether an enthesis presents signs of erosion, proliferation, or robusticity. This study used Villotte's Group 2 method for one enthesis, which scores based on the absence or presence of enthesophytes or an erosion surface. Lastly, the absence/presence

TABLE 2 The "non-archers" (Group N) used in the study.

Site	Region	Grave/inventory number	Sex	Age	Grave context
Augsburg, Uni-Süd 1991	Bavaria (DE)	5	Male[a]	20–35	No archery context[b] (Kociumaka & Dietrich, 1992)
Brandýsek	Bohemia (CZ)	18	Male[a]	16–24	Bowl (Kytlicová, 1960; Hájek, 1968a, 1968b)
Brandýsek	Bohemia (CZ)	26	Male	<50	Bowl, bone pendant (Kytlicová, 1960; Hájek, 1968a, 1968b)
Brno-Juliánov	Moravia (CZ)	1/67, 242	Male	<60	Jug (Dvořák, 1992; Peškař, 1968; Stloukal, 1968)
Franzhausen II	Lower Austria (AT)	3382	Male	30–50	2 cups, oriented N-S facing East, surrounded by circular ditch (Kern, 2011)
Gemeinlebarn	Lower Austria (AT)	3559	Male	30–50	Beaker, two jugs, and two metal rings (Neugebauer & Neugebauer, 1997; Neugebauer & Neugebauer-Maresch, 2001)
Henzing	Lower Austria (AT)	3	Male[a]	15–20	Grave group with Henzing grave 1, 2, animal bones, oriented N-S facing east (Friesinger, 1976; Jungwirth, 1976)
Holubice IV	Bohemia (CZ)	7	Male	<50	Bell beaker (Rakovský, 1985)
Hoštice 1, za Hanou	Moravia (CZ)	818	Male	<50	Ceramics, fragments of a copper plate (Drozdová et al., 2011)
Hoštice 1, za Hanou	Moravia (CZ)	859	Male[a]	<60	Ceramics (Drozdová et al., 2011)
Hoštice 1, za Hanou	Moravia (CZ)	931	Male	<50	Ceramics, stone tool, and animal bones (Drozdová et al., 2011)
Hulín 1	Moravia (CZ)	72	Male	<60	No archery context (Peška, 2013b)
Kněževes	Bohemia (CZ)	12	Male[a]	30–60	Bowl, jug (Kytlicová, 1956; Hájek, 1968a, 1968b)
Laa Thaya	Lower Austria (AT)	NL 46	Male	~23	No archery context (Kern (2003), and personal communication)
Landau SO 1992	Bavaria (DE)	7	Male	<60	Beaker, cup, jug, v-shaped buttons, and dagger (Heyd, 2000; Husty, 1993)
Leopoldsdorf	Lower Austria (AT)	5	Male[a]	25–35	Grave group of five: several cups (some decorated), bowls, other ceramic forms, two gold burl rings, two simple gold rings, two faience pearls, amber jewelry, and animal bones (Willvonseder, 1937)
Lhánice	Moravia (CZ)	1	Male[a]	<60	Pot, cup, sheep bones (Moucha, 2005)
Libochovice	Bohemia (CZ)	32,244	Male	<60	Bowl, cup, animal bones (Zápotocký, 1962)
Lochenice	Bohemia (CZ)	8	Male[a]	<60	None (Buchvaldek, 1990)
Lochenice	Bohemia (CZ)	15	Male	<60	Jug, animal bones (Buchvaldek, 1990)
Morkůvky	Moravia (CZ)	9544	Male[a]	40–50	Jugs, bowl, and animal bones (domestic) (Dvořák et al., 1996; Unger, 1984)
Ostopovice	Moravia (CZ)	20	Male[a]	25–40	None (Dvořák, 1992)
Pavlov	Bohemia (CZ)	516	Male[a]	<50	Jug (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	517	Male	<50	Bowl (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	525	Male[a]	<50	None (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	566	Male	14–26	Bowl (Dvořák et al., 1996)
Pavlov	Bohemia (CZ)	570	Male	<60	Two bell beakers, copper dagger, and lithic industry (Dvořák et al., 1996)
Plotiště nad Labem	Bohemia (CZ)	36,100	Male[a]	20–29	Bone awl, flint blade, and bone clasps (Vokolek, 1981)
Radovesice	Bohemia (CZ)	2/80	Male	<60	Ceramic fragment (Turek, 2006)
Roštín	Moravia (CZ)	1	Male[a]	<60	Jug (Spurný, 1957)
Straubing-Lerchenhaid	Bavaria (DE)	2	Male[a]	30–60	No archery context (personal contact with archaeologist Prof. Volker Heyd; Sjögren et al., 2019)
Straubing-Lerchenhaid	Bavaria (DE)	13	Male	20–39	No archery context (personal contact with archaeologist Prof. Volker Heyd; Sjögren et al., 2019)

TABLE 2 (Continued)

Site	Region	Grave/inventory number	Sex	Age	Grave context
Sulejovice	Bohemia (CZ)	2	Male	30–40	Found with two small children, bell beaker, flint blade, three pearls, two belt plates (Hájek, 1962, 1968a, 1968b)
Tišice	Bohemia (CZ)	30,634	Male	<60	Bell beaker, bowl, and jug (Hájek, 1968a, 1968b)
Tišice	Bohemia (CZ)	30,635	Male	<60	Bell beaker, bowl (Hájek, 1968a, 1968b)
Tödling	Upper Austria (AT)	3	Male	25–40	Bowl with animal bones, handled cup, and orientation NNW–SSE (Kern and Wiltschke-Schrotta, in press)
Tödling	Upper Austria (AT)	6	Male[a]	15–21	Likely meat offerings (goat and sheep), orientation NE–SW (Kern and Wiltschke-Schrotta, in press)
Vyškov	Moravia (CZ)	2/1958, 136	Male	20–29	Four jugs, copper pin, three bone buttons (Ondráček, 1961; Stloukal, 1961)
Želešice	Moravia (CZ)	1/81	Male	<60	None (Dvořák, 1992)
Zwingendorf Alicenhof	Lower Austria (AT)	16	Male	35–45	None (Wiltschke-Schrotta et al., 2001)

[a]A sex determination using the DSP 2 method.

[b]The source only discusses grave 3, implying that all other graves have no additional burial context apart from a few ceramics.

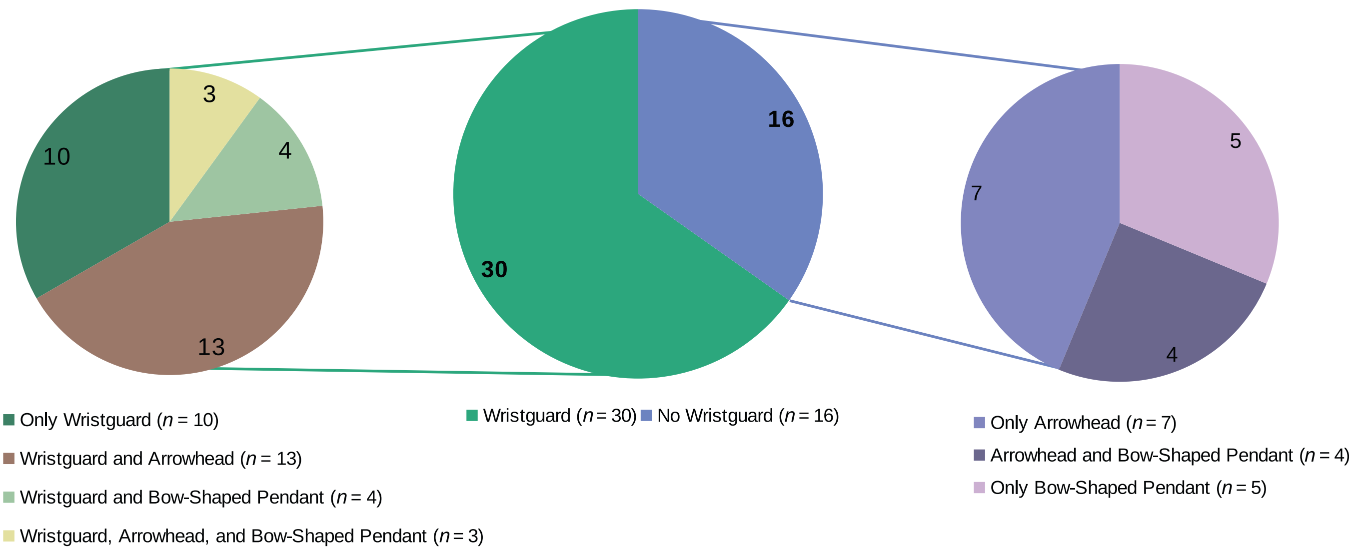


FIGURE 2 The appearance of stone wristguards, arrowheads, and bow-shaped pendants in 46 suspected "archer" burials (males only).

method existed primarily for certain muscle origins and the small insertions of the wrist and hand that are rarely preserved, and the presence classification had two further subcategories specifying a color or texture change versus a pathological irregular surface. Table 7 summarizes these scoring methods and Table 5 lists the method used to score each origin and insertion.

2.5 | Analyses of pathologies

Lastly, this study controlled for the absence or presence of DJD, rheumatoid arthritis (RA), diffuse idiopathic skeletal hyperostosis (DISH), and ankylosing spondylitis (AS). DJD is of interest because while it is linked to biomechanics, it can also be influenced by factors such as age and genetic predisposition (Rogers & Waldron, 1995; Steckel et al., 2005; Waldron, 2009). RA, DISH, and AS required controls because they are examples of pathologies that can lead to EC, but do not have a biomechanical origin (Aufderheide et al., 1998; Mann & Hunt, 2005; Rothschild et al., 1990; Steckel et al., 2005; Waldron, 2009). For this reason, analyses must exclude individuals with these three pathologies; however, due to its links to biomechanics and the exclusion of senior individuals, analyses included skeletons with DJD, noting the specific locations as well as how it manifested on bone. Table 8 contains a summary of the criteria used to identify each pathology. Lastly, it is important to note that preservation did not always allow for a diagnosis of each pathology. Absence of a diagnosis therefore does not necessarily mean absence of a pathology; for example, a DISH diagnosis requires a preserved vertebral column, and

TABLE 3 The measurements taken for each individual when preservation allowed; all measurements and codes are based on the standards from Martin and Saller (1957); from Ryan-Despraz (2021, Table 34).

Bone	Measurement	Code
Clavicle	Maximum length	δ1
	Vertical midshaft diameter	δ4
	Sagittal midshaft diameter	δ5
	Midshaft circumference	δ6
Scapula	Anatomical width	ε1
	Anatomical length	ε2
	Margo axillaris length	ε3
	Supraspinatus fossa width	ε6
	Length of scapular spine	ε7
	Largest acromion width	ε9
	Glenoid height	ε12
	Transverse diameter of glenoid cavity	ε13
	Maximum thickness of spinal crest	-
Humerus	Maximum length	ζ1
	Breadth of proximal epiphysis	ζ3
	Maximum distal breadth	ζ4
	Maximum midshaft diameter	ζ5
	Minimum midshaft diameter	ζ6
	Midshaft circumference (at deltoid tuberosity)	ζ7a
	Head circumference	ζ8
	Transverse head diameter	ζ9
	Vertical head diameter	ζ10
	Breadth of trochlea	ζ11
	Breadth of capitulum	ζ12
	Breadth of olecranon fossa	ζ14
Radius	Maximum length	η1
	Minimum circumference	η3
	Maximum transverse shaft diameter	η4a
	Minimum sagittal shaft diameter	η5a
	Capitulum circumference	η5(3)
	Maximum distal breadth	η5(6)
Ulna	Maximum length	θ1
	Minimum circumference	θ3
	Olecranon breadth	θ6
	Olecranon depth	θ7
	Dorso-volar diameter	θ11
	Transverse diameter	θ12
Femur	Maximum length	λ1
	Sagittal midshaft diameter	λ6
	Transverse midshaft diameter	λ7
	Circumference of midshaft	λ8
	Upper transverse diaphysis diameter	λ9
	Upper sagittal diaphysis diameter	λ10
	Circumference of femoral neck	λ17
	Vertical head diameter	λ18
	Transverse head diameter	λ19
	Circumference of the head	λ20
	Epicondyle width	λ21
Tibia	Maximum length	ν1
	Maximum proximal breadth	ν3
	Maximum distal breadth	ν6
	Maximum midshaft diameter	ν8
	Transverse midshaft diameter	ν9
	Midshaft circumference	ν10
Fibula	Maximum length	ξ1
	Midshaft circumference	ξ4

not all individuals had this. This study excluded individuals with a positive diagnosis, but included individuals where a diagnosis was not possible. While this study acknowledges that such decisions are less than ideal, not including those individuals would have drastically reduced the sample size, even making many analyses impossible. This was additionally considered possible due to the very low prevalence of these pathologies—out of 48 individuals for whom a diagnosis was possible, only one case of DISH and zero cases of AS and RA were found (thus leaving 39 undiagnosed individuals).

2.6 | Data analysis

This study performed all data analyses in R (version 3.6.3) and these included hypothesis tests, dimension reduction, and MANOVA. The basic hypothesis tests aimed to signal possible variations between the measurements and EC of groups A and N and consisted of a t-test (Student's or Welch's depending on variance), Wilcoxon rank-sum test, Fisher's Exact test, and a chi-squared test. This study attempted to improve reliability by additionally performing bootstrapped *t*-tests, bootstrapped tests for the absolute value of the difference in median measurements, a Bonferroni correction, and controlling for each instance of a data outlier. Such tests applied to all datasets with an $n \geq 5$ and an alpha value set at 0.05. Dimension reduction models involved principal component analysis (PCA) for the continuous data (measurements) and multiple correspondence analysis (MCA) for the categorical data (EC). MANOVA tests then further evaluated the resulting dimensions of each PCA and MCA.

Bootstrapped calculations aimed to improve reliability and compensate for unequal datasets, and non-bootstrapped tests were included to compare the two techniques. The bootstrapped tests created a data matrix for the given dataset, then ran 10,000 tests with a seed set at 99, and used resampling to obtain a final p-value.

TABLE 4 Each of the calculated ratios, with all original measurements defined by Martin and Saller (1957); adapted from Ryan-Despraz (2021, Table 54).

Ratios	
Scapula	ε9R – ε9L/AVG
	ε12R–ε12L/AVG
	ε13R–ε13L/AVG
Clavicle	δ4R–δ4L/AVG
	δ5R–δ5L/AVG
	δ6R–δ6L/AVG
	δ4R/δ1R
	δ4L/δ1L
	δ5R/δ1R
	δ5L/δ1L
Humerus	ζ1R–ζ1L/AVG
	ζ3R–ζ3L/AVG
	ζ4R–ζ4L/AVG
	ζ5R–ζ5L/AVG
	ζ6R–ζ6L/AVG
	ζ7aR–ζ7aL/AVG
	ζ10R–ζ10L/AVG
	ζ11R–ζ11L/AVG
	ζ12R–ζ12L/AVG
	ζ14R–ζ14L/AVG
	ζ5R/ζ1R
	ζ5L/ζ1L
	ζ6R/ζ1R
	ζ6L/ζ1L
	ζ7aR/ζ1R
	ζ7aL/ζ1L
Radius	η1R–η1L/AVG
	η3R–η3L/AVG
	η4aR–η4aL/AVG
	η5aR–η5aL/AVG
	η5(6)R–η5(6)L/AVG
Ulna	θ1R–θ1L/AVG
	θ3R–θ3L/AVG
	θ6R–θ6L/AVG
	θ7R–θ7L/AVG
	θ11R–θ11L/AVG
	θ12R–θ12L/AVG
	θ11R/θ1R
	θ11L/θ1L
Femur	λ1R–λ1L/AVG
	λ6R–λ6L/AVG
	λ7R–λ7L/AVG
	λ8R–λ8L/AVG
	λ17R–λ17L/AVG
	λ18R–λ18L/AVG
	λ19R–λ19L/AVG
	λ20R–λ20L/AVG
Tibia	ν6R–ν6L/AVG
	ν8R–ν8L/AVG
	ν9R–ν9L/AVG
	ν10R–ν10L/AVG
Fibula	ξ4R–ξ4L/AVG

PCA and MCA are not possible on datasets containing missingness, which is a common problem with archaeological data. In order to address this issue, this study also tested multiple imputation models. For the PCA, each dataset required listwise deletion to lower the missingness to ≤30% before applying the MICE package (multivariate imputation by chained equations) (Buuren & Groothuis-Oudshoorn, 2011; Katitas, 2019; Lee & Simpson, 2014; Serneels & Verdonck, 2008; Zhang et al., 2019). This package imputes the missing data with plausible values in order to estimate regression coefficients not affected by the missing values. This follows a Conditional Multiple Imputation approach, which allows for increased flexibility as the distribution is calculated for each variable as opposed to each entire dataset (Buuren & Groothuis-Oudshoorn, 2011; Katitas, 2019). The imputation parameters include: number of multiple imputations based on percent missingness (e.g., 17% missingness applied 17 imputations), the predictive mean matching imputation model, 50 maximum iterations, and a seed set to 99. Imputations for the MCA applied a similar approach with the adapted package missMDA and the function imputeMCA, which uses regularized iterative MCA (Husson & Josse, 2014; Josse et al., 2012). Such methods have been tested in biological anthropology and identified as potential solutions to analyses with missing data (Wissler et al., 2022).

2.7 | Analyses at the individual level

Analyses at the individual level involved symmetry scores following the biomechanics profile. This was a two-step process: (1) organize the entheses according to draw arm, bow arm, or both arm activation (Table 5) and (2) note the symmetry of each. In other words, when an enthesis was visible for both the right and left sides, a comparison was made as to which side exhibited greater surface modification. Because this study assumes an association between enthesis appearance and muscle activation, this symmetry score could indicate whether a muscle was more physically developed on the right or left side. Therefore, the idea is that by organizing these symmetry scores with respect to the biomechanics of muscle activation in archery, it could be possible to identify specialized archers. When applicable, these individual analyses also considered the presence of trauma and DJD.

TABLE 5 The list of muscles associated with the draw arm, bow arm, and both arms in archery, scored for origins and insertions, according to various researchers (Ryan-Despraz, 2021, 2023).

	Activated muscle	Source and location distribution (draw arm/both arms/bow arm)	Sources	Scoring method
Draw arm	*m. extensor indicis*	1/0/0	Kosar and Demirel (2004)	A/P—Origin, A/P—Insertion
	m. extensor digiti minimi	1/0/0	Kosar and Demirel (2004)	A/P—Insertion
	m. extensor carpi radialis longus	2/0/0	Kosar and Demirel (2004) and Sessa (1994)	A/P—Insertion
	m. extensor carpi radialis brevis	2/0/0	Kosar and Demirel (2004), Sessa (1994)	A/P—Insertion
	m. brachialis	3/0/0	Kosar and Demirel (2004), Lapostolle (2004), and Sessa (1994)	Mariotti et al.—Insertion
	m. extensor digitorum	5/1/0	Açıkada et al. (2004), Clarys et al. (1990), Ertan et al. (2003), Kosar and Demirel (2004), Martin et al. (1990), and Tinazci (2011)	A/P—Insertion
	m. flexor digitorum profundus	2/1/0	Ahmad et al. (2014), Kaymak et al. (2012), and Kosar and Demirel (2004)	A/P—Origin, A/P—Insertion
	m. flexor digitorum superficialis	5/1/0	Ahmad et al. (2014), Clarys et al. (1990), Ertan et al. (2003), Kosar and Demirel (2004), Martin et al. (1990), and Tinazci (2011)	Mariotti et al.—Origin, A/P—Insertion
	m. biceps brachii	5/0/1	Açıkada et al. (2004), Clarys et al. (1990), Kosar and Demirel (2004), Lapostolle (2004), Nishizono et al. (1987), and Sessa (1994)	Mariotti et al.—Origin, Coimbra—Insertion
	m. trapezius	3/1/0	Clarys et al. (1990), Hu and Tang (2005), Tinazci (2011), and Zipp (1979)	Mariotti et al.—Insertion, A/P—Insertion
	Superior *m. trapezius*	1/0/0	Nishizono et al. (1987)	A/P—Insertion
	Middle *m. trapezius*	3/2/0	Kosar and Demirel (2004), Lapostolle (2004), Littke (2004), Nishizono et al. (1987), and Sessa (1994)	Mariotti et al.—Insertion
	Inferior *m. trapezius*	1/1/0	Kosar and Demirel (2004) and Littke (2004)	Mariotti et al.—Insertion
	m. rhomboid major	2/1/0	Kosar and Demirel (2004), Lapostolle (2004), and Littke (2004)	Mariotti et al.—Insertion
	m. rhomboid minor	2/1/0	Kosar and Demirel (2004), Lapostolle (2004), and Littke (2004)	Mariotti et al.—Insertion
	Posterior *m. deltoid*	3/1/0	Kosar and Demirel (2004), Lapostolle (2004), Sessa (1994), and Tinazci (2011)	Mariotti et al.—Origin
	m. infraspinatus	1/1/0	Kosar and Demirel (2004) and Littke (2004)	A/P—Origin, Coimbra—Insertion
	m. teres major	1/1/0	Kosar and Demirel (2004) and Lapostolle (2004)	Mariotti et al.—Origin, Mariotti et al.—Insertion
	m. brachioradialis	1/1/0	Clarys et al. (1990) and Kosar and Demirel (2004)	Mariotti et al.—Origin, A/P—Insertion
	lig.costoclavicular	2/0/0	Park et al. (2013) and Tihanyi et al. (2015)	Coimbra—Insertion

TABLE 5 (Continued)

	Activated muscle	Source and location distribution (draw arm/both arms/bow arm)	Sources	Scoring method
Both arms	*m. palmar interossei*	1/0/1	Kosar and Demirel (2004) and Sessa (1994)	A/P—Origin, A/P—Insertion
	m. pronator teres	0/1/0	Kosar and Demirel (2004)	Mariotti et al.—Origin, Mariotti et al.—Insertion
	m. pronator quadratus	0/1/0	Kosar and Demirel (2004)	Mariotti et al.—Origin, A/P—Insertion
	m. supinator	0/1/0	Lapostolle (2004)	Mariotti et al.—Origin, A/P—Insertion
	m. latissimus dorsi	0/1/0	Kosar and Demirel (2004)	Mariotti et al.—Origin, Mariotti et al.—Insertion
	m. pectoralis major	1/0/1	Açıkada et al. (2004) and Kosar and Demirel (2004)	Mariotti et al.—Origin, Mariotti et al.—Insertion
	m. subscapularis	0/1/0	Lapostolle (2004)	Mariotti et al.—Origin, Coimbra—Insertion
	m. supraspinatus	1/1/1	Kosar and Demirel (2004), Lapostolle (2004), and Littke (2004)	A/P—Origin, Coimbra—Insertion
	m. teres minor	0/1/0	Kosar and Demirel (2004) and Littke (2004)	Mariotti et al.—Origin, Coimbra—Insertion
	m. deltoids	3/1/3	Açıkada et al. (2004), Ahmad et al. (2014), Hu and Tang (2005), Kosar and Demirel (2004), Littke (2004), and Stirland, 2013, Zipp	Mariotti et al.—Insertion
	Lateral *m. deltoid*	1/0/1	Clarys et al. (1990) and Nishizono et al. (1987)	Mariotti et al.—Origin
	m. serratus anterior	0/1/0	Kosar and Demirel (2004)	Mariotti et al.—Insertion
	m. extensor carpi ulnaris	1/0/1	Kosar and Demirel (2004) and Sessa (1994)	A/P—Insertion
Bow arm	*m. flexor digiti minimi brevis*	0/0/1	Kosar and Demirel (2004)	A/P—Insertion
	m. opponens digiti minimi	0/0/1	Kosar and Demirel (2004)	A/P—Insertion
	m. dorsal interossei	0/0/1	Kosar and Demirel (2004)	A/P—Origin, A/P—Insertion
	m. lumbricales	0/0/1	Kosar and Demirel (2004)	A/P—Insertion
	m. anconeous	0/0/1	Kosar and Demirel (2004)	Coimbra—Origin, Mariotti et al.—Insertion
	m. flexor carpi ulnaris	0/0/2	Kosar and Demirel (2004) and Sessa (1994)	A/P—Insertion (pisiform, hamate)
	m. flexor carpi radialis	0/0/1	Kosar and Demirel (2004)	A/P—Insertion
	m. triceps brachii	0/1/5	Açıkada et al. (2004), Clarys et al. (1990), Kosar and Demirel (2004), Lapostolle (2004), Nishizono et al. (1987), and Sessa (1994)	Coimbra-Origin (long hd.), Mariotti et al.—Origin (lateral), A/P-Origin (medial), Villotte—Insertion
	Anterior *m. deltoid*	0/1/1	Kosar and Demirel (2004) and Sessa (1994)	Mariotti et al.—Origin

Abbreviations: A/P, Absence/presence method.

Note: "Source and Location Distribution" indicates the number of sources citing each location (x/y/z = draw arm/both arms/bow arm), for example 2/1/0 signifies that 2 sources link this muscle only to the draw arm, 1 source links it to both arms, and no sources link it only to the bow arm, from Ryan-Despraz (2021, Table 28). The last column indicates the method used to score each enthesis as well as if it was applied to a muscle origin or insertion.

TABLE 6 Common injuries associated with specialized archery (Ryan-Despraz, 2021, 2023).

	Common Injuries	Sources
Draw arm	Shoulder tendinitis—mainly the *m. supraspinatus*, but also the *m. infraspinatus*, *m. teres minor*, and *m. subscapularis*	Gopal Adkitte et al. (2016), Hildenbrand and Rayan (2010), Kaynaroğlu and Kiliç (2012), and Mann and Littke (1989)
	Shoulder impingement	Kaynaroğlu and Kiliç (2012), Littke (2004), Mann and Littke (1989), Naraen et al. (1999), Niestroj et al. (2018), Prine et al. (2016), and Singh and Lhee (2016)
	Biceps tendinitis	Kaynaroğlu and Kiliç (2012) and Mann and Littke (1989)
Bow arm	Epicondylitis	Frostick et al. (1999), Lapostolle et al. (2004), Niestroj et al. (2018), Rayan (1992), Sessa (1994), Singh and Lhee (2016), and Whiteside and Andrews (1989)
	Osteochondritis dissecans	Andrews and Whiteside (1993)
	Osseous Hypertrophy at the elbow	Andrews and Whiteside (1993)
	De Quervain's Tenosynovitis	Kaynaroğlu and Kiliç (2012) and Rayan (1992)

TABLE 7 The four methods used to classify the enthesis, their basic criteria, and notations, with thorough definitions and references available in the corresponding publications (Henderson et al., 2013, 2016; Mariotti et al., 2004, 2007; Villotte, 2006, 2009), an increasing notation (number or letter) denotes a larger or more prominent surface modification (e.g., a stage 2 will cover more of the enthesis surface than stage 1).

	Criteria—appearance on bone	Notation/ EC Score
Coimbra method (Henderson et al., 2013, 2016)	Contour: Bone formation (OP)	0, 1, or 2
	Contour: Bone erosion (OL)	0, 1, or 2
	Center: Texture change	0 or 1
	Center: Bone formation (OP)	0, 1, or 2
	Center: Erosion (OL)	0, 1, or 2
	Center: Fine porosity (OL)	0, 1, or 2
	Center: Macro-porosity (OL)	0, 1, or 2
	Center: Cavitation (OL)	0, 1, or 2
Mariotti et al.'s method (Mariotti et al., 2004, 2007)	Robusticity	1a, 1b, 1c, 2, or 3
	Osteophytic formation (OP)	0, 1, 2, or 3
	Osteolytic formation (OL)	0, 1, 2, 3a, or 3b
Villotte.'s Method (Villotte, 2006; 2009)	Absence of EC	A
	Enthesophyte presence (OP)	Ba or Ca
	Erosion surface (OL)	Bb or Cb
Absence/presence method	Absence (no EC, no color/texture change)	A
	Color/texture change	B
	Presence (irregular surface)	C

Abbreviations: OP, osteophytic development; OL, osteolytic development.

3 | RESULTS

All data is available through the original PhD thesis, which is available in open access through the University of Geneva's Archive Ouverte website (https://archive-ouverte.unige.ch/unige:151360).

3.1 | Population Analyses—"Archer" Burials (A) vs. "Non-archer" Burials (N)

139 hypothesis tests looking at individual measurements revealed no significant differences between groups. PCA analyses also found no clustering in the data, a finding that was additionally supported through a MANOVA test for the principal components, with $F(32,2) = 1.0433$, $p = 0.3651$, Pillai's Trace $= 0.0671$, partial $\eta^2 = 0.07$. This finding remained true when group A was further sub-categorized according to wristguard and arrowhead presence, with no visible patterns in the data. A comparison between the regular *t*-test and the bootstrapped *t*-test results found the similar values, indicating no significant difference in overall reliability.

Assessments of each individual score yielded few significant differences in EC manifestation frequencies between groups, with only one passing the Bonferroni correction (the robusticity score for the right *m. pronator teres*), and none between right and left sides. Further analyses aiming to broaden the scope created two binary sub-classifications of the EC: (1) general osteophytic and osteolytic modifications (i.e., bone proliferation vs. bone surface erosion) (Table 7), and (2) general presence or absence of EC (i.e., scores of 0 or A vs. all other scores). These examinations revealed that groups A and N have similar types of surface modifications (i.e., osteophytic and osteolytic development), but not similar levels of overall EC presence (Table 9). Overall, group N exhibited significantly more EC than group A.

The general MCA results illustrated similar patterns as the EC hypothesis test data, with a first dimension separating fairly well

TABLE 8 The pathologies controlled for in this study and the diagnosis criteria.

	Criteria	Source
Degenerative joint disease (DJD)	Absence or presence of eburnation If no eburnation, then must have two of the following: • Marginal osteophyte • New bone on joint surface • Pitting on joint surface • Alteration in joint contour	Rogers and Waldron (1995) Waldron (2009)
Rheumatoid arthritis (RA)	Any combination of: • Symmetrical, marginal erosions of small joints in the hands and/or feet • Sparing of sacroiliac joints • Minimal new bone formation • Absence of spinal fusion	Waldron (2009) Biehler-Gomez and Cattaneo (2018)
Diffuse idiopathic skeletal hyperostosis (DISH)	Absence or presence of paraspinal ligament ossification between at least two vertebrae Classification stages: 1. Vertebrae not available for observation 2. No evidence of DISH 3. Features of DISH are present	Belanger and Rowe (2001) Maat et al. (1995) Mann and Hunt (2005) Resnick and Niwayama (1978) Steckel et al. (2005) Vaishya et al. (2017) Weinfeld et al. (1997)
Ankylosing spondylitis (AS)	Scoring classification: 0. Vertebral and sacral bodies not available for observation 1. No AS visible in the preserved bones 2. Symmetrical fusion of both sacroiliac joints AND spinal fusion with no skip lesions	Khan (2002) Mann and Hunt (2005) Šlaus et al. (2012) Waldron (2009)

groups A and N, including slightly more clustering in group A and slightly more variation in group N (Figure 3). The variables most responsible for the dimension 1 variation include the *m. teres major*, *m. biceps brachii*, *m. deltoid*, *m. palmar interossei*, *m. pronator quadratus*, *m. pectoralis major*, *m. brachialis*, *t. common extensor*, and the *m. anconeus*. A MANOVA also signaled trends in the data, with a significant *p*-value but a mid-value Pillai's trace, with $F(49,2) = 9.9261$, $p = 0.0003$, Pillai's Trace $= 0.3015$, partial $\eta^2 = 0.30$. This discrepancy indicates that while the independent variables might not have an extremely strong effect on the dependent variables, there is still evidence of a statistically significant effect. A focused MCA controlling for wristguard and arrowhead presence revealed no additional trends in the data.

3.2 | Individual analyses—assessing the individuals of Group A for signs of specialized archery

These results examined each individual of group A for EC symmetry scores linked to specialized archery according to the previously established biomechanics profile. However, due to a lack of complete bone preservation, a symmetry score was not possible for all entheses. A "specialized archer" assessment required each individual to have this data at $n \geq 5$, and a lack of bone preservation excluded 20 individuals from this analysis. Of the remaining 26 individuals (including Lochenice 3, who was not included in the population analyses due to an undetermined sex), observations identified 11 as "confirmed" archers (C) and 15 as "improbable" archers (IA) based on biomechanic consistency (Table 10). Those individuals include possible right-handed archers: Hoštice 1–862, Hoštice 1–821, Oberstimm II/1982–2, and Vykáň—1, and possible left-handed archers: Altenmarkt—11, Hoštice 1–915, Hoštice 1–884, Hulín 1–73, Lochenice—3, Radovesice—59/80-II, and Rosnice—I/59. Analyses using Fisher's Exact test found that these two new datasets (right-handed and left-handed "C" archers) are indeed statistically unusual (Table 11). Tests revealed significant differences for the symmetry frequencies of the draw arm vs. the bow arm in right-handed archers, the draw arm vs. the bow arm in left-handed archers, and the draw arms of right-handed archers vs. left-handed archers. The MCA examining these individuals also revealed trends in the data, with the first dimension managing to cluster individuals according to suspected archery handedness (Figure 4). There were two outliers, one right-handed (Vykáň 1) and one left-handed suspected archer (Lochenice 3), separated from the others by both dimensions, and from each other by the second dimension. The variables most responsible for the dimension 1 variation include: the *m. common extensor*, *l. costoclavicular*, *m. supraspinatus*, *m. pectoralis majors*, left *m. anconeous*, *m. biceps brachii*, *m. teres minor*, *m. pronator quadratus*, *m. latissimus dorsi*, *m. teres major*, and the *m. deltoids*. A MANOVA was not possible due to the low sample size. PCA models and hypothesis tests examining the measurements revealed no patterns in the data. A distribution of the archery-related items showed no link between grave goods and a "confirmed" archer classification (Figure 5).

Six individuals from group A had confirmed DJD, two of whom classified as "C" (Lochenice 3 and Osterhofen 11), two as "IA", and two did not present enough data for a classification. Both "C" individuals and one "IA" individual presented asymmetrical manifestations in the upper limb (Table 10).

4 | DISCUSSION

The first aim of this study was to analyze the Bell Beaker sample at a "population" level by comparing the skeletons of "archers" (Group A) and "non-archers" (Group N). Because "archer" burials tended to be more "wealthy", the purpose of this analysis was to assess a potential link between burial wealth and skeletal morphology, in particular with regard to physical activity.

TABLE 9 The results of population analyses ("archers" (A) and "non-archers" (N)) of EC for osteophytic (OP) vs. osteolytic (OL) surface changes and overall presence of any surface modification vs. absence.

	OP vs. OL		Surface modification presence vs. absence	
	Test result	95% CI prop. test	Test result	95% CI prop.test
Coimbra method—Origins (χ^2 test)	$\chi^2(1, N_a = 977, N_n = 941) = 1.73, p = 0.19$	[−0.0313, 0.1461]	$\chi^2(1, N_a = 977, N_n = 941) = 11.7, p < 0.001$ Group N tended to have more instances of surface modifications	[−0.1278, −0.0335]
Coimbra method—–insertions (χ^2 test)	$\chi^2(1, N_a = 1652, N_n = 1342) = 0.20, p = 0.65$	[−0.0832, 0.0529]	$\chi^2(1, N_a = 1652, N_n = 1342) = 12.07, p < 0.001$ Group N tended to have more instances of surface modifications	[−0.1013, −0.0273]
Villotte method—Insertion (Fisher's Exact test)	$(N_a = 41, N_n = 29), p = 0.15$	N/A	$(N_a = 41, N_n = 29), p = 1$	N/A
Mariotti et al. method—origins (χ^2 test)	$\chi^2(1, N_a = 535, N_n = 590) = 5.48, p = 0.02$ Group N tended to have more OL than group A	[−0.0459, 0.4267]	$\chi^2(1, N_a = 535, N_n = 590) = 0.77, p = 0.38$	[−0.1352, 0.0542]
Mariotti et al. Method—Insertions (χ^2 test)	$\chi^2(1, N_a = 757, N_n = 779) = 0.53, p = 0.47$	[−0.0637, 0.1337]	$\chi^2(1, N_a = 757, N_n = 779) = 13.33, p < 0.001$ Group N tended to have more instances of surface modifications	[−0.1490, −0.0434]
Absence/presence method—–origins (χ^2 test)	N/A	N/A	$\chi^2(1, N_a = 120, N_n = 169) = 16, p < 0.001$ Group N tended to have more instances of surface modifications	[0.1381, 0.4300]
Absence/presence method—–Insertions (χ^2 test)	N/A	N/A	$\chi^2(1, N_a = 206, N_n = 217) = 26.14, p < 0.001$ Group N tended to have more instances of surface modifications	[0.224, 0.4694]
All methods combined (χ^2 test)	$\chi^2(1, N_a = 3962, N_n = 3681) = 1.08, p = 0.3$	[−0.0205, 0.0649]	$\chi^2(1, N_a = 3962, N_n = 3681) = 65.26, p < 0.001$ Group N tended to have more instances of surface modifications	[−0.1150, −0.0698]

Note: Each test also included a proportion test (R function "prop.test") and this provides a confidence interval for the difference in proportions; the alpha value was set to 0.05.

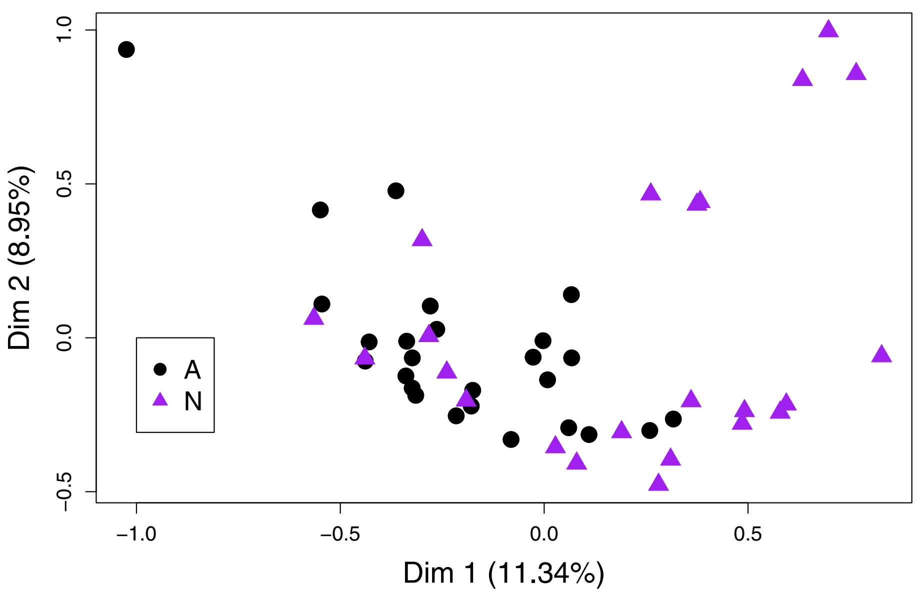


FIGURE 3 The MCA plot controlling for entheseal changes scores between the "archers" (A) and "non-archers" (N).

TABLE 10 All suspected "archers" ($n = 26$) that provided at least five symmetry data points ("right," "left," or "symmetric" entheseal modification prominence comparison), the associated muscles for each arm can be found in Table 3.

Individual	Draw Arm (20 associated muscles)			Both Arms (13 associated muscles)			Bow Arm (9 associated muscles)			DJD		Assessment Result
	Right	Left	Symmetric	Right	Left	Symmetric	Right	Left	Symmetric	Manifestation	Location	
Altenmarkt, 2 (M)	5	0	3	10	2	4	7	1	3	2, 3, 4, and 5	Vertebrae, right distal clavicle, right distal ulna, and both proximal ulnas	IA
Altenmarkt, 6 (M)	2	1	4	3	2	5	2	1	2			IA
Altenmarkt, 10 (M)	0	0	1	1	0	2	2	0	1			IA
Altenmarkt, 11 (M)	1	3	7	6	1	8	2	0	6	2, 4	Right glenoid cavity, both acromions, both proximal clavicles, and right distal ulna	C, left-handed
Gemeinlebarn, 2071 (M)	2	1	0	0	0	1	1	0	0			IA
Hoštice 1, 863 (M)	1	0	1	3	0	1	0	0	0			IA
Hoštice 1, 862 (M)	1	0	1	1	0	2	0	1	0			C, right-handed
Hoštice 1, 821 (M)	1	0	1	1	0	4	0	0	0			C, right-handed
Hoštice 1, 949 (M)	1	1	3	1	0	2	1	0	2	2, 3	Vertebrae	IA
Hoštice 1, 915 (M)	1	2	0	2	0	5	1	0	0			C, left-handed
Hoštice 1, 884 (M)	0	1	4	1	1	2	0	0	3			C, left-handed
Hulín 1, 66 (M)	1	0	3	5	2	4	1	1	2			IA
Hulín 1, 73 (M)	3	0	3	2	0	6	0	0	2			C, left-handed
Hulín 1, 85 (M)	0	0	3	0	1	3	0	1	4			IA
Lochenice, 3 (ND)	0	2	5	0	1	7	2	0	1	2, 3, and 4	Right thumb, both glenoid cavities	C, left-handed
Oberstimm II/1982, 2 (M)	3	0	0	1	0	3	0	0	1			C, right-handed
Praha 8-Kobylisy, 36,749, obj. 13 (M)	1	1	5	3	0	5	0	0	3			IA
Radovesice, 59/80-II (M)	2	3	1	2	4	5	4	0	0			C, left-handed
Radovesice, 53/80-I (M)	2	1	4	3	2	6	1	1	3			IA
Rosnice, I/59 (M)	0	2	1	1	0	0	1	0	0			C, left-handed
Stehelčeves, 2 (M)	1	0	3	2	0	3	0	0	3			IA
Straubing Stadtäcker, 1 (M)	2	0	0	0	1	1	0	0	2			IA
Velké Přílepy, 2 (M)	2	2	2	5	0	3	0	0	1			IA
Vykáň, 1 (M)	4	0	1	3	2	7	1	0	4			C, right-handed
Weichering, 17 (M)	2	0	5	3	1	5	2	0	0			IA
Žabovřesky (P7A 32,293) (M)	0	0	4	0	0	4	0	0	1			IA

Note: Estimated sex is indicated in parentheses, with M = male and ND = not determined; C = "confirmed" archer with the handedness assessment and IA = improbable archer; DJD manifestations include: 1 (eburnation), 2 (marginal osteophyte), 3 (new bone on joint surface), 4 (pitting on joint surface), and 5 (alteration in joint contour) (Rogers & Waldron, 1995; Waldron, 2009); from Ryan-Despraz (2021, Tables 109 and 116).

TABLE 11 The results of frequency tests controlling archery draw and bow arm activation for group C; R-H = right-handed, L-H = left-handed; from Ryan-Despraz (2021, Table 111).

Comparisons (Fisher's exact test) for asymmetric frequencies between "confirmed" archers		
Test groups	**Test parameters**	**Test result**
R-H Archers	Draw arm (D) vs. Bow arm (B)	($n_D = 10$, $n_B = 5$), $p = 0.04$
L-H Archers	Draw arm (D) vs. Bow arm (B)	($n_D = 31$, $n_B = 19$), $p = 0.006$
R-H vs. L-H Archers	Draw arm	($n_{Right} = 10$, $n_{Left} = 31$), $p = 0.003$
R-H vs. L-H Archers	Bow arm	($n_{Right} = 5$, $n_{Left} = 19$), $p = 0.08$
R-H vs. L-H Archers	Both arms	($n_{Right} = 27$, $n_{Left} = 64$), $p = 0.68$

4.1 | The population analyses

Looking first at the measurement data, the lack of differentiation between A and N indicates that the two groups were not variable in terms of physical size and proportion. This is not necessarily surprising since these individuals were part of the same population. However, the measurement data, including values linked to "robusticity," does not seem to function as a proxy for more internalized measurements. The lack of significance for these values contrasts with the EC findings, which did note differences in surface morphology between groups A and N. While more data are needed, this study cannot attest to the reliability of such analyses as a potential stand-in for analyses of diaphyseal geometry.

The EC results of the population analyses emphasized a difference between the type of surface modification and the overall amount of EC. In particular, the finding that groups A and N had similar occurrences of osteophytic and osteolytic modifications could demonstrate that the two groups shared a similar type of biomechanical stress—meaning that they lived in similar conditions with similar daily constraints. However, the finding that group N consistently had more instances of overall EC than group A could indicate the level of biomechanical stress. That is to say, while these two groups were part of the same general population, group N possibly had a more physically strenuous daily life. This could exhibit the presence of labor differentiation that is additionally identifiable through cultural burial practice. If "archer" burials were indeed more prestigious or wealthy (either socially, monetarily, or both), this could draw a direct link between that and lower levels of physical activity. Notably, the burials of group N were generally less rich, in both quality and quantity of grave goods (e.g., fewer instances of metal items or carved stone). This correlation between fewer EC and an archer burial could indicate a relationship in Bell Beaker society between labor and grave goods. At the same time, this study was not able to differentiate "archer" burials further through the type of archery-related item. There was no statistical significance when tests sub-categorized the burials according to wristguard or arrowhead presence (a lack of samples excluded analyses controlling only for bow-shaped pendants). Yet, while wristguards and arrowheads are associated with the same activity, they do not appear together consistently in the same burial context—only 16 out of the 46 "archer" burials had both items. It is therefore possible that they did not have the same cultural function for the Bell Beaker peoples.

4.2 | The individual analyses

The second primary aim of this study was to assess the "archers" at an "individual" level for osteological indications of specialized archer activity. In other words, the goal was to see if the burial-item profile ("archery") matched the biological profile ("archer" occupation). However, a lack of adequate preservation meant individual analyses were not possible for 20 skeletons. For the 11 possibly "confirmed" archers, four followed the expected patterns for a right-handed archer and seven for a left-handed archer. Initially, this result is surprising because the vast majority of *homo sapiens* throughout time and space are right-handed (74%–96%) (Faurie & Raymond, 2004; Llaurens et al., 2009; Uomini, 2009). Further investigation found that such a finding could be linked to eye laterality rather than hand laterality. Just as humans have a preferred hand, they also have a preferred eye, and while the two are often on the same side, this is not always the case. Bourassa et al. (1996) found that while on average 10% of people are left-handed, 33% are left-eye dominant, with additional studies reporting similar and even higher levels of cross dominance (Puri & Sethi, 2017; Robison et al., 1995). Most instructors advise cross-dominant archers to choose a side and adapt either the hand or the eye, and because precision is so vital to success, most archers choose to adapt their hand (Axford, 1995; Laborde et al., 2009; Porac & Coren, 1981). However, while these findings are important to consider, they are not sufficient for explaining this study's higher level of possible left-handed archers. At the same time, while this finding is noteworthy, statistically speaking the difference in frequencies is not significant.

Hypothesis tests for group C found a $p < 0.05$ for three out of four tests comparing the possible left- and right-handed archers. This signals something unusual in the data that merits further exploration and indeed, MCA analyses revealed similar trends. Examining the variables responsible for this variation could help improve osteological analyses of specialized archer activity. These findings indicate that this study's biomechanical theory managed to identify separate groups of individuals whose muscular development is somehow linked. This includes comparisons between not only draw and bow arms, but also the general comparison between possible right- and left-handed archers, which exhibits the potential efficacy of applying a biomechanics model when attempting to interpret specialized archery, including on datasets containing missingness. However, this final dataset of "C" individuals remains small, so additional approaches on other individuals would improve interpretations.

FIGURE 4 The MCA plot controlling for the right- (R) and left-handed (L) "C" suspected archers.

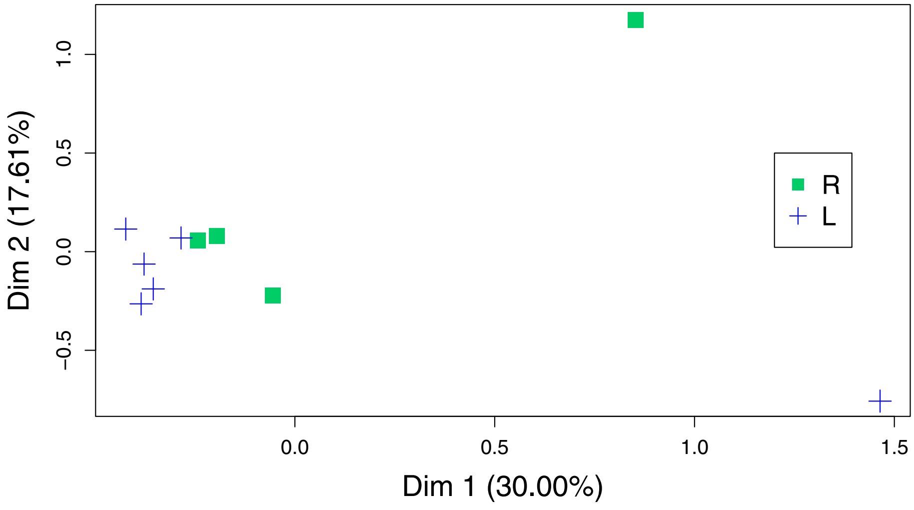
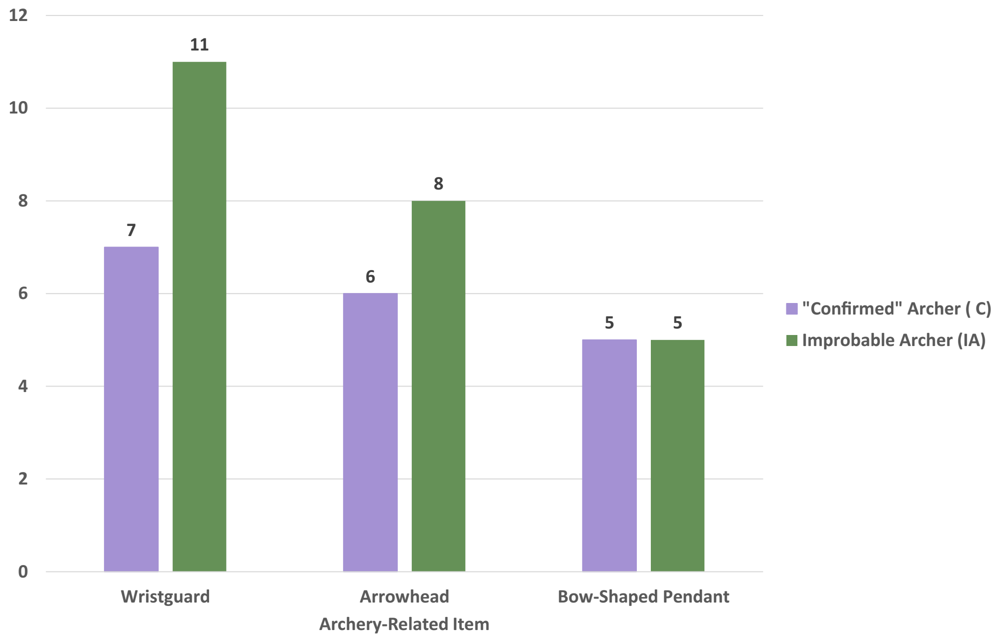


FIGURE 5 The relationship between archery-related grave goods and individual classifications of specialized archery occupation ("confirmed" archers and improbably archers); adapted from Ryan-Despraz (2021, Figure 90).



Assessing group C for patterns in grave good appearance and distribution revealed no relationship between the archaeological context and a "confirmed" archer classification (Figure 5). This contributes to the conclusion that there are no black-and-white rules linking burial context to a likely occupation—not all of group A were likely specialized archers just as some members of group N could have been specialized archers. From an archaeological perspective, this could mean that grave goods, such as stone wristguards, represented a social function rather than an occupational function in Bell Beaker society. Therefore, rather than labeling an individual buried with archery-related items as an "archer", it could be more accurate to identify this individual as someone of social importance. In terms of specialized occupation, it would be more reliable to examine each individual according to his or her biological attributes, including those individuals without the corresponding archaeological context (i.e., group N). A direct link between cultural identity (as exhibited through grave goods) and occupational identity emphasizes the individual (i.e., an archer); however a lack of association, such as this study found, shifts this focus to the concept of archery as an ideal within Bell Beaker society.

4.3 | Limitations

As mentioned throughout this article, data missingness is a constant issue, and prehistoric skeletons are rarely fully preserved. Studies such as this rely on comparisons, and this becomes complicated when each individual presents different levels of preservation. For analyses at the population level, measurement and EC evaluations did not necessarily contain data from the same individuals, which is of course less than ideal, though it is also unavoidable. The question will always remain as to how the absence or presence of certain individuals may have influenced the results. A controlled evaluation of each individual from group A helped to remove this bias, however even those individual analyses did not necessarily include symmetry assumptions for the same enthesis. One EC will probably not indicate an activity, however the ensemble could help to paint a clearer overview—this is why the application of the biomechanics profile was essential. Furthermore, due to small sample sizes and broad age determinations, this study was not able to further assess patterns linked to age groups, which could also be an important consideration in future studies. Overall, this study aimed to reduce the effects of data missingness and bias by examining several skeletal characteristics, applying several methods of data analysis, and evaluating the skeletons both as a broad population and as individuals.

A primary objective of this study was to test whether or not the individuals buried with archery-related items practiced a specialized archery occupation—meaning individual analyses only focused on group A. While this was a measured decision based on the specific research question, it would also have been interesting to consider individual archery analyses of "non-archers" (group N). This would have provided an additional layer of comparison with group A, especially in terms of interpreting social organization. It could therefore prove beneficial for any future studies to expand individual analyses in order to promote more complex population assessments.

Many researchers also question the reliability, repeatability, and efficacy of scoring entheseal changes, which remains a valid concern. This study attempted to address these limits by applying multiple methods best adapted to each enthesis, as well as scoring simply according to the absence or presence, thus removing possible biases linked to subjectivity. The individual analyses also applied a binary comparison between right and left sides, which limits the risk of error due to a possibly arbitrary classification. However, these methods lack quantification. More accurate evaluations will require the development of methods capable of quantifying bone surface morphology. Additionally, determining activity from the skeleton remains an unconfirmed field because researchers have still not been able to define exactly how biomechanics influences bone morphology or how to differentiate it from other etiologies. As such, many researchers have also begun to study bone microarchitecture with regard to physical activity (Agarwal et al., 2004; Berthon et al., 2015; Bouvard et al., 2012; Courteix et al., 1998; Ding et al., 2002; Griffin et al., 2010; Huiskes et al., 2000; T. M. Ryan & Shaw, 2012; Wallace et al., 2017). Ultimately, studies such as this assume a direct association between muscle activation and entheseal morphology, yet this is likely an oversimplification of the underlying biological processes. In particular, this study was based on a biomechanics profile for archery and therefore studied the EC for this specific group of entheses, which can be considered heterogeneous (see for instance Villotte & Santos, 2023). Some of these recorded EC are likely alterations caused by micro-trauma while others are possibly more adaptations (normal physiological responses to loading) (see Villotte, 2023). With this in mind, further research is required to better understand the relationship between the patterns identified in the biomechanics-based EC presence and the underlying processes that led to them. This is also noteworthy considering that this study combined analyses of fibrous and fibrocartilaginous EC; however when considering what is currently known about these attachment sites, it is perhaps not appropriate to assume that they would respond the same way to stimulations. Lastly, the clinical data on modern archers describe soft tissue injuries and pain locations, however without clearer definitions as to the underlying biology, this information is difficult to transfer to analyses of dry bone. While there is obvious room for improvement in the field, the overall concept of linking activity-related skeletal changes and biomechanics to evaluate specialized activity remains promising.

5 | CONCLUSION

This study examined activity-related skeletal changes as a means for understanding Bell Beaker daily life and social organization with respect to archery. At a population level, differences in entheseal modifications between "archers" and "non-archers" exhibit a possible link between burial context and physical activity, such as manual labor. "Non-archer" burials were seemingly less prestigious, both in terms of quality and quantity of goods, and this corresponded to greater levels of entheseal changes potentially linked to physical activity. At an individual level, the data found that not all "archers" were likely specialized archers and that there is no correlation between a probable archer occupation and an archery burial context. This suggests that male Bell Beaker burials containing archery-related goods tended to reflect an individual's social identity or role in society rather than their specialized, daily activities. Lastly, these findings support the premise that biological anthropologists can apply methods in osteology, biomechanics, and data analysis as a means for evaluating possible specialized activity, daily life, and behavior.

AUTHOR CONTRIBUTIONS

J. Despraz: Conceptualization (lead); data curation (lead); formal analysis (lead); funding acquisition (lead); investigation (lead); methodology (lead); project administration (lead); visualization (lead); writing – original draft (lead); writing – review and editing (lead). **S. Villotte:** Formal analysis (supporting); methodology (supporting); supervision (lead); validation (supporting); writing – review and editing (supporting). **J. Desideri:** Conceptualization (supporting); project administration (supporting); supervision (lead); validation (supporting). **M. Besse:** Conceptualization (supporting); funding acquisition (supporting); project administration (lead); resources (supporting); supervision (lead); validation (equal); writing – review and editing (supporting).

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DATA AVAILABILITY STATEMENT

Three additional Figures are submitted for the Supplementary Information. All data are available in open access on the University of Geneva's Archive Ouverte website for the original PhD thesis: https://archive-ouverte.unige.ch/unige:151360.

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Additional supporting information can be found online in the Supporting Information section at the end of this article.

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