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Fixed and Fluid: The Two Faces of Gender Roles—A Combined Study of Activity Patterns and Burial Practices in the European Neolithic

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ABSTRACT

Objectives: This study investigates gender roles in the European Neolithic by analyzing activity-related skeletal changes (ARSCs) and burial practices at two Polgár microregion sites in Hungary: Polgár-Ferenci-hát (5300–5070 cal. BCE) and Polgár-Csőszhalom (4800–4650 cal. BCE).

Materials and Methods: A total of 125 well-preserved adult skeletons were included in the study. Types of ARSCs examined include spondylolysis (overall workload), humeral enthesopathies (unilateral upper-limb overuse), and metatarsal facets (habitual postures). Burial positions and grave goods were analyzed to assess sex-based differences in burial practices.

Results: Polgár-Ferenci-hát exhibited no clear differences in burial treatment between the sexes, while Polgár-Csőszhalom displayed marked sex-related distinctions in burial practices. Individuals at Polgár-Csőszhalom bore greater physical workloads than those at Polgár-Ferenci-hát, though no consistent sex-based differences in lesions emerged. Males at both sites demonstrated recurrent right upper limb overuse, aligning with broader prehistoric European trends. At Polgár-Csőszhalom, nine males and one female buried with male-associated items also exhibited metatarsal facets, linking sex-associated activity, posture, and social identity.

Discussion: The findings suggest that society at Csőszhalom was structured around gendered roles, yet allowed for individual variation. While the limited number of individuals and the inherent uncertainty in interpreting activity markers call for caution, this study enhances our understanding of prehistoric social organization by revealing both recurring sex-related patterns of behavior and local flexibility in the expression of gender roles.

1 | Introduction

The majority of documented human societies manifest, to varying extents, normative expectations regarding the roles attributed to individuals on the basis of their biological sex (e.g., Alesina et al. 2013; Robinson 2018; Wood and Eagly 2002). The

resulting differential participation of men and women in the various spheres of social life within a given cultural context will hereafter be referred to as “gender roles,” following Conkey and Spector (1984, 15): “Gender roles describe what people do and what activities and behaviors are deemed appropriate for the gender category.” Gender roles constitute a particularly relevant

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subject of study in prehistoric archeology, as they can be explored through relatively abundant traces, including direct evidence from human remains and the ways in which the deceased were treated by their community, as reflected in burial practices (i.e., the culturally defined ways surrounding the disposal and commemoration of the dead).

Building on this dual perspective, bioarcheological and burial analyses together provide complementary insights into the social construction and expression of gender roles. Patterns of skeletal robusticity and enthesal change frequencies can indicate differences in habitual activities and workloads between sexes, suggesting a gendered division of labor (Knüsel 2000; Larsen 2015; Villotte 2024). Additionally, dental wear and isotopic analysis offer insights into dietary differences and food preparation roles, while trauma patterns and pathological conditions may highlight occupational hazards associated with specific tasks (Larsen 2015). Burial practices further contribute to the discussion of gender roles through variations in body positioning, grave goods, and burial treatment, potentially reflecting societal expectations and divisions of labor (Masclans, Hamon, et al. 2021; Rebay-Salisbury et al. 2022; Robb and Harris 2018).

In Europe, strong evidence of gendered burial practices appears predominantly from the beginning of the Bronze Age (ca. 3000 cal. BCE) (Rebay-Salisbury et al. 2022; Robb and Harris 2018). However, expressions of gender in burial practices (differences in grave goods, orientation, and locations) can be traced back to the Early Neolithic, where they tend to be more subtle and highly variable across cultures and regions (Robb and Harris 2018). These variations have led to the suggestion that gender may have emerged during the Neolithic in different ways at different stages of social life, depending on the context (Robb and Harris 2018). While this hypothesis remains debated, many authors nonetheless emphasize the considerable influence of biological sex on social structures and daily practices during the European Neolithic (Gaydarska et al. 2023). Moreover, a substantial number of studies of skeletal modifications attributable to activities performed during life have provided evidence for the probable existence of a sex-based division of labor, and thus gender roles, during the Neolithic period (Macintosh et al. 2014; Marchi et al. 2006; Sládek et al. 2016; Varalli et al. 2020; Villotte and Knüsel 2014). This pattern appears frequently enough to suggest that such societal structuring was present from the beginning of the period and was relatively widespread. Furthermore, these results from different regions of Europe are sufficiently consistent to suggest a degree of uniformity in the expression of the sex-based division of labor and, by extension, some dimensions of gender roles.

One way to advance the debate and better understand the nature of gender roles in the Neolithic is to compare data on activity-related skeletal changes (ARSCs) with burial practices, an approach that has rarely been applied to this period (Masclans, Tvrdý, et al. 2021; Thomas 2014). Such a comparison would allow us to assess the extent to which the gender roles attributed to or recognized by society for the deceased align with the activities actually performed by the individual during their lifetime, an analysis that, to our knowledge, has not been applied to homogeneous samples with contrasting burial practices from a specific area.

This analysis aims to compare ARSC with burial treatment patterns (specifically body position and grave goods) in Neolithic contexts, while accounting for the biological sex of the individuals. The study focuses on present-day Hungary, where Anatolian-origin populations introduced the Neolithic way of life in the sixth millennium BCE (Szécsényi-Nagy et al. 2025). This transition included an agricultural economy based on non-native crops and domesticated animals, alongside innovations such as permanent settlements, ceramics, polished stone tools, and textile production (Whittle et al. 2013). The analysis centers on two Neolithic burial assemblages from the Polgár microregion (Figure 1), a loess-covered rise of about 65 km² on the left bank of the Tisza River in the Upper Tisza region (Raczky and Anders 2009). Polgár-Ferenci-hát (FH) and Polgár-Csőszhalom (CS), situated only 4 km apart on Polgár Island, display markedly different burial patterns despite their close proximity. At FH (5300–5070 cal. BCE), grave goods were scarce, and no clear differentiation was observed in burial treatment (Anders and Nagy 2019; Whittle et al. 2013). At CS (4800–4650 cal. BCE), however, the position of the body and the inclusion of grave goods appear

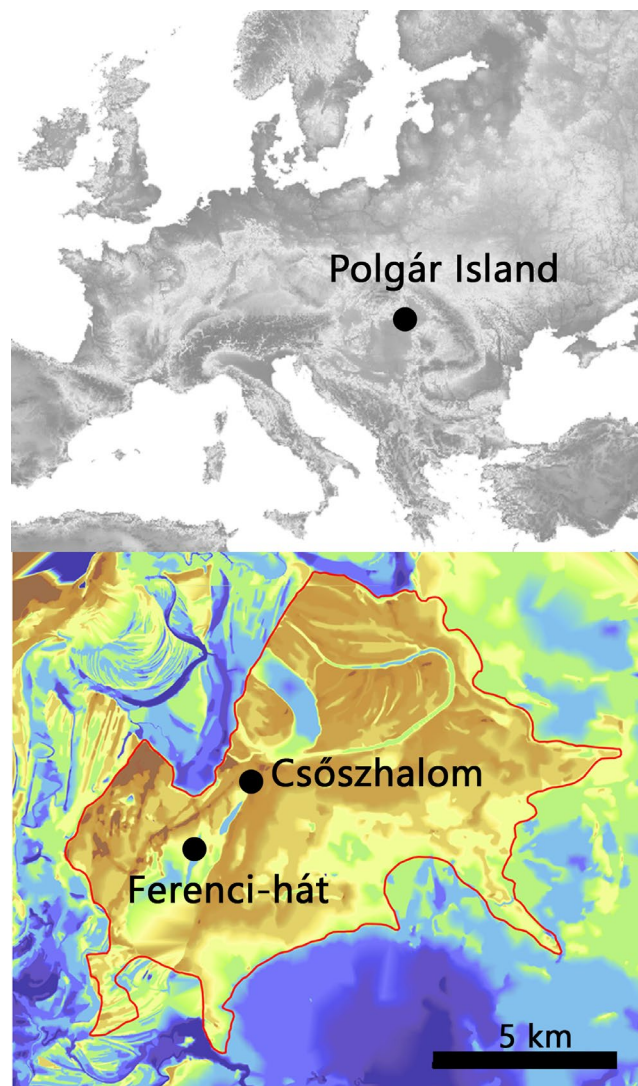


FIGURE 1 | Location of Polgár Island and the position of two archaeological sites under study in the Polgár micro-region.



FIGURE 2 | Illustration of activity-related skeletal changes recorded in this study. Left: Enthesopathy at the medial epicondyle of the humerus. Top right: Fifth lumbar vertebra with complete separation of the vertebral arch at the *pars interarticularis*. Bottom right: Extension of the distal articular surface of a first metatarsal.

to have been strongly influenced by the biological sex of the deceased (Anders and Nagy 2019; Anders and Siklósi 2023; Raczky and Anders 2017).

Polgár Island presents an ideal setting for investigating gender role dynamics in the Neolithic. First, the area's landscape and climatic conditions have remained relatively stable (Mesterházy 2021; Sümegi et al. 2012), providing a unique opportunity for an in-depth study of long-term changes within a consistent environmental framework. Second, the two sites under study have yielded large numbers of human remains and are both extremely close geographically and relatively close chronologically. In addition, recent aDNA analyses have also revealed genetic connections between the two communities (Szécsényi-Nagy et al. 2025). Third, the excavations in the area have yielded a large number of human remains and evidence of occupation spanning several periods of the Neolithic. Moreover, the excavation and documentation of the two sites under study were carried out during the last decade of the 20th century, almost simultaneously, using the same methods, with observations conducted by the same archeologists.

In this study, we examined 125 adults from FH and CS, focusing on three ARSCs that provide different types of information (Figure 2): spondylolysis of lumbar vertebrae, which documents overall physical workload (Merbs 2002); enthesopathies distribution at the humeral epicondyles, indicative of unilateral upper-limb overuse (Villote and Knüsel 2014); and metatarsal facets, which are considered skeletal adaptations to repeated hyperextension of the toes (Molleson 1989; Ubelaker 1979). We explored the distribution of these indicators within the groups based on collection, biological sex, and burial practices applied to the deceased, with the aim of identifying broad activity patterns—that is, general trends in biomechanical stress and

functional variation—rather than reconstructing specific tasks or behaviors.

By comparing these indicators between the two assemblages, we aim to assess whether differences in burial treatment could reflect patterns of activity during life. This approach allows us to explore how socially constructed gender roles—that is, expectations regarding behaviors and activity patterns associated with biological sex—may have been materially expressed, and to what extent the roles recognized in death might have mirrored those experienced during life, without attempting to reconstruct broader aspects of gender identity or experience.

2 | Materials and Methods

2.1 | Materials

At FH, 113 burials interspersed among the structures of a settlement were discovered (Whittle et al. 2013). These burials date to the period between 5300 and 5070 cal. BCE and are associated with the Alföld Linearband Pottery culture (a local variant of the Linearbandkeramik [LBK] culture [ca. 5500–5000 cal. BCE]). The site of CS, located 4 km away, consists of a Late Neolithic settlement complex (Raczky and Anders 2017). The single-layer part of this settlement yielded 125 burials dated to approximately 4800–4650 cal. BCE (Anders and Siklósi 2023).

The reanalysis of these collections revealed human remains corresponding to 132 individuals at FH and 147 individuals at CS, providing the basis for subsequent osteological analyses. Only individuals who had reached adult stature were included in the study (94 at FH and 106 at CS), with adulthood determined based on the fusion of the epiphyses of major long bones.

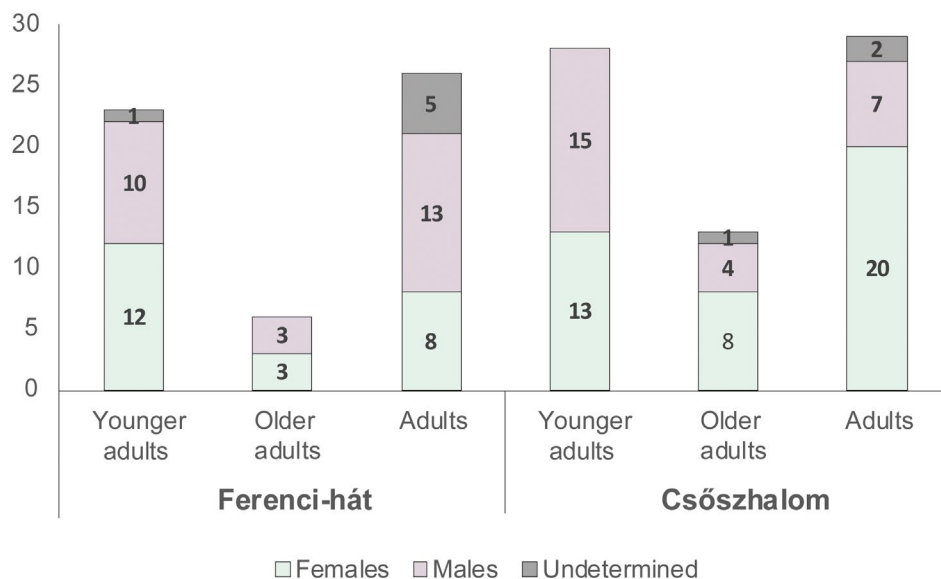


FIGURE 3 | Number of individuals by sex (male, female, and undetermined) and age category, showing those who died before 50 years (younger adults) and those who died at or after 50 years (older adults), as well as individuals of undetermined age, for both sites.

Individuals providing at least one piece of information for one of the three selected ARSCs were included, resulting in a total of 125 individuals (55 from FH and 70 from CS). Our sample thus represents a substantial proportion of the excavated archeological assemblage for these two sites, comprising 58.5% of the adult sample for FH and 66.0% for CS.

Sex estimation was primarily based on the morphology and morphometrics of the ossa coxae (Brůžek et al. 2017; Santos et al. 2019), allowing us to estimate sex for 94 individuals. For 22 additional subjects, ancient DNA analysis and reliable secondary sex assessments using discriminant function analysis (Murail et al. 1999) were employed, resulting in a final estimation of 64 females and 52 males. Age at death was estimated based on the fusion of later-fusing secondary ossification centers (Albert and Maples 1995; Webb and Suchey 1985), the morphology of the pubic symphyseal face, and age-related degenerative changes of the sacroiliac surface of the os coxae (Schmitt 2005; Schmitt and Georges 2008). We used these different methods to identify adults who died before the age of 50 (younger adults) and those who died at 50 or older (older adults). Demographic data are summarized in Figure 3, and detailed individual data are provided in Supporting Information S1.

2.2 | Coding Burial Treatment by Biological Sex

At FH, previous studies have noted that the deceased were generally placed in a flexed position, most often lying on their left side, irrespective of biological sex (Anders and Nagy 2019). In the present study, of the 44 male and female individuals for whom body position could be determined, 42 were interred on their left side, while only 2 (1 male and 1 female) were placed on their right side (Supporting Information S1 and Figure 4). As reported in earlier research (Anders 2023; Anders and Nagy 2019), grave goods are infrequent in the studied population and primarily associated with children. In adult burials, grave goods are rare, and adornments are virtually absent. Therefore, this aspect was not considered in the present analysis.

At CS, sex-based distinctions were considered as manifest in burial practices, where the position of the deceased seemed to adhere to established conventions (Anders and Nagy 2019). Specifically, according to the analysis of available data in both archeology and biological anthropology, females tend to be positioned on the left side, while males are positioned on the right in the Neolithic of the Great Hungarian Plain (Anders and Tóth 2024; Siklósi 2013, 175). The body position could be established for 66 adult individuals from CS included in this study, and the side of deposition indeed shows a strong association with the biological sex of the deceased (Supporting Information S1 and Figure 4). It should be noted, however, that seven individuals showed a discrepancy between biological sex and expected body position in death, suggesting that this association was not absolute.

The inclusion of grave goods and personal adornments has also been interpreted as reflecting distinctions related to the biological sex of the deceased. In particular, girdle belts made of *Spondylus* beads have been regarded as characteristic of female attire, whereas polished stone tools are generally associated with male burials (Anders and Nagy 2019). On the basis of these associations, categories were established for grave goods and adornments: items typically linked to one or the other sex (girdle belts or polished stone tools), while individuals furnished with grave goods or adornments that did not include either girdle belts or polished stone tools were recorded under the category “other items” (Supporting Information S1). These patterns correspond closely to biological sex, with only one female interred with a polished stone tool and no males exhibiting *Spondylus* shell belts (Figure 4).

2.3 | Recording ARSCs

Overall physical workload was assessed through the presence of spondylolysis—a spinal condition involving the partial or complete separation of a vertebral arch at the *pars interarticularis*,

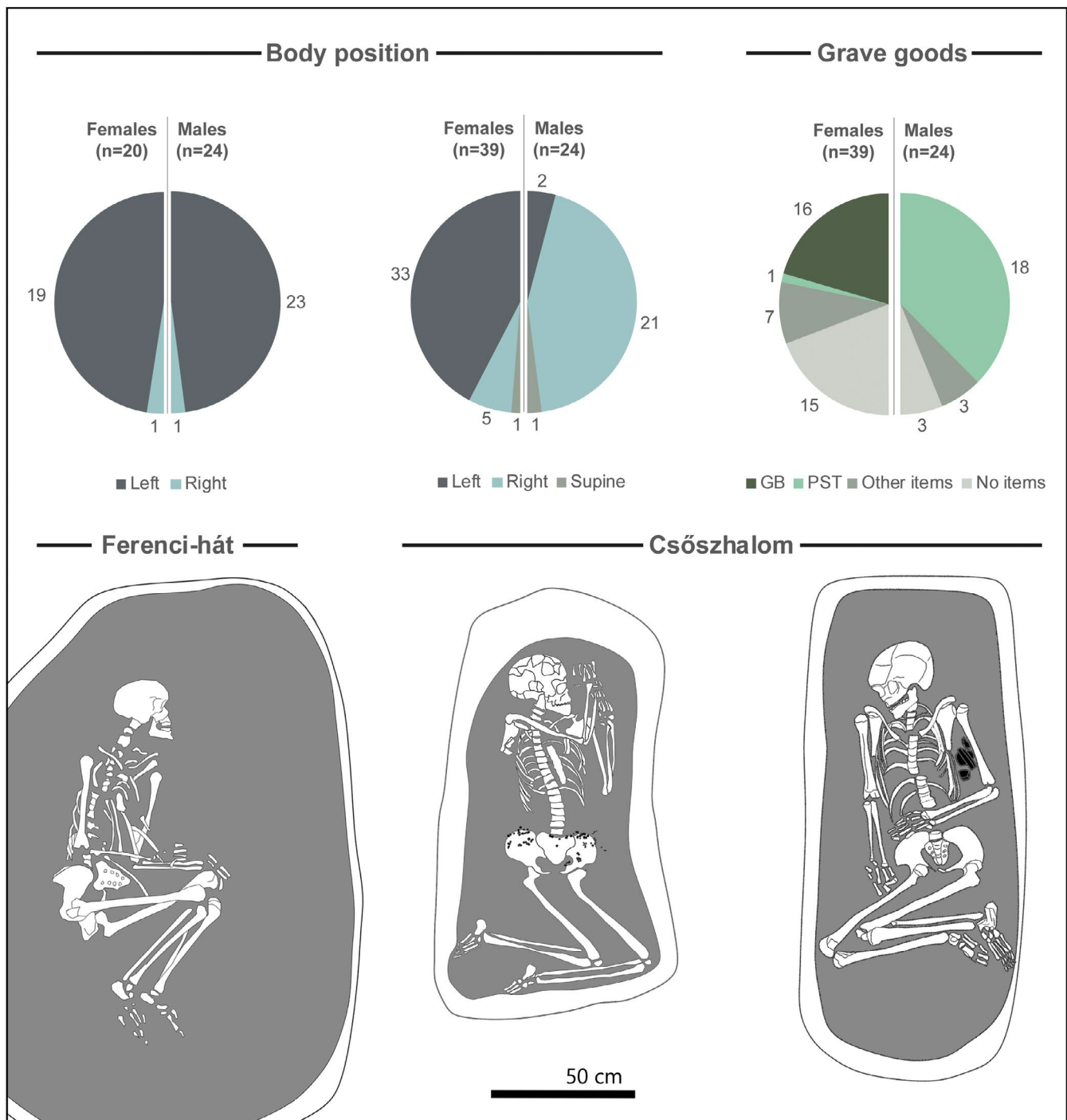


FIGURE 4 | Top left: Burial position according to sex at Polgár-Ferenci-hát. Middle: Burial position according to sex at Polgár-Csőszhalom. Right: Distribution of burial items by sex at Polgár-Csőszhalom. GB, girdle belt; PST, polished stone tool. Individuals of undetermined sex are excluded from these figures; their data are provided in Supporting Information S1. Bottom: Examples of Neolithic burial practices. Left: Male individual from Polgár-Ferenci-hát, buried in a flexed position on the left side without grave goods—a typical practice for both sexes at this site. Middle: A female individual from Polgár-Csőszhalom, placed in a flexed position on the left side, and adorned with a girdle belt made of *Spondylus* beads characteristic of female burials. Right: Male individual from Polgár-Csőszhalom, buried in a flexed position on the right side, accompanied by flint tools and a polished stone tool, representative of male burial customs.

often caused by stress fractures (Standaert and Herring 2000). The lumbosacral regions of the vertebral columns were examined for spondylolysis, with records detailing the vertebrae affected, the side of the neural arch, unilateral or bilateral occurrences, and the location of the defect within the vertebral arch (*pars interarticularis*, lamina, or pedicle) (Merbs 2002).

Associations with vertebral anomalies such as lumbarization or sacralization were investigated, given their known positive relationship with spondylolysis (Weiss 2009). Considering that these defects are overwhelmingly found at the last two lumbar vertebrae (Devos et al. 2022; Merbs 2002; Weiss 2009), individuals with at least one observable region for the fourth or

fifth lumbar vertebrae were included in the analysis. In modern cases, spondylolysis most often results from stress fractures caused by repetitive or sustained spinal loading, and its presence in skeletal remains is therefore generally interpreted as evidence of similar mechanical strain (see Merbs 1996 for a review). Certain sports participants are particularly at risk, with frequencies exceeding 10% among both symptomatic and asymptomatic athletes (e.g., Rossi and Dragoni 2001; Soler and Calderón 2000). However, genetic, developmental, and physiological factors may also contribute to its formation (e.g., Chung and Shimer 2021; Fredrickson et al. 1984; Verna and Villotte 2016), so spondylolysis cannot be attributed solely to specific behaviors. Still, when considered alongside other skeletal indicators and contextual evidence, it can provide valuable insights into general patterns of mechanical loading and activity within a population (Merbs 1996; Villotte 2024).

Unilateral upper-limb overuse was assessed by considering the medial-to-lateral epicondyle ratio. Entheses (tendon and ligament attachment sites) are regularly subjected to mechanical strain, and skeletal changes at these sites have long been used to infer past physical activities (Capasso et al. 1999; Jurmain et al. 2012). In the medical literature, enthesopathies (i.e., pathological changes of entheses) are associated with aging as well as conditions such as seronegative spondyloarthropathies, overuse or traumatic injuries, and diffuse idiopathic skeletal hyperostosis (Niepel and Sit'Aj 1979; Resnick and Niwayama 1983). Lesions at specific attachment sites, particularly the fibrocartilaginous entheses of the upper limbs, may provide insight into activity patterns in past populations (Villotte et al. 2010). However, the influence of age—especially beyond 50 years—remains a significant challenge in archeological studies due to the difficulty of reliably estimating adult age at death (e.g., Márquez-Grant 2015). To address this, it has been proposed to focus on recurrent patterns observed in both living populations and skeletal samples that appear independent of age (Villotte and Knüsel 2014). For example, the frequency of enthesopathies at the medial and lateral epicondyles of the humerus almost invariably shows a predominance at the lateral epicondyle, regardless of age group; a reversal of this pattern could indicate specific functional constraints, not for an individual, but for the sample as a whole (Villotte and Knüsel 2014). Frequencies of lateral and medial epicondyle enthesopathies for the humeri in the sample were calculated, with all entheses examinations following the same methodological criteria (Villotte 2006; Villotte et al. 2010). Upper limbs with evidence of fractures or significant morphological deformation were excluded from the analyses, as were individuals showing signs of systemic pathologies that could cause nonmechanical enthesopathies (Villotte et al. 2010).

Finally, we examined habitual postures through the study of metatarsal facets, that is, neo-articular surfaces on the superior surface of the distal end of the metatarsals. Several authors have associated neo-articular surfaces on the superior aspect of the distal metatarsals with the kneeling position (e.g., Ubelaker 1979; Molleson 1989; Prada and Sterpone 2000; Villotte and Prada Marcos 2010). Although direct medical data are lacking, it seems evident that these modifications are related to hyperextension of the toes. However, while these facets are almost always considered markers of kneeling, Osing (2023) suggested that other positions could also contribute to their

formation. These facets can vary considerably, from a proximal extension of the distal articular surface to a ridge on the superior surface (Ubelaker 1979). This variability likely explains the absence of a standardized method for recording their presence. Because these changes are more pronounced and easier to observe on the first metatarsal, our analysis focused on this bone, specifically on the dorsal extension of the articular surface on the neck. Only facets with well-defined contours covering at least 5 mm in both length and width were considered. The presence of at least one recordable first metatarsal was sufficient for inclusion in the analyses.

While we consider the selected ARSC among the most relevant for discussing activity patterns in past populations, we also acknowledge the inherent limitations of their study—including methodological constraints, issues related to missing data, and the multiple factors contributing to their appearance. They are thus interpreted within a broad framework of activity patterns, reflecting general biomechanical trends and habitual postures rather than specific tasks.

2.4 | Statistical Analyses

The prevalence of spondylolysis and metatarsal facets was calculated by dividing the number of positive cases by the total number of possible observations. This calculation of prevalence allows missing elements to be taken into account during data analysis and thus controls for preservation (e.g., Waldron 2008).

Confidence intervals for prevalence were computed using the “binom.test” function in R. Frequencies between groups were compared using Fisher's exact test. For statistically notable differences, the effect size and its associated confidence interval were determined using the odds ratio. Statistical analyses were conducted with R statistical software (v4.3.2; R Core Team 2022) using the BioProbability package (Saavedra-Nieves and Saavedra-Nieves 2020). The significance threshold was arbitrarily set at 5%.

It has been shown that calculating a ratio of lateral and medial lesions for each side, within a given sample, helps control for the well-documented effect of age on enthesopathies (Villotte et al. 2010; Villotte and Santos 2023), permitting the focus to remain on anomalies in the distribution of lesions within a given sample. The original calculation of the “*L/M* ratio,” proposed in 2014, consisted of dividing, for a given side, the frequency of lesions observed on the lateral epicondyle by that of the medial epicondyle (Villotte and Knüsel 2014). However, as noted by Smith in the context of sexual dimorphism (Smith 1999), this type of ratio is asymmetric, and it is nonlinear when the denominator is larger. Following Smith's observation, we therefore decided to transform the *L/M* ratio using its logarithm, hereafter called the “*Ln (L/M ratio)*.” A value above 0 indicates, for a specific side (left or right) within a given group, a preponderance of lesions at the lateral epicondyle compared to the medial one, whereas a value below 0 indicates the opposite.

For large comparative samples, confidence intervals were computed for the *Ln (L/M ratio)* using the delta method (Agresti 2002). The delta method allows for the approximation

TABLE 1 | Overview of results for the entire Neolithic sample, categorized by collection and sex.

		Spondylolysis		Metatarsal facets		Ln (L/M ratio) right side		Ln (L/M ratio) left side	
		n/N	%	n/N	%	N	Ln (L/M ratio)	N	Ln (L/M ratio)
Collections	Polgár-Ferenci-hát	1/20	5.0	11/34	32.4	44	0.00	39	0.64
	Polgár-Csőszhalom	8/30	26.7	21/55	38.2	49	0.13	44	0.20
Sexes	Females	3/21	14.3	17/49	34.7	46	0.43	38	0.26
	Males	4/26	15.4	14/37	37.8	40	−0.51	39	0.52
Total		9/50	18.0%	32/89	36.0%	93	0.06	83	0.34

Note: The table presents the prevalence of spondylolysis and metatarsal facets (number of positive cases relative to the number of individuals with preserved areas) as well as the Ln (L/M ratio) for the right and left humerus.

of the asymptotic variance of the maximum likelihood estimator of the log-transformed L/M ratio. Standard errors derived from this variance were used to construct Wald 95% confidence intervals. Overlap (or lack thereof) between the confidence intervals was used to infer potential differences in lesion distribution patterns between groups.

3 | Results

3.1 | General Biomechanical Load

Nine individuals (out of 50 observable cases) exhibit at least one case of spondylolysis in L4 or L5 (Table 1). Among these nine cases, there is no clear pattern of distribution by biological sex, although it is noteworthy that seven occurred in younger adults. However, the small sample size limits any definitive interpretation of these observations (Table S1). In two cases (one individual of indeterminate sex from FH and one male from CS), this condition appears directly linked to another vertebral anomaly (Table S1). The remaining seven cases are from CS, including three males, three females, and one individual of indeterminate sex (Table S1). Differences in prevalence, whether including or excluding the two aforementioned cases, are noteworthy: FH shows either 0/19 or 1/20 cases, while CS presents 7/29 or 8/30 cases. These differences are close to the threshold of statistical significance with or without these two cases ($p=0.067$ and 0.033 , respectively). However, the most striking result is the exceptionally high frequency of spondylolysis at CS, even when considering the lowest computed prevalence (24.1% [95% CI: 10.3%–43.5%]). While data for European Neolithic samples from the same period are limited, the prevalence at CS stands out as markedly higher than the reported frequencies (Devos et al. 2022; Garłowska 2001; Köhler 2024; Tvrdý 2016), which range from 0.0% to 14.1% (Table 2).

3.2 | Unilateral Upper-Limb Overuse

The logarithm of the ratio of frequencies of lesions at the lateral and medial epicondyles of the humerus (Ln [L/M ratio]) was calculated for each side (Table 1). This ratio is consistently equal to or greater than 0, except in the male sample

for the right side only. This pattern is observed for males in both the FH and CS samples, as well as for CS individuals buried in a “right-side position” or with a polished stone tool (Table S2). The Ln (L/M ratios) for the FH and CS samples are plotted against those from a previous study (Villotte and Knüsel 2014) in Figure 5. The results are consistent with prior findings: in skeletal samples, the ratio is generally positive across periods, sides, and sexes, except in prehistoric males, where it is reversed on the right side. The comparable proportions of males and females dying before and after 50 years in our sample (Figure 3), together with the age-independent ratio employed here (Villotte and Knüsel 2014), suggest that the observed variation in Ln (L/M ratio) cannot be attributed to age differences and likely reflects differences in habitual upper limb behavior between the sexes.

3.3 | Frequently Adopted Posture

Metatarsal facets are relatively common in the entire sample, with similar frequencies observed across both sites and sexes (Table 1). Among the 89 individuals for whom this indicator could be assessed, approximately one-third (32/89) exhibit these changes. The proportion of individuals with metatarsal facets is comparable between those who died before 50 years of age (12/36) and those who died after 50 years (7/17) (see Supporting Information S1). The frequency of metatarsal facets at the FH and CS sites is very similar; however, their distribution within each site varies significantly (Table 3). At FH, females more often exhibit signs of hyperextension of the toes than do males, whereas at CS, the reverse is true. These differences between sexes are not statistically significant ($p=0.135$ and 0.086 , respectively). When the aspects of burial practices (rather than biological sex) are considered at CS, clearer patterns emerge. Specifically, metatarsal facets are distributed non-randomly across the “girdle belts,” “polished stone tools,” and “other items + no items” categories ($p=0.018$). Individuals buried with a polished stone tool in the grave show significantly more metatarsal facets than the other CS individuals ($p=0.014$; OR = 4.92, 95% CI = [1.21–22.96]).

This difference vanishes when the left versus right burial position is taken into account ($p=0.160$; OR = 2.42, 95% CI = [0.78–7.54]). These findings point to an undetermined activity associated

TABLE 2 | Prevalence of spondylolysis in Polgár-Ferenci-hát, Polgár-Csőszhalom, and various contemporary Neolithic samples.

Site	Country	Dates (BCE)	N adults	N adults with L4 or L5 preserved	n cases	Crude prevalence	Corrected prevalence	References
Nitra-Horné Krškany	Slovakia	5400–5000	49	38	1	2.0%	2.6%	Tvrđý (2016)
Polgár-Ferenci-hát	Hungary	5300–5070	55	20	1	1.8%	5.0%	This study
Stuttgart-Mülhausen	Germany	5200–5000	94	64	9	9.6%	14.1%	Devos et al. (2022), Macintosh et al. (2014)
Polgár-Csőszhalom	Hungary	4800–4650	70	30	8	11.4%	26.7%	This study
Gurgy “Les Noisats”	France	4850–4500	67	7	0	0.0%	0.0%	Devos et al. (2022), Rivollat et al. (2023)
Alsónyék-Bátaszék	Hungary	4800–4400	405		3	0.7%		Bánffy et al. (2016), Köhler (2024)
Several sites from Vaud and Valais	Switzerland	4500–3800	98	51	4	4.1%	7.8%	Devos et al. (2022), Rosselet-Christ et al. (2024)
Ośłonki	Poland	4300–4000	61		2	3.3%		Garłowska (2001)

Note: Observations for Stuttgart-Mülhausen, Gurgy “Les Noisats,” and the Middle Neolithic Swiss sites were made by the first author of this study, with some data previously published. For Nitra-Horné Krškany, the number of adults with preserved L4 or L5 is an estimate based on the catalog of skeletal remains. For Ośłonki and Alsónyék-Bátaszék, the number of adults with preserved L4 and L5 vertebrae was not provided by the authors.

with these tools, likely with a specialized or symbolic function within the group. Made from metamorphic rocks and amphibolite (Szakmány et al. 2019), primarily sourced from regional materials, these tools show significant variation in size (ranging from 3 to 12 cm in length and from 2.5 to 4.5 cm in width) and use wear. Unfortunately, preliminary analyses of these objects have not yet clarified their exact purpose.

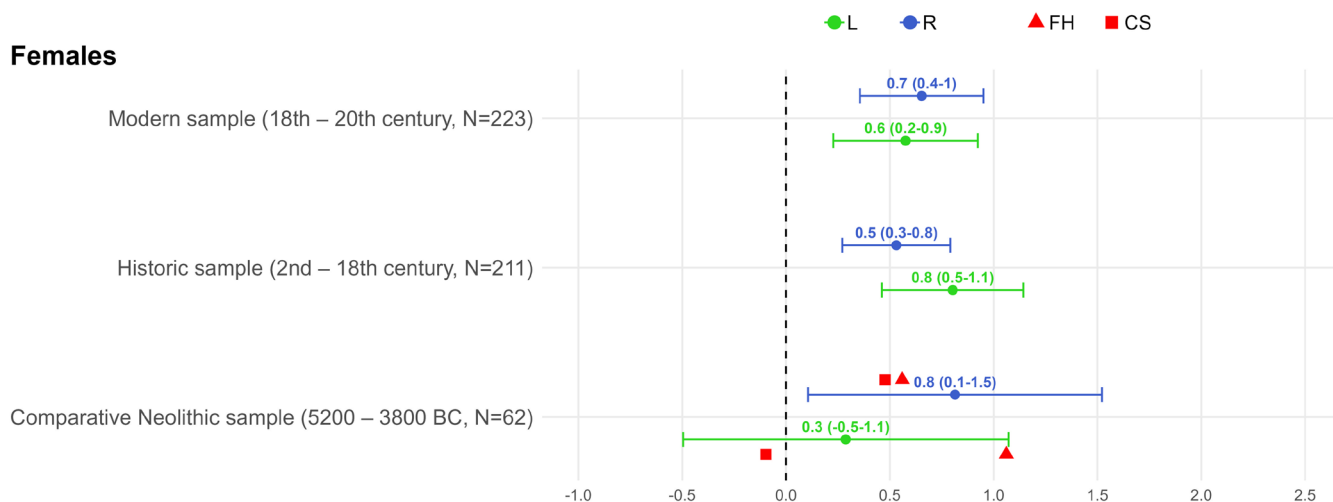
4 | Discussion

Our study focused on three indicators of activities practiced by individuals comprising human skeletal collections from the Neolithic period, distinguished by radically different burial practices. We did not attempt to “reconstruct” the activities practiced individually or collectively by the individuals buried at the two sites. This is a clear theoretical stance, based partly on the inherent limitations of studying ARSC (Villotte 2024). Most of these changes provide general information, and even in specific cases, it seems difficult to attribute a single activity to a given “marker.” Furthermore, like any skeletal manifestation, the appearance of an ARSC results from the combination of biomechanical stresses and individual and population-level thresholds linked to genetic background, which remain extremely difficult to define. Additionally, this type of interpretation

largely relies on three foundations: the archeological record, the ethnological record, and our preconceived notions. This often leads to a limited and restrictive perspective, particularly when considering gender roles. Therefore, we believe it is more prudent—and more honest—to focus on the distribution patterns of these ARSCs within the samples and to attempt to identify their potential causes.

Our results reveal some similarities but also significant differences between FH and CS, which can be interpreted in terms of lifestyle and social structure. Regarding the similarities, postures involving hyperextension of the toes appear to have been frequent in both groups. Unfortunately, the recorded frequencies cannot be directly compared to other Neolithic samples, as such data are not available. According to Molleson's research, kneeling was likely a common practice among Western Asian Neolithic groups (Molleson 1989). However, this author does not provide specific prevalence data for this condition. The frequencies recorded for FH and CS fall within the average range of values reported for more recent populations of diverse origins (Osing 2023; Ostendorf Smith and Woollen 2020; Prada and Sterpone 2000; Sheridan 2020; Ubelaker 1979). It can be assumed that this ARSC, if investigated with consistent methodology in other Neolithic groups, would likely also be documented elsewhere.

Females



Males

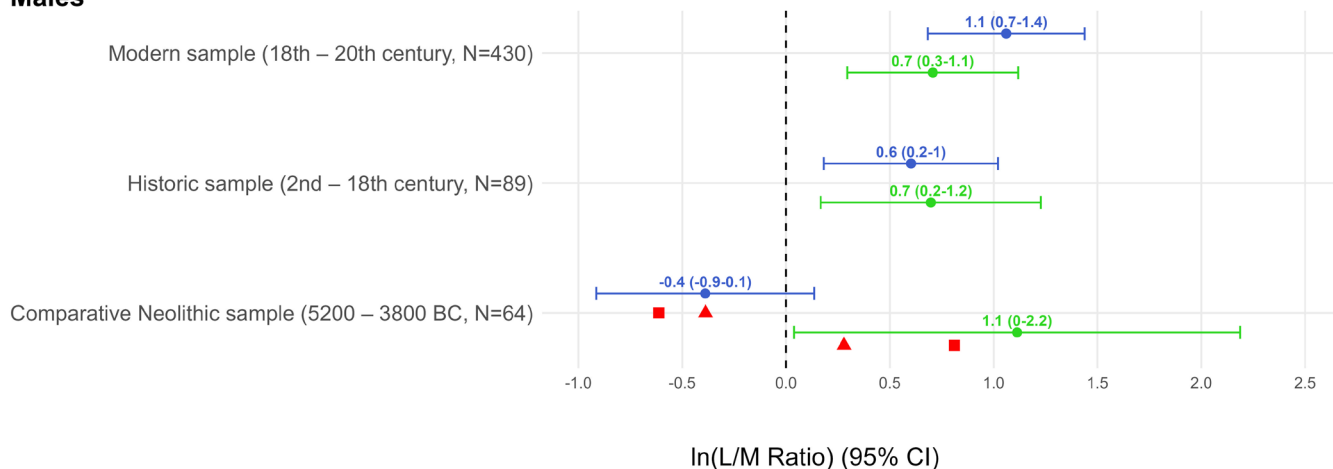


FIGURE 5 | Logarithms (with 95% confidence intervals) of the ratio of frequencies of lesions at the lateral and medial epicondyles of the humerus, calculated for each side. The Ln (L/M ratios) for the FH and CS samples are plotted against those of other comparative Neolithic, historic, and modern samples.

TABLE 3 | Prevalence of metatarsal facets in Polgár-Ferenci-hát and Polgár-Csőszhalom according to sex, burial position, and burial attributes.

			n/N	%
Polgár-Ferenci-hát	Sex	Females	8/16	50.0
		Males	3/16	18.8
Polgár-Csőszhalom	Sex	Females	9/33	27.3
		Males	11/21	52.4
	Burial position	Left side	9/29	31.0
		Right-side	12/23	52.2
	Burial attributes	GB	2/13	15.4
		PST	10/15	66.7
		Other items/no items	9/26	34.6

Abbreviations: GB, girdle belts; PST, polished stone tools.

Another similarity between the two groups concerns the preferential location of lesions on the medial compartment of the right elbow in males, as indicated by Ln (L/M ratio) below 0. In living people, nearly all clinical studies of large modern cohorts show an Ln (L/M ratio) above 0 (i.e., more lesions at the lateral epicondyle), except in young pitchers (see tab. 1 in Villotte and Knüsel 2014), where the ratio approximates -0.7 for the throwing arm (Lyman et al. 2001). This reversal is linked to the “valgus extension overload syndrome,” the most common cause of elbow injuries in throwing athletes (e.g., Ciccotti et al. 2004; Jobe and Ciccotti 1994; Stevens et al. 2024). This repetitive-stress condition is caused by the high forces generated during repetitive overhead throwing motions. The values observed in pitchers today are similar to those recorded for the right humerus in European prehistoric males from several sites (Villotte and Knüsel 2014), as well as those observed at FH and CS in the present study. It suggests unilateral upper-limb overuse in male groups. The systematic nature of this result is particularly intriguing. It seems improbable that exactly the same activities caused this phenomenon in all prehistoric groups studied. A more plausible explanation is that multiple activities—varying

by period or within groups—that involve throwing movements were predominantly performed by males. This interpretation resonates with ethnographic data, which suggest that in many traditional societies, activities involving throwing motions (e.g., javelin, hammerstone, axe, or adze use) are typically, though not universally, carried out by males (Testart 1986).

This primarily asymmetric use of the upper limbs among males has already been demonstrated for the Neolithic period in several studies (one of which included a small sample of eight skeletons from FH) through another ARSC: the cross-sectional geometric properties of the humerus (Macintosh et al. 2014; Marchi et al. 2006; Sládek et al. 2016; Varalli et al. 2020). These two indicators, which reflect significant mechanical stress of distinctly different types—one indicating cortical bone adaptation and the other showing lesions at fibrocartilaginous insertions—both support the hypothesis of a sex-based division of labor, which may, in turn, suggest the presence of socially constructed gender roles within the European Neolithic groups studied. Our results suggest that individuals inhumated at FH and CS structured their societies, at least in part, around certain sex-associated values common to many prehistoric European groups. These values appear to transcend burial treatment—specific and contrasting in CS and FH—and align with broader patterns. A final point concerns the use of upper limbs among females. Regarding upper limb robustness, Sládek et al. suggest that “the reduction of directional asymmetry in the female sample during the early agricultural Holocene can be seen as a specific skeletal feature associated with early agricultural subsistence throughout most of Europe” (Sládek et al. 2016). They directly interpret their results as a consequence of female use of saddle querns for grinding grain. While this hypothesis is plausible, it is also worth considering that a range of varied and physically demanding activities could similarly produce low or even negligible asymmetry, coupled with significant robustness in both upper limbs (Macintosh et al. 2017). This alternative hypothesis might help explain the slightly negative Ln (L/M ratio) observed for the left side in females at CS (-0.09)—a phenomenon also reported for the LBK collection from Stuttgart–Mühlhausen (Villotte and Knüsel 2014).

For FH, previous studies on nonspecific stress indicators and carious lesions suggest different exposures to risk factors between sexes during childhood and adulthood (Whittle et al. 2013), while our results on medial epicondyle lesions point to the possible existence of sex-associated, codified roles. Taken together, these findings suggest that females and males may have experienced distinct ways of life, shaped or imposed by the social expectations and organizational structures of their group. However, these distinctions do not appear to have been represented in the treatment of the deceased. Conversely, for reasons unknown to us, at FH, emphasis seems to have been placed on a limited number of individuals, notably very young children (Anders and Nagy 2019). The absence of markers in burial contexts related to the sex-based division of labor at FH suggests a disconnection between lived gendered roles—reflected in activities allocated to each sex—and representations of social status in funerary rituals, which may have been inherited or acquired during life for various reasons.

Despite the above-mentioned similarities, CS could be distinguished from FH in terms of daily activities, as indicated by the

frequency of cases of spondylolysis, which is particularly high compared to FH, Neolithic comparative data, and modern populations. In living adults, the prevalence of spondylolysis is estimated at 3%–6% (Fredrickson et al. 1984), but higher frequencies (10%–40%) are observed among athletes engaged in activities such as throwing sports, gymnastics, and rowing (e.g., Rossi and Dragoni 2001; Soler and Calderón 2000). The exact pathophysiology of this lesion remains unclear, but a biomechanical component is well-documented (Boszczyk et al. 2006), and data on athletes indicate that, in some cases, repetitive or high-intensity physical activities play a direct role in its development (for a review, see Devos et al. 2022). Additionally, a genetic component is strongly suspected, with various factors likely interacting in the manifestation of these lesions (Albanese and Pizzuttillo 1982; Verna and Villotte 2016). Thus, it seems reasonable to consider that a high frequency in an archeological sample reflects significant and/or unusual biomechanical loads, possibly compounded by a genetic predisposition to the condition. Interestingly, ancient DNA analysis indicates that the Late Neolithic CS population can be genetically modeled as deriving directly from the earlier Middle Neolithic FH population, with no evidence of significant exogenous gene flow (Szécsényi-Nagy et al. 2025). This suggests that genetic predisposition to this condition was likely similar in both groups, reinforcing the hypothesis that differences in biomechanical stress—rather than genetic variation—played a primary role in shaping prevalence patterns. In bioarchaeology, spondylolysis tends to be more frequent in males (Devos et al. 2022; Merbs 2002; Weiss 2009). However, in CS, no clear pattern is detectable according to biological sex (Table S1). This suggests that if these lesions are at least partially attributable to the physical demands of activities performed by these individuals, those demands were likely similar across gender roles.

In addition, at CS, there is a relationship between the presence of polished stone tools in the burial and the fact that these individuals tended to habitually hyperextend their toes during their lives. The group of individuals with polished stone tools in their burial and presenting metatarsal facets is primarily composed of males (nine individuals), but also includes one female, CS 2018.7.035 (Grave 337). It thus seems that at CS, there were activities dedicated to one sex (indicated by the frequency of elbow lesions and metatarsal facets) but also specialized activities within these gendered roles. Unlike FH, these social roles are reflected in burial practices, particularly through the presence of artifacts in the grave (e.g., polished stone tools). This alignment in CS between social roles and statuses, structured around distinctions between males and females, does not preclude complex individual trajectories. Females may have assumed roles traditionally associated with males (and possibly vice versa), and some individuals were treated in death with funerary markers characteristic of both sexes.

This study is, of course, not without limitations. One concerns the inherent constraints of studying ARSC, which we have detailed in Section 2 and at the beginning of this discussion. Another, equally important limitation relates to the representativeness of the analyzed samples. The data examined cover only a portion of the adult individuals excavated from the sites, which themselves represent only a small fraction of the population that lived in this region at the transition between the sixth and fifth millennia BCE. Nevertheless, these are relatively large collections for the period in question, with the additional advantage of originating from two

geographically close sites and comprising individuals who appear to be genetically similar. Consequently, interpretations of the observed skeletal modifications can primarily focus on behavioral aspects—excluding, for example, variations related to climate or genetics—but they must remain cautious given the limitations in representativeness. In addition, postdepositional and preservation processes may have affected the observable skeletal features, potentially obscuring some ARSCs and introducing a degree of bias that cannot be fully controlled.

5 | Conclusion

This study presents a case analysis of two Neolithic sites in Hungary, integrating evidence of ARSCs with burial data to explore gender roles. Burial practices provide insight into how communities represented individuals, offering indirect evidence of their social identities, while skeletal markers, though limited in precision, yield complementary information about activities performed during life. By combining these approaches, we aimed to demonstrate how their integration can generate new perspectives on social differentiation in the Neolithic. Bioarcheological evidence reveals aspects of the lived experiences of these two communities. Some patterns align with broader Pan-European trends—such as the unilateral upper-limb overuse among males—whereas others highlight local and culturally specificities that appear highly context-dependent. These results, therefore, illustrate the full complexity of the issues raised by Robb and Harris (2018), as further discussed by Gaydarska et al. (2023). This is particularly evident at CS, where an activity involving hyperextension of the toes and associated with polished stone tools—an activity primarily, though not exclusively, undertaken by men—contrasts with the pattern observed at FH. At FH, females exhibit these traits more frequently than males. At CS, however, the presence of metatarsal facets is symbolically linked to male burials, especially those with polished stone tools, underscoring the context-specific and fluid nature of gendered practices. Rather than indicating a rigid binary division of behavior, the evidence suggests that gender roles at CS were fluid and shaped by multiple intersecting factors.

We advocate for further research using the same approach as this study to expand our knowledge of gender roles in the past and to gradually address the encountered limitations, particularly regarding sample size. Future work should focus on a limited number of robust and reliable indicators—such as those proposed here—as a foundation for comparative analyses. This approach can help identify activity patterns that transcend geographic and cultural boundaries and clarify the relationships between material culture in graves and skeletal traces. Even in assemblages with larger datasets, these comparisons may reveal connections otherwise invisible through single lines of evidence. Ultimately, such work will refine our understanding of the social roles that males and females may have held within prehistoric societies.

Author Contributions

Sébastien Villotte: conceptualization, writing – original draft, writing – review and editing, funding acquisition, formal analysis, data

curation, investigation. **Tamás Szeniczey:** writing – review and editing, formal analysis. **Sacha Kacki:** writing – review and editing, investigation. **Alexandra Anders:** funding acquisition, data curation, writing – review and editing, investigation.

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Ethics Statement

The research was conducted on archeological human skeletal material curated at the Hungarian Natural History Museum, Budapest. All necessary permissions for the study of these remains were obtained from the curating institution. All methods were carried out in accordance with relevant guidelines and regulations governing the study of human remains at the Hungarian Natural History Museum.

Consent

As the study involved ancient human remains, informed consent was not applicable.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available in Supporting Information (Data S1) of this article.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Data S1:** Raw individual data used in the analyses. **Table S1:** Details of the individuals with spondylolysis. **Table S2:** Frequencies of lesions at the lateral and medial epicondyles.