

Social Determinants of Head Trauma? Skull Fractures in Nineteenth-Century Male Prisoners in Graz, Austria-Hungary

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ABSTRACT

This study investigates whether social factors influence patterns of head trauma in a bioarchaeological population sample of known identity. By examining the relationship between individual-level social variables and head trauma, it is hypothesized that social determinants shape behaviors leading to injury. Skulls and crania of 135 males who died in Karlau Prison, Graz, Austria-Hungary, between 1858 and 1908 were analyzed. Head trauma was quantified statistically by region (cranial base, vault, and face) and type. Social variables were defined from historical records and included age, legitimacy status at birth, language, and occupation. Head trauma was present in 23.0% of all individuals, with 2.2% to cranial bases, 20.5% to vaults, and 5.9% to faces. The social variables considered have a limited impact on the occurrence and patterns of head injuries in this group. The only significant patterns observed related to legitimacy status in individuals older than 40 years. Individuals born to married parents displayed a higher trauma rate, as well as Slovenian speakers classified as unskilled laborers. A logistic regression analysis revealed that social variables poorly predicted trauma outcomes, despite the well-contextualized sample. The random pattern of head trauma could possibly be linked to the social dynamics within the prison system, rather than life outside the institution that the variables considered in this study reflect. This study highlights how social complexity, which is evident from the historical records pertaining to these individuals, does not necessarily manifest as patterns of health and injury in bioarchaeological population samples.

Keywords: anatomical collection; criminology; Habsburg; SDoH; violence

Die vorliegende Studie untersucht anhand in einer bioarchäologischen Stichprobe bekannter Identität, ob soziale Faktoren das Auftreten von Schädeltraumata beeinflussen. Nach Betrachtung der Beziehung individueller sozialer Variablen mit Schädeltraumata wurde die Hypothese aufgestellt, dass soziale Determinanten Verhaltensweisen beeinflussen können, die zu letztlich Verletzungen führten. Analysiert wurden Schädel von 135 Männern, die zwischen 1858 und 1908 im Karlau Strafhaus, Graz, Österreich-Ungarn, verstorben waren. Schädeltraumata wurden statistisch nach Region (Schädelbasis, Kalotte und Gesicht) und Art quantifiziert. Soziale Variablen wurden auf Grundlage historischer Aufzeichnungen definiert, beinhalteten Alter, Legitimitätsstatus bei Geburt, Sprache und Beruf. Nachweisbare Schädeltraumata existierten bei 23,0% aller Individuen; 2,2% an der Schädelbasis, 20,5% Kalotten-nah und 5,9% am Viszerocranium. Die vorliegenden sozialen Variablen hatten begrenzten Einfluss auf das Auftreten und die Muster von Kopfverletzungen dieser Gruppe. Ein signifikantes Muster waren der Legitimitätsstatus bei Individuen älter als 40 Jahre. Nachkommen verheirateter Eltern wiesen höhere Traumata-Raten, ebenso ungelernte, slowenischsprachige Arbeiter. Logistische Regressionsanalysen ergaben, dass sich trotz der gut kontextualisierten Stichprobe aus sozialen Variablen Schädeltraumata kaum vorhersagen lassen. Das eher zufällige Muster von Schädeltraumata könnte daher eher mit sozialen Dynamiken innerhalb des Gefängnisystems in Verbindung gebracht stehen; weniger mit dem

Leben außerhalb dieser Institutionen, das die in dieser Studie berücksichtigten Variablen widerspiegeln. Diese Studie verdeutlicht, dass sich soziale Komplexität, wie sie in den historischen Aufzeichnungen über diese Individuen erkennbar ist, nicht zwangsläufig in Mustern von Gesundheit und Verletzungen in bioarchäologischen Stichproben widerspiegelt.

Stichwörter: Anatomische Sammlung; Gewalt; Kriminologie; Habsburg; SDoH (Soziale Determinanten der Gesundheit)

Introduction

The intersection of social history and bioarchaeology provides a potent framework for investigating the influence of societal structures on health and injury in past populations (Geber 2015; Klaus et al. 2017; Mays 2023; Murphy and Klaus 2017). Consequently, the relationship between social complexity and head trauma rates has been explored in various studies, often linked to community interactions (Baustian 2018) and broader dimensions such as population dynamics, environmental stability, subsistence strategies, social hierarchies, and cultural norms (de la Cova 2010; Fibiger et al. 2023; Geber and O'Donnabhain 2020; Scaffidi and Tung 2020; Walker 1989). However, these investigations are generally relying on broad inferences about social living conditions and environments derived from burial contexts, which may not accurately represent the individual's true experiences.

While studies of individuals with known identities and detailed biographies offer a more nuanced approach, these are often limited to those of high social status (e.g., Kacki et al. 2018; Karsten and Manhag 2017). Named or identified individuals in historical anatomical collections, primarily composed of individuals from lower social strata, provide a notable exception. The significance of these collections—and the ethics pertaining to them—has often been argued from a scientific point of view (Campanacho and Cardoso 2018; Marinho et al. 2018), which reflects how they were collected in the first place. In more recent years, however, the importance of these collections for gaining a better understanding of how social and cultural environments shape and impact human health and development have gained momentum (Zuckerman 2018), as well as insights into attitudes and “othering” in social power relations in the past (Robbins Schug et al. 2025; Zuckerman et al. 2021).

This research explores patterns of head trauma on the skulls of male prisoners who died in Karlau Prison (Provinzialstrafanstalt Graz-Karlau) in the city of Graz in Styria, Austria-Hungary, between November 1858 and December 1908. During this period, the bodies of unclaimed deceased prisoners were anatomized at the Institute of Anatomy of Karl-Franzens-University, and some skeletal remains were included in its anatomical collection. As the identities of these

individuals are known, it has been possible to obtain detailed biographical information through church records, dissection protocols, collection catalogues, newspaper articles, published literature, and more. These sources give an unprecedented insight into the social environment during the lives of these individuals, and this information enables a critical assessment of the biocultural linkages between social factors and head trauma patterns (cf. Mant et al. 2020; Martin and Harrod 2015; Perry and Gowland 2022).

Building upon findings from studies of contemporary prison populations (Davies et al. 2012; McMillan et al. 2021; McMillan et al. 2022; Williams et al. 2010), it is hypothesized that social circumstances, as well as the behaviors associated with these, influence the risk of head injuries. The aim of the study is to investigate whether specific social factors may explain patterns of head trauma within Karlau Prison during the latter half of the nineteenth century. The research question is underpinned by the Social Determinants of Health (SDoH) framework, which highlights the impact of sociopolitical context (e.g., labor market access and education), structural factors (e.g., socioeconomic status and class), and intermediate determinants (e.g., work/living conditions, and lifestyle factors) on health outcomes (Braveman 2023:5–15; Solar and Irwin 2010). While biocultural in its application to bioarchaeology, the SDoH approach specifically aims to elucidate the sociocultural determinants of health outcomes. This represents a more precise focus compared to the traditionally broader, holistic, and contextual examination of the interplay between biology, society, and culture in bioarchaeology but generally requires well-contextualized and detailed life history accounts or data that are not always readily available (see Cherverko 2021:67 ff.).

Karlau Prison, Anatomization of Prisoners' Bodies at Karl-Franzens-University, and Rehumanizing the Anatomical Collection

Karlau Prison (Fig. 1) is located west of the river Mur, on what in the nineteenth century was the southwestern outskirts of the city of Graz, and was first established as a provincial prison in 1809. The building itself was originally a late sixteenth-century



Figure 1. A postcard photograph of Karla Prison from 1911, by Anton Schlauer (Graz, Verlag). Source: University of Graz (<https://gams.uni-graz.at/o:gm.6237>). CC BY-SA 3.0 AT.

royal hunting lodge/castle (Hammer-Luza 2017). During a few months in 1859, it was used as a penal institution for political prisoners from the Crownland Kingdom of Lombardy-Venetia. From September 1859, Karla Prison functioned as a forced labor institution for prisoners from Lower Austria, until it was officially reverted to its function as a provincial male prison in 1863 (Hammer-Luza 2019:71–74). Between 1869 and 1872, the prison underwent significant reconstruction to facilitate the solitary confinement of prisoners in accordance with the so-called Pennsylvania system prison reform, which argued that separating prisoners from each other within the institution would prevent them from further “moral corruption” (see Vaux 1884). By 1888, the institution, which, other than the prison and associated buildings, included a garden and farmlands, covered over five hectares enclosed within 3.2-meter-high walls. In December that year, the Karla Prison held 745 prisoners, of whom 24 were sentenced to life and 85 served sentences of between 10 and 20 years (Leitmaier 1890:340–350).

The prison was one of several public institutions (such as hospitals and asylums) in Graz that supplied postmortem human bodies for anatomical study at the Anatomical Institute at Karl-Franzens-University. The Anatomical Institute, first established when the (new) university was founded in 1848, was located in a purpose-built and state-of-the-art facility on Harrachgasse 21 in the center of Graz. It housed its own anatomical collection and museum, which was considered an essential component of any anatomical institution at the time. In Austria, there was a seemingly tolerant attitude toward human dissection, at least among those who

partook in the public debate. This perspective likely reflected both the Roman Catholic (the dominant religion of the Habsburg Monarchy) theological focus on the immortality of the soul relative to the mortality of the body, and the broader context of political liberalism, modernity, and the societal benefits gained through the advance of anatomical knowledge overall during the nineteenth century (Buklijas 2008, 2018).

In Graz, mirroring the practice in Vienna, the Anatomical Institute interred dissected bodies in coffins within a designated cemetery plot. This practice suggests that the deceased were not merely treated as “cadavers” but afforded a degree of dignity, being buried in consecrated ground in accordance with societal norms (Buklijas 2008). This respect is further evidenced by the recording and maintenance of the individuals’ names in institutional records and the anatomical collection. Integrating these documentary sources with osteobiographies of human remains, through osteological and palaeopathological analysis, allows for efforts toward rehumanizing the collection (Zuckerman et al. 2024). This rehumanization is crucial not only to avoid further “othering” of the remains but also to potentially illuminate subaltern voices from the past, often silenced in historical records and whose stories have largely been forgotten. Or as Franz Rabl (No. 651, b. 5 January 1856), whose convictions included four murders, five robberies, eight arsons, and 12 counts of theft and fraud, uttered shortly before his execution on 11 November 1890 (Grazer Volksblatt 1890):

Forgive me, and remember me... [*Verzeiht mir, und seid meiner eingedenk...*]

Material and Methods

The sample comprised 135 identified individuals: 127 skulls (seven missing the calotte), two crania (one missing the calotte), and six complete skeletons. Two of these individuals did not die in Karlau Prison but were included in the study on the basis of context as they had been imprisoned in life: one individual, who was convicted of murder, died from stroke (*Gehirn-lähmung*) in the city's Lunatic Asylum (*Feldhof Irrenanstalt*) in 1873, and another convicted murderer (Franz Rabl, see above) died by public execution in the courtyard of the State Courthouse (*Landes-Gerichtsgebäude*) at the old jail (*Kriminalgebäude/Inquisitions- und Arresthaus*) (see Hammer-Luza 2008) in the city. The main cause of death in the total population sample, however, was respiratory disease (65.9%; 89/135), most commonly due to tuberculosis. All individuals were male, which was confirmed through macroscopic analysis following a standard osteological protocol (Buikstra and Ubelaker 1994; Sjøvold 1988). Most of the human remains included in this study (78.5%; 106/135) were anatomized during the tenure of Professor Emil Zuckerkandl (1849–1910), who joined Graz in 1882 (Höflechner 2006:357–387). The expansion of the collection that occurred during this time appears to be part of an intent to establish a research theme on anatomical variation and morphology, as well as bring the anatomical collections to equal standing with other institutions, such as Vienna, where Zuckerkandl had come from (Hyrtl 1869).

The remains are curated by the Division of Macroscopic and Clinical Anatomy at the Medical University of Graz, which is the successor institution to the former Anatomical Institute. The remains are exceptionally well-preserved, with the exception of the dentitions, which are very fragile and frequently damaged. This might be attributable to the maceration process (described in detail in an article published in the *Archiv für Anatomie und Entwicklungsgeschichte*), which involved soaking in warm water (up to 50°C) and degreasing in a gasoline solution, followed by cleaning with soap and water and sun-bleaching (Planer 1877). The skulls are marked with a number (typically a paper label affixed to the glabella) that corresponds to the register of the inventory of the former anatomical museum (when located at Harrachgasse 21). In some instances, the catalogue number (in addition to the paper label) was written in pencil on the skulls, primarily on an occipital condyle or on one of the mandibular ramii. Originally, the names of the individuals, their age at death, provenance (location of birth and death), and crime conviction were written in ink on the squama of the temporal bones,

mostly on the left bone or on both. This writing was, for various undisclosed reasons, deliberately erased in the early 2000s from most of the skulls but could be partly or completely discerned in this study with the aid of an ultraviolet LED light torch (LUXNOVAC, 30 W at 365 nm). Through this method, it was possible to read partial or complete writings on 103 skulls.

Given that the sample comprised named individuals, the study first sought to validate or refute the recorded identities by cross-referencing all the available sources in conjunction with the results of the osteological analysis. These written sources included, in addition to the inventory catalogues, primarily dissection registers and church records. All these sources give, to varying degrees, the same information relating to name, sex, age and date of death, place of birth, “ethnicity” (see below), profession, and criminal convictions. Occasionally, notes about observed anatomical anomalies and variations are also included in the museum catalogue descriptions, which could be used to confirm that the register entry is linked to the correct skull. Of the total sample, mismatched identities were noted in only two cases. In these, the number label attached to the glabella did not match the description of the skull in the catalogue inventory, but the correct numbers could be discerned from vague pencil or ink writings on the bones.

Age at Death

The age at death was calculated from birth and death dates recorded in the relevant church records, as only stated known ages at death are valid if they can be confirmed from primary sources. While it was possible to locate the death dates for all individuals, birth records could not be found for 13 individuals. There was, however, a strong correlation between *recorded* ($\bar{x} = 38.9$, $SD = 14.8$) and *actual* ($\bar{x} = 38.5$ years, $SD = 14.8$) age at death ($r_s = .996$, $p < 0.001$, $N = 122$). To ensure consistency in the data, however, only actual ages at death were used for analysis. Recorded ages at death were, however, used for missing cases when assigning individuals to age groups. The age group classifications used are those employed in nineteenth-century Austrian crime statistics (K. K. Justiz-Ministerium 1852): 14–20 years, 20–30 years, 30–40 years, and 40+ years.

Recording, Classification, and Quantification of Head Trauma

Head trauma (involving the whole skull) was recorded by location and type (Dedouit et al. 2024) and

included both antemortem and perimortem injuries. Healed bony calluses on skulls in general tend to be small and are often difficult to discern, in contrast to postcranial elements (Cunha and Pinheiro 2009), and can easily be misdiagnosed from normal anatomical variation and potential alternative causes like dermoid cysts and infectious lesions (e.g., tuberculosis, treponemal disease). To avoid overdiagnosis, Botham (2019) proposed a more strict and standardized descriptive diagnostic protocol considering lesion margins, shape, size, location, and endocranial table involvement. Bone remodeling in well-healed lesions, however, often obscures these features, making descriptions difficult. In the current study, clear cases of depression fractures were only evident in lesions measuring more than 3×3 mm in size. As virtually all lesions were healed (see below), diagnosing and describing trauma was aided through computed tomography scans (Siemens Somatom Definition AS+, axial slice orientation, slice thickness 0.6 mm, no slice increment), which were processed and analyzed using Amira 3D (Thermo Fisher Scientific, v. 2024.1).

Definition of Social Variables

This study defines a social variable as an attribute or characteristic that influences interactions and behaviors in individuals, as well as within and between groups. In archaeology, social dimensions are generally only informed and contextualized by mortuary contexts. While this approach is appropriate (Baker and Agarwal 2017), it is fundamentally imperfect in the sense that it is built on general understandings of how past communities and societies were structured (i.e., gender roles, how social stratifications were manifested, etc.) that do not necessarily always apply on an individual level. In contrast, identified human remains, for which individual social circumstances can be determined, offer significant advantages for understanding how social complexities manifest in human skeletal biology and, consequently, how this biology responds and adapts to social environments. The details of biographical information pertaining to named individuals can vary greatly, however (see Cardoso 2018), and the choice of social variables to include in the study is limited by the information available in archival sources. The evident bias in these archival sources leans toward demographic data (birth and death records), social conditions (such as societal position, family structure, and committed crimes), and health variables (specifically the cause of death), reflecting what was deemed important to wider society.

(Social) Age: Social dimensions in relation to age are multifaceted and theoretically complex. For example, Johfre and Saperstein (2023) discuss social age within a multilevel system where age can determine behavioral expectations in new interactions, such as dominance, submission, violence, or respect. Thus, age in this sample may be considered a social factor influencing behavior and trauma outcomes, even though it is not possible to determine at what age episodes of head trauma occurred. Bioarchaeological assessments of social age generally rely on biologically estimated chronological age, informed by stages of dental development and mineralization, as well as bone degeneration (Mays 2021:55–97). Despite the aim of these osteological techniques to approximate chronological age at death within a certain range, their inherent methodological limitations prevent the determination of specific ages. The present study overcomes this limitation by utilizing the known chronological age at death of the individuals, thus permitting a more direct examination of age as a social variable.

Legitimacy Status at Birth: Church records generally record the legitimacy status of newborn children, thereby providing potential insight into early childhood social conditions. For most of the nineteenth century, legal restrictions, so-called *Politischer Ehekonsens* (“Political Marriage Consent”), were in place in Austria and across the Habsburg Monarchy that restricted the ability of those with lesser or no resources to marry (Kytir and Münz 1986), meaning that illegitimacy came to be linked with poverty and social position. When a child’s legitimacy is not explicitly stated in church records, it can be inferred indirectly. If no father is listed, illegitimacy is assumed. Similarly, if the individual’s surname in adulthood matches the mother’s maiden name, an illegitimate status at birth can be assumed.

Language: In the multiethnic Austrian-Hungarian state, ethnocultural affiliations were complex and officially defined through linguistic classification (see Stergar and Scheer 2018). From 1880 onward, the census in the Austrian half of the Double Monarchy specified the mandatory recording of one of nine languages (*Umgangssprache*, the “every-day language” used): German, Bohemian-Moravian-Slovak, Polish, Ruthenian, Slovenian, Serbian-Croatian, Italian-Ladino, Romanian, and Hungarian. The archival records for individuals in this study largely adhere to these categories, with the exception of two individuals identified as French and seven others with unclear or unknown classifications. Due to ethnopolitical complexities embedded within the Habsburg Monarchy, where ethnocultural affiliations were linked to not only tradition and identity but also societal influence,

tensions became increasingly marked throughout the nineteenth century (Hubbard 1970; Wingfield 2004). These tensions frequently found expression in stereotypes contrasting “civilized” peoples with *Naturmenschen*; for example, German speakers were viewed as economic, industrious, and diligent, Hungarians as vain and hot-tempered, and Romanians and Croats as hardened, lazy, wild, and drunken (see Vári 2004). It is reasonable to assume that these stereotypes and attitudes also affected the lives of the individuals considered in this study.

Social Class (by Occupation): Social mobility in Graz during most of the nineteenth century was generally stagnant, and with increasing industrialization during the latter half of the nineteenth century, society became more and more characterized by socioeconomic stratifications linked to professions, even among the working classes (e.g., skilled versus unskilled laborers) (Hubbard 1984). These social categorizations, based on occupation, are also evident in the census and reflected in the archives pertaining to the individuals considered in this study. These occupations, which can be viewed as an indicator of the social position held in later life, were categorized as self-employed/independent (e.g., master tradesmen, merchants, and privaters), skilled laborers (craft workers, including apprentices), unskilled laborers (including servants and day laborers), and unemployed (including beggars and vagrants) (Hubbard 1984; Kořalka 2010). For five younger individuals (less than 30 years), the recorded occupation of their fathers was used.

Classification of Criminal Offenses

Following the definitions used at the time (Oberster Gerichts- und Cassationshof 1884:49–51), the individuals studied were convicted of 13 different categories of crimes (including attempts), which were classified into the three broad categories used by the Habsburg judicial system (K. K. Justiz-Ministerium 1852:Section XX): violent offenses (*Gewaltthätige Handlungsweise*, e.g., murder, manslaughter, sexual crimes, arson), property/economic offenses (*Gewinn-sucht*, e.g., theft, robbery, and fraud), and political crimes (*Verbrechen politischer Natur*, e.g., lese-majesté, counterfeiting, and forgery). It was possible to assign a criminal offense category to 133 individuals in the present study. The convictions only refer to the last judicial sentence given to the individuals, however. From notes in the archival sources, it is evident that some prisoners were repeat offenders, but it has not been possible to trace the full criminal records for all individuals.

Statistical Analysis

Data analyses were conducted using SPSS (IBM, Version 29.0.1.0). A Spearman's Rho correlation test was employed when investigating the relationship between ranked variables and chi-square tests for categorical variables. A Fisher's exact test was used in sparse data sets (five or fewer cell counts). A logistic regression model was applied to investigate the probability of head trauma (dependent variable) when linked to age, legitimacy status at birth, language, and social class (independent variables).

Results

Age at death averaged at 38.5 years, ranging from 15.9 years to 73.1 years (SD = 14.8, $N = 122$), which gives a good reflection of the mortality pattern of the prison at the time but not the age structure of the living prison population. The majority of the individuals were German speakers from the Styria region (including Lower Styria, now part of Slovenia). In December 1888, the prison population ($N = 745$) consisted of 66.8% German speakers, 30.2% Slovenian speakers, 0.1% Hungarian speakers, and 2.8% other language groups (Leitmaier 1890:349). In the study sample ($N = 128$), 60.9% spoke German as their everyday language, 31.3% Slovenian, 0.8% Hungarian, and 7.0% other languages, which suggests that the collection is a close representation of the ethnocultural composition of the prison inmates at the time. Most individuals (51.1%; 69/135) were unskilled laborers belonging to lower social classes (Table 1).

Fracture Frequencies

The overall prevalence of head trauma in the Karlaug Prison population sample was 23.0% (31/135), affecting the posterior cranial base in three individuals, the cranial vault in 26 individuals, and the face in eight individuals (Table 2). A Wilcoxon signed-rank test indicated no apparent side dominance to where fractures most commonly occurred on the skulls ($T = 25.50$, $z = -1.112$, $p = 0.266$). Weak correlations were observed between facial fractures and injuries to the cranial base ($r_s = 0.18$, $p = 0.042$, $N = 135$) and cranial vault ($r_s = 0.27$, $p = 0.002$, $N = 127$), suggesting that trauma affecting different regions of the head in an individual had generally occurred on separate occasions. Of those affected ($N = 31$), the number of diagnosed fractures ranged from 1 to 5 ($\bar{x} = 1.7$, SD = 1.1).

Cranial base fractures are typically classified by region: anterior (frontobasal) fractures often result

Table 1. Baseline characteristics of the prevalence of head trauma by social variable categories in the Karlau Prison population sample.

Variable	Statistic	Total	Head Trauma		χ^2 (df)	<i>p</i> -value
			Present	Not present		
Age at death [years]	N_{obs} (N_{miss}) $\bar{x}$ (SD) Range	122 (13) 38.5 (14.8) 15.9–73.1	30 (1) 38.7 (15.7) 15.9–73.1	92 (12) 38.5 (14.6) 17.4–70.7	110.3 (105)	0.342
Age group [years]	N_{obs} (N_{miss}) N (%)	135 (0) 6 (4.4)	31 (0) 1 (3.2)	104 (0) 5 (4.8)	1.5 (3)	0.702
14–20	N (%)	43 (31.9)	9 (29.0)	34 (32.7)		
20–30	N (%)	25 (18.5)	8 (25.8)	17 (16.3)		
30–40	N (%)	61 (45.2)	13 (41.9)	48 (46.2)		
40+	N (%)	119 (16)	28 (3)	91 (13)	0.4 (1)	0.545
Legitimacy status at birth	N_{obs} (N_{miss}) N (%)	75 (63.0)	19 (67.9)	56 (61.5)		
Legitimate	N (%)	44 (37.0)	9 (32.1)	35 (38.5)		
Illegitimate	N (%)	128 (7)	29 (2)	99 (5)	3.6 (6)	0.742
Language	N_{obs} (N_{miss}) N (%)	78 (60.9)	17 (58.6)	61 (61.6)		
German	N (%)	2 (1.6)	1 (3.4)	1 (1.0)		
Bohemian-Moravian-Slovak	N (%)	40 (31.3)	10 (34.5)	30 (30.3)		
Slovenian	N (%)	1 (0.8)	0 (0.0)	1 (1.0)		
Serbian-Croatian	N (%)	4 (3.1)	0 (0.0)	4 (4.0)		
Italian-Ladino	N (%)	1 (0.8)	0 (0.0)	1 (1.0)		
Hungarian	N (%)	2 (1.6)	1 (3.2)	1 (1.0)		
Other (foreign)	N (%)	135 (0)	31 (0)	104 (0)	2.3 (3)	0.516
Social category (by profession)	N_{obs} (N_{miss}) N (%)	7 (5.2)	1 (3.2)	6 (5.8)		
Self-employed/independent	N (%)	47 (34.8)	13 (41.9)	34 (32.7)		
Skilled laborer	N (%)	69 (51.1)	16 (51.6)	53 (51.0)		
Unskilled laborer	N (%)	12 (8.9)	1 (3.2)	11 (10.6)		
Unemployed/destitute						

Table 2. Quantification of skull fractures, by region and fracture type.

Region/Fracture Type	<i>N</i> (%) [individuals affected]	Side [number of fractures]	
		Left	Right
Cranial base (posterior) (<i>N</i> = 135)	3 (2.2)	3	2
Linear	2 (1.5)	2	0
Diastatic	2 (1.5)	1	1
Hole	1 (0.7)	0	1
Cranial vault (<i>N</i> = 127)	26 (20.5)	21	15
Depression	13 (10.2)	12	6
Linear	10 (7.9)	4	6
Multiple Linear	3 (2.4)	2	1
Diastatic	1 (0.8)	1	0
?Gutter	1 (0.8)	1	0
Stellate	1 (0.8)	0	1
Hole	2 (1.6)	1	1
Facial (<i>N</i> = 135)	8 (5.9)	7	5
Frontal sinus	2 (1.5)	1	1
Infraorbital rim	1 (0.7)	0	1
Mandible	1 (0.7)	1	0
Nasoorbitoethmoid	1 (0.7)	1	0
Nose	5 (3.7)	3	3
Zygomaticomaxillary complex	1 (0.7)	1	0

from direct frontal impact, central skull base fractures commonly extend from frontobasal fractures, and posterior skull base fractures usually occur due to direct occipital impact and may extend into the petrous part of the temporal bone (Baugnon and Hudgins 2014). Only posterior skull base fractures, affecting three individuals, were observed in the

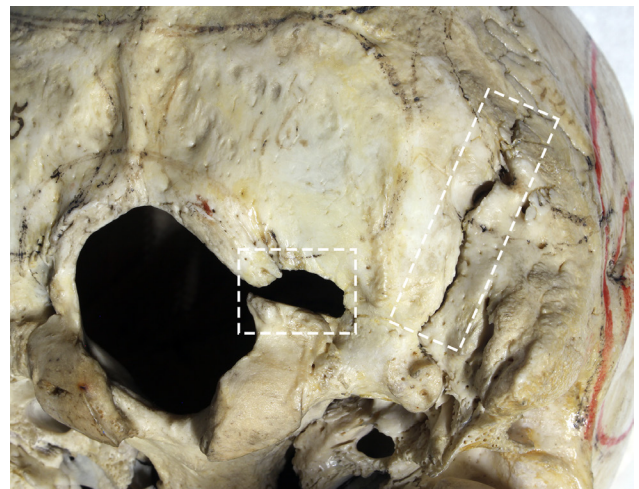


Figure 2. Perimortem fractures observed in the posterior cranial base of a 26.4-year-old (No. 137), who died by judicial hanging. A hole fracture is noted immediately posterior to the right occipital condyle, as well as an occipitomastoid diastasis on the right side of the skull base. Photo: Jonny Geber.

Karlau Prison population sample. One of these cases comprised two perimortem fractures in an individual (No. 137) who died by judicial hanging. These fractures included a unilateral (right) occipitomastoid diastasis and a hole fracture (approximately 8 × 6 mm in size) posterior to the right occipital condyle and extending to the lateral margin of the foramen magnum (Fig. 2). The fractures are likely directly related to the cause of death rather than damage caused

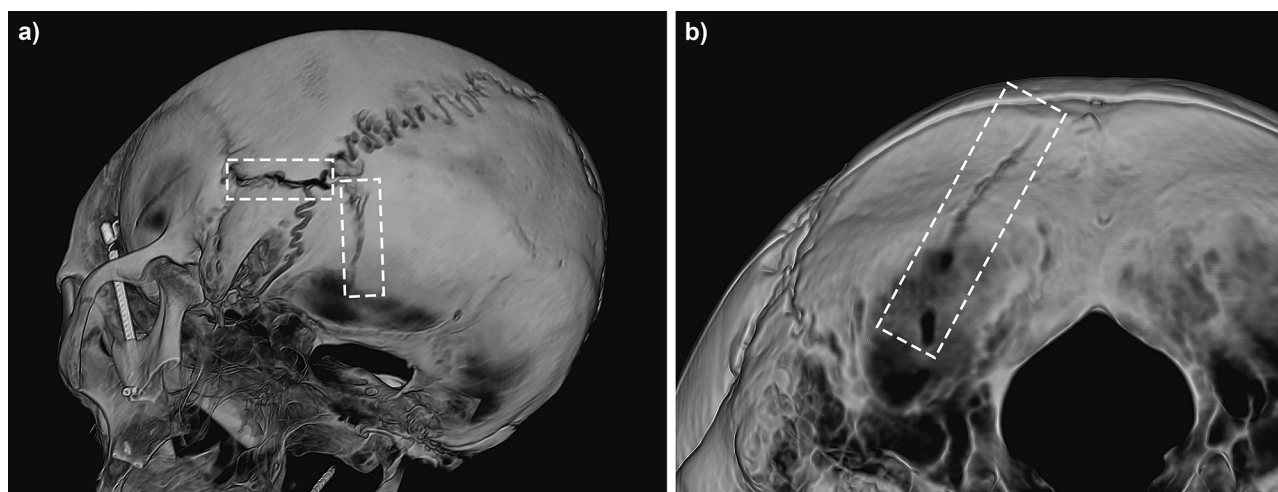


Figure 3. Fractures of the posterior cranial base in two individuals, affecting the skulls of a 44.0-year-old (No. 78), where a diastatic and linear fracture (in the process of healing) are present on the left aspect (a), and a 57.0-year-old (No. 124) with a healed linear fracture on the posterior-left part of the head (b). Images generated from CT scans through Amira 3D (Thermo Fisher Scientific, v. 2024.2), by Jonny Geber.

during the anatomical dissection. Occipitomastoid diastatic fractures have been reported in other cases of judicial hanging-related skeletal trauma (Campanacho and Garcia 2021; Waldron 1996; Wood-Jones 1913).

The additional two individuals with injuries to the cranial base displayed antemortem fractures (Fig. 3). These included a linear fracture in the process of healing on the left aspect of the occipital bone of a 44.0-year-old individual (No. 78), where a fracture line extended onto the temporoparietal suture where it is diastatic. The second skull belonged to a 57.0-year-old individual (No. 124), which displayed a healed linear fracture running diagonally across the left aspect from the jugular junction to the external protuberance. Linear fractures affecting the neurocranium generally originate distant from the in-bending impact area of the bone and radiate both toward and away from where the impact occurred (Galloway 1999). The linear fractures in these individuals were both confined to the occipital bone, and both on the same side, likely as a consequence of being struck from the front or left while moving the face away from an aggressor.

Overall, the majority (72.2%; 13/18) of cranial vault lesions affected the frontal bone, with the remaining fractures present on parietal bones (27.8%; 5/18). Most of the cranial vault injuries were depression fractures (Fig. 4a), with approximate surface areas (length $\times$ width) ranging from 0.1 to 14.8 cm², with a median of 0.6 cm² (SD = 3.6 cm², N = 18). The morphology of cranial vault depressions depends on the size and shape of the object that causes the injuries, and is generally the result of objects that are of “moderate”

size not exceeding the cranial vault dimensions at the site of impact (Galloway 1999). Linear fractures (Fig. 4b) on skulls tend to occur when the head is struck by larger surface objects, and these fracture types were present in 12 individuals. In addition, there was also a case of a stellate fracture (Fig. 4c) observed on the right parietal bone of a 15.9-year-old (No. 1414), who was also the youngest individual in the population sample. Stellate fractures originate at the point of impact and sometimes result in a depression at the point of impact (Galloway 1999), which was also observed in this case.

Less common cranial vault injuries in the population sample included hole fractures and a potential gutter fracture that may be indicative of healed gunshot trauma (Fig. 5) in three individuals. These males had been convicted of violent (public violence and rape) and property (robbery) crimes. The hole fractures, similar in size and shape, exhibit smooth margins with pitted reactive bone on the ectocranial surface and smaller healed fragments on the endocranial surface. It was not possible to identify any radiating fracture lines originating from the perforations, which, however, may have become indiscernible through the healing process (Cunha and Pinheiro 2009). The potential gutter fracture (Fig. 5c), located on the left parietal bone of a prisoner convicted of robbery, is less definitive due to the bone remodeling process of the margins. It presents as a shallow depression with two parallel linear leveled bases on the ectocranial surface, possibly indicative of a grazing bullet wound (Berryman 2019).

Facial fractures predominately affected the nose and mid-face in the population sample. Healed



Figure 4. Examples of healed cranial vault fractures, which include a depression fracture (a) on the frontal bone (No. 145) of a 31.3-year-old, a linear fracture (b) running from the right mid-coronal suture to the mid-squama of the temporal bone in the skull (No. 180) of a 30.9-year-old, and a stellate fracture (c) on the superior portion of the right parietal bone in a skull belonging to a 15.9-year-old (No. 1414). Photo: Jonny Geber.

complex fracture patterns, which are the result of high-force trauma, were present in three individuals. These exhibited fractures involving the nasoorbitoethmoid (Fig. 6a) and zygomaticomaxillary complex (see Fig. 6c) on the left side of the face. In one of these cases, a skull (No. 178) belonging to a convicted assassin also involved a fracture of the left coronoid process of the mandible (see Figure 6d), which is reportedly rare in the clinical literature and today most commonly the result of falls and road traffic accidents (Diab et al. 2022; Galloway 1999). Other facial fractures observed involved the infraorbital rim and the frontal sinus (Fig. 6a) in two individuals. Nasal fractures (Fig. 6b) were the most commonly observed facial trauma in the group. These are, as with cranial vault trauma, most commonly attributed to interpersonal violence (Magalhães et al. 2020).

Associations between Criminal Offense and Head Trauma

Within the group, there was a relatively even distribution of individuals convicted of violent (51.9%; 69/133) and property/economic crimes (43.6%; 58/133), while political crimes were the least common conviction at only 4.5% (6/133). There was only a weak correlation between crime offense convictions and age ($r_s = -0.208$, $p = 0.022$, $N = 121$), which indicates that these social variables did not influence the criminal offense data within this sample. No statistically significant associations between criminal offense category and head trauma were observed in the sample on an overall level ($\chi^2(2) = 0.171$, $p = 1.000$), but when investigating the association by age group, a chi-square test identified a difference in fracture rates of

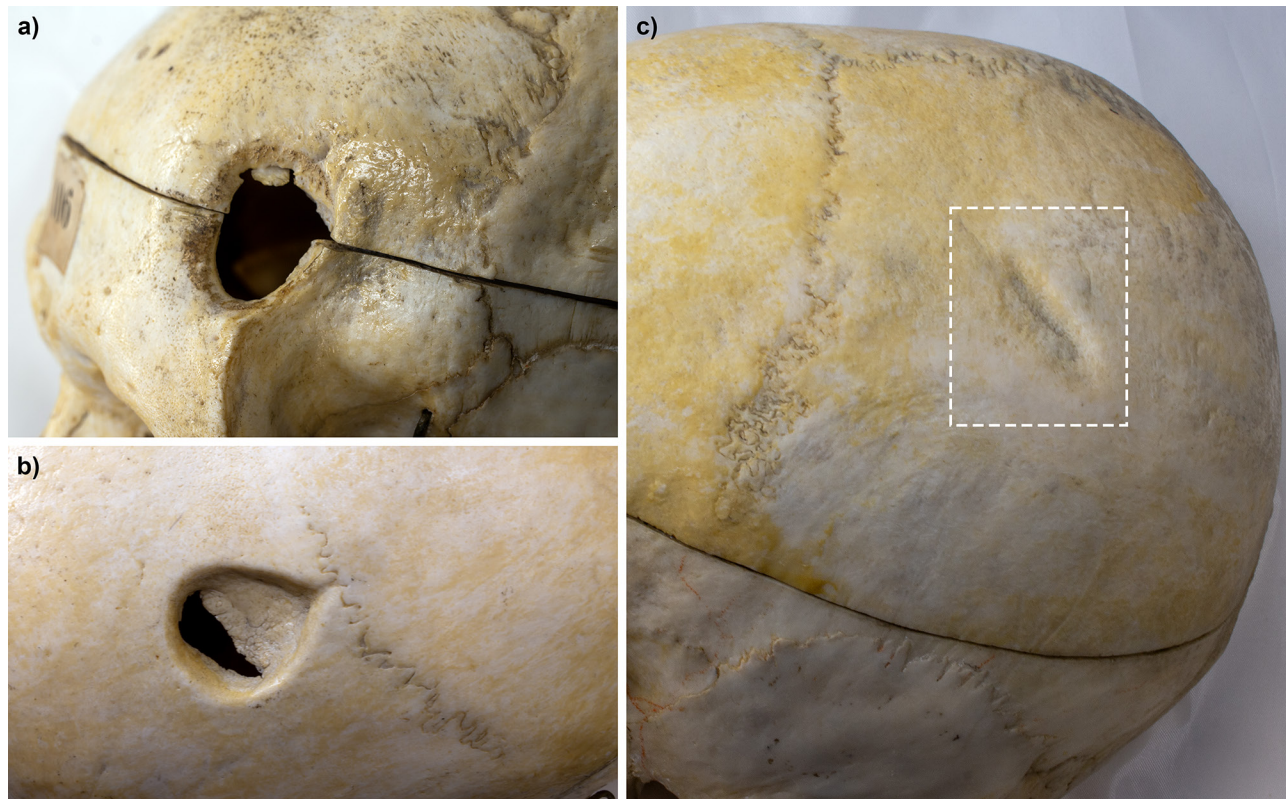


Figure 5. Healed hole fracture fractures on right aspect of the frontal bone (a) of a 30.8-year-old (No. 106) and on the right parietal bone (b), adjacent to the coronal suture, belonging to a 73.1-year-old (No. 215), and a potential gutter fracture (c) on the superolateral aspect of the left parietal bone of a 42.3-year-old (No. 166). Photo: Jonny Geber.

cranial vaults in the 20- to 30-year age group ($\chi^2(2) = 7.151$, $p = 0.035$), where prisoners who had committed property/economic crimes were more than twice as likely to display fractures compared to prisoners with violent and political crime convictions (Fig. 7).

Relationship between Social Variables and Head Trauma Patterns

While the age of injury cannot be established for these individuals, age may serve as a useful interpretive variable under the hypothesis that the risk of certain trauma types was linked to age, potentially evident as cumulative rates or an increased number of fractures in older versus younger individuals. The data, however, show no association between the prevalence of head trauma ($r_s = -.004$, $p = 0.915$, $N = 122$) and the number of fractures ($r_s = 0.062$, $p = 0.062$, $N = 122$) with age at death, which suggests that there is no relationship between age as a social variable and head trauma patterns in this population sample. The only pattern relating to age noted appears to be random. When the data were analyzed by age group, it was found that among 40+-year-olds, there was a

significantly higher rate of cranial vault trauma in those born as legitimate children: 27.3% (9/33) were affected, compared to none (0.0%; 0/15) among those born illegitimate ($\chi^2(1) = 5.035$, $p = 0.041$, $N = 48$). Another observation is that there was a statistically significantly higher rate of cranial vault trauma in individuals aged 20–30 years convicted of property offenses within the German-speaking group ($\chi^2(2) = 8.404$, $p = 0.010$, $N = 35$).

Legitimacy status at birth also stands out as the only variable associated with facial trauma in the overall sample, where it was observed only in individuals (8.0%; 6/69) born to parents who were married ($\chi^2(2) = 3.707$, $p = 0.054$, $N = 119$). If it is accepted that legitimacy status can be used as a proxy for social status in early childhood, then this would suggest that poverty or a lower family social position at the beginning of life had no influence on later life outcomes in terms of exposure to trauma. Austrian crime statistics from the late nineteenth century recorded the legitimacy status of offenders (e.g., K. K. Statistischen Central-Commission 1896), and it is noteworthy that from these data, the prevailing perception linking illegitimate birth to increased adult criminality was increasingly being questioned, albeit

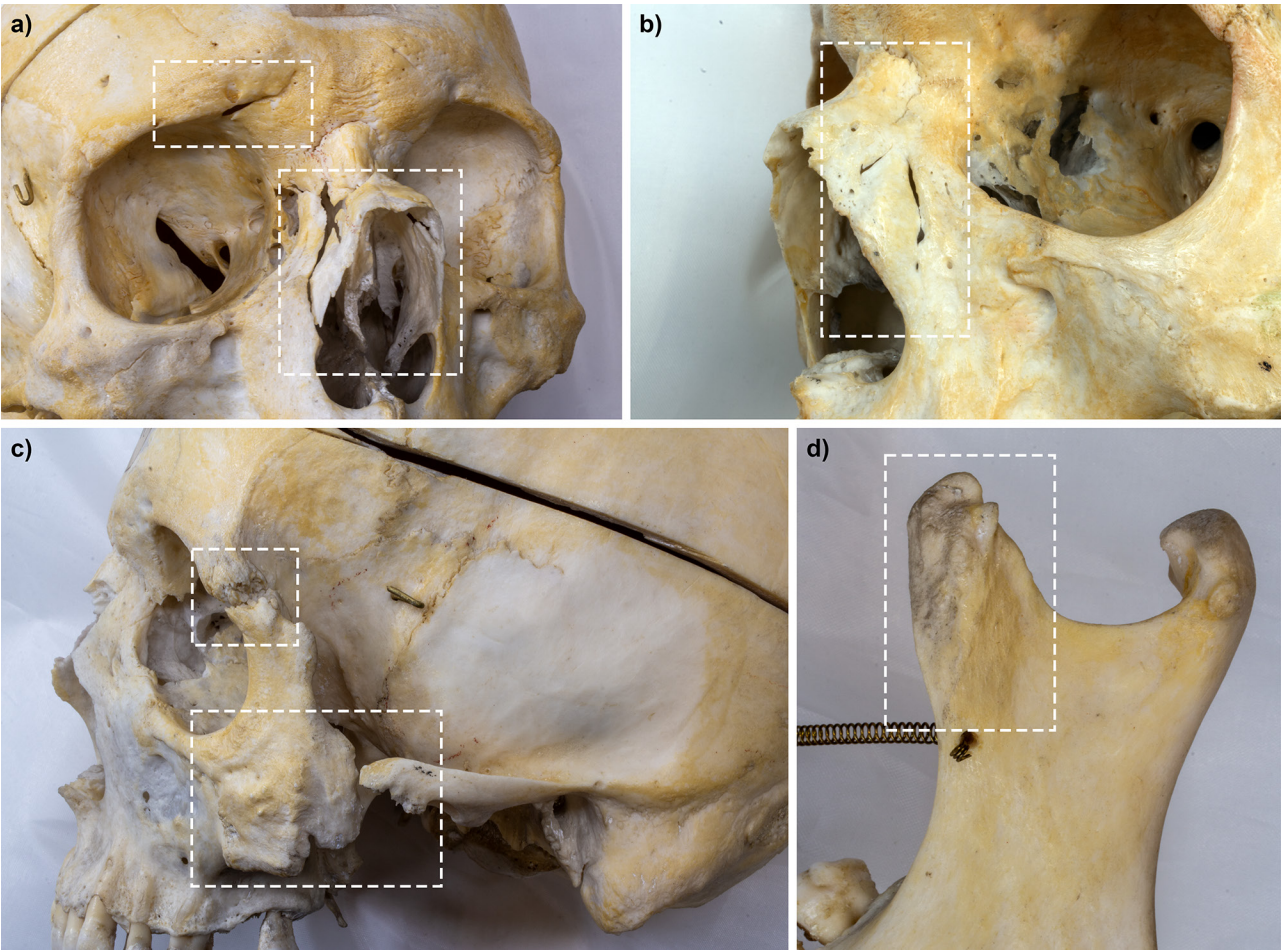


Figure 6. Examples of healed facial fractures, affecting the frontal sinus and naso-orbitoethmoid complex (a) on the right side of the face of a 57.0-year-old (No. 124), the left side of the nose (b) in a 64.2-year-old (No. 216), and the zygomaticomaxillary complex (c) and coronoid process of the mandible (d) on the left side of the face of a 22.7-year-old (No. 178). Photo: Jonny Geber.

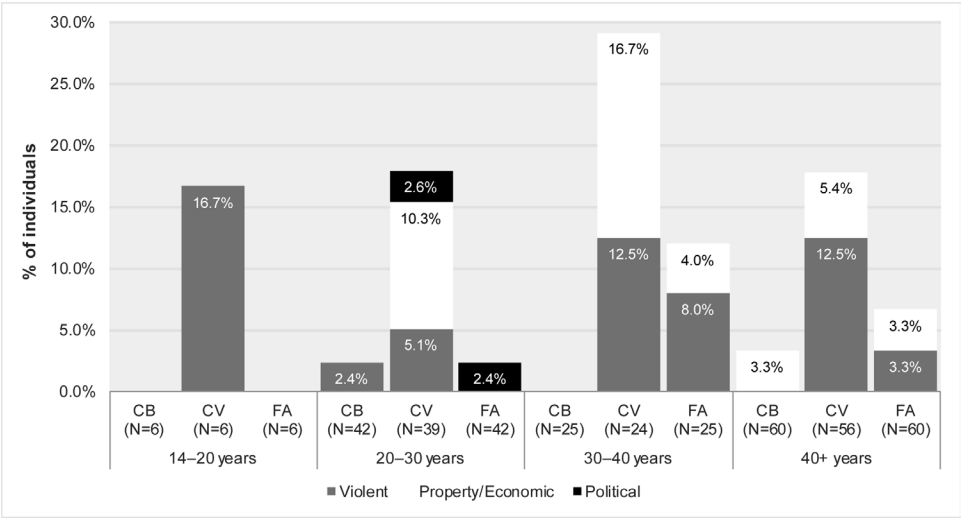


Figure 7. Bar chart displaying prevalence of head trauma by age group, region of head (CB = cranial base, CV = cranial vault, FA = face), and criminal offence category.

with some reluctance (see Morrison 1897:121ff.). By the early twentieth century, reports indicated that 13.8% of male prisoners in Austria were born illegitimate, only marginally higher than the 13.7% recorded for the general population (von Borosini 1913).

No direct associations between language, as a proxy for ethnocultural identity, and head trauma patterns were observed in the population sample. As German speakers dominate the overall sample, however, any potentially cultural patterns of trauma (see Brickley and Smith 2006; de la Cova 2010; Geber and O'Donnabhain 2020) may be obscured in the data. When considering social groups by profession, it was noted, however, that a higher rate of facial fractures was present among unskilled laborers ($\chi^2(2) = 14.139$, $p = 0.015$, $N = 65$) who spoke Slovenian. As with the observation noted among German-speaking property offenders (see above), this difference appears to be random. On the overall level, no relationship between head trauma frequencies ($\chi^2(3) = 2.338$, $p = 0.505$, $N = 135$) and social group was observed in the sample.

Logistic Regression Analysis

When considering all the data together, a logistic regression analysis revealed that the tested social variables were not significant predictors of head trauma ($\chi^2(11) = 8.018$, $p = 0.712$). The model explained a relatively small proportion of the variance (Cox & Snell $R^2 = 7.0\%$; Nagelkerke $R^2 = 10.4\%$), with 76.8% correctly predicted. These findings suggest that social factors, as measured and analyzed in this study, have a limited impact on the occurrence of skull fractures in the Karlau Prison population sample.

Discussion

The Austro-Hungarian Monarchy was a geopolitically complex state characterized by underlying ethnic, political, and cultural tensions—a Europe *en miniature* (Weinmann 1867:97)—that would influence the industrial, scientific, and social development that characterized much of the nineteenth century (Beller 2018; Middleton 2020). Throughout the lifetime of many of the individuals included in this study, much of Habsburg society was locked in political and social turmoil (Sperber 2005). These conflicts led to the formation of the Austro-Hungarian compromise in 1867 and eventually collapse through the catastrophe of World War I from 1914 to 1918 (Beller 2018). In terms of the SDoH framework, these political tensions form the backdrop of the social

conditions the individuals from Karlau Prison lived in prior to and during imprisonment. This includes their socioeconomic positions within society, which in this study can be partly denoted by the recorded professions they held in life.

While the professions are a valid reflection of social structure and position within society (Hubbard 1984), it should be noted that social stratification is not always expressed equally within the same cohort. For instance, sociologist Max Weber included power as a determining factor in hierarchical relations, meaning that the “standing” of individuals could very much have depended on specific contexts (Hurst 2016:213–221). This is exemplified by one of the individuals in the present study, a man called Leopold Kendler (b. 19 October 1833). According to the records, he was a road sweeper from Sankt Leonard am Forst in Lower Austria. He died in Karlau Prison on the morning of 7 November 1882 due to pulmonary tuberculosis. His skull (No. 225) showed no evidence of trauma. While his occupation would indicate that he held a low social position, the archives noted that he was the leader of a band of thieves, which would have ranked him high within his own social context, from which he would have benefited in terms of access to resources and other means.

Leopold was born as an illegitimate child to Katharina Kendler, an unmarried maid. While legitimacy status reflects an intersection between both the religious (in the Christian faith, a family founding sacrament) and the secular (as a legal contract) domains, it was grounded in morals within the community. Illegitimacy was much more common in Austria than in many other European countries, varied by region, but did not necessarily have exclusively negative connotations (Shorter et al. 1971; Sumnall 2009, 2020). The *Politischer Ehekonsens* system, intended to prevent pauperism within the population, was disbanded in the late 1860s mostly for administrative reasons (Lanzinger 2003). What followed was a drastic decline in illegitimate births across Austria, which suggests that common law practices had been solidly in place and that the status of illegitimacy probably had few social consequences on a broader scale (Shorter et al. 1971; von Borosini 1913). Only five individuals in this study were born in the years after *Politischer Ehekonsens* was disbanded, and four of them were illegitimate at birth. It is therefore not possible to estimate whether the reform had any impact on social patterns related to head trauma.

The third element of the SDoH framework discusses intermediary determinants through which structural determinants, such as social status and class, operate (Solar and Irwin 2010:36–43). This relates to both working and living conditions, as well as

lifestyle choices, which in this context can be denoted by the crimes committed by the individuals considered in this study. As previously stated, no correlation or association between crime convictions and head trauma patterns was observed in this study. It should be noted, however, that the classification of crimes into broad categories may hide nuances in the type and severity of the crimes committed.

Head Trauma Related to Imprisonment?

In comparison with other nineteenth-century populations, the prevalence rate of head trauma in the Karlau Prison group is high (Table 3) and statistically significant ($\chi^2(5) = 25.291$, $p < 0.001$, $N = 1,402$). However, rates of head fractures in bioarchaeological samples vary significantly due to how trauma rates are quantified and reported, and they may also be population-specific. For instance, in de la Cova's study of the Terry, Hamann-Todd, and Cobb Anatomical Collections, nasal fracture rates were exceptionally high (de la Cova 2008:253–264) and hence skew the overall prevalence of head trauma if not differentiated from other regions of the skull in that study.

The seemingly random pattern of head trauma observed in Karlau prisoners may be better explained by considering the unique social dynamics within the prison environment. The prison system likely fostered distinct social hierarchies and relationships, both between prisoners and guards and among the prisoners themselves. These dynamics may have differed significantly from the social structures experienced by these individuals outside of the prison, potentially contributing to the observed (nonevident) patterns of head trauma. The aforementioned case of a male that displayed a cranial base fracture in the process of healing (Fig. 3a), might, for instance, be a reflection of trauma that occurred in the prison. This

skull (No. 78) belonged to Ferdinand Wick (b. 11 April 1845), a day laborer from Upper Austria who was convicted of theft and died in Karlau Prison on 27 April 1889 due to pulmonary tuberculosis. He is listed as a wanted criminal, for having stolen clothes, in the Central Police Gazette (*Central-Polizei-Blatt*) from 21 September 1887 (K. K. Polizei-Direktion zu Wien 1888:200). This is likely the specific offense he was convicted of, and he must therefore have been imprisoned for up to one and a half years prior to his death.

As mentioned previously, between 1869 and 1872, the Karlau prison was rebuilt in order to adhere to the Pennsylvania system (Leitmaier 1890:340–350). This prison reform, which was the first of its kind in Austria, advocated for solitary confinement as a means for prisoners' moral and social reform, and part of their rehabilitation (Sellin 1970). It is, however, unclear to what extent solitary confinement was upheld within the institution in practice. A report published in the *Laibacher Tagblatt* in February 1872 described the newly rebuilt prison with narrow corridors and 260 bright cells closed off with thick wooden doors through which prisoners were fed via a hatch. Large-barred windows could be opened with a bar to provide ventilation, and the cells were furnished with a single bed, a table, a stool, and a rake and a rack to keep the space clean (*Laibacher Tagblatt* 1872). Ten years later, it was reported that the prison in Karlau (and Ljubljana) was overcrowded by 480 prisoners (Haus der Abgeordneten des österreichischen Reichsrathes 1882:XIII. Ministerium der Justiz), which may mean that some cells were used for more than one prisoner.

While solitary confinement was argued to be beneficial to prisoners, by means of protecting them from bad influence by other incarcerated criminals, more recent debates on prison reform would suggest that it is likely to have had a drastic effect on both mental and physical health and well-being instead.

Table 3. Frequencies of head trauma in nineteenth-century population samples (males only).

Population	Social Strata	Head Trauma		Source
		%	No./Total	
Karlau Prison, Graz, Austria, 1858–1908	Lower/middle	19.7	25/127	This study
Kilkenny Union Workhouse, Ireland, 1847–1851	Lower	6.3	12/190	Geber and O'Donnabhain (2020)
Terry/Hamann-Todd/Cobb, United States, 1812–1870	Lower	9.4	57/605	de la Cova (2008)
Freedman's Cemetery, Texas, United States, c. 1869–1907	Lower	5.6	13/231	Davidson et al. (2002)
St Marylebone, London, England, c. 1700–1859	Middle/upper	4.7	5/106	Miles et al. (2008)
St Mary and St Michael, London, England, 1843–1854	Lower	9.1	13/143	Henderson et al. (2013)

Due to differences in how rates of head trauma have been defined and quantified in various studies, the highest rate by region was selected from studies that differentiated between trauma to different regions of the skull. For de la Cova's study of the Terry, Hamann-Todd, and Cobb Anatomical Collections (de la Cova 2008), however, only cranial vault rates were considered, as the exceptionally high rate of nasal fractures in these samples (43.5%; 263/605) distorted the data.

This, in turn, could have aggravated violence within the prison population, including self-harm (see Kaba et al. 2014). This is exemplified by the case of Matthäus Ulbl (b. 4 February 1825), whose story was published in the Swedish newspaper *Westernorrlands Allehanda* in January 1876. Matthäus had worked as a painter's assistant but followed a criminal career path from a young age. In 1868, after 20 years in prison, he was pardoned, but upon his release, he took out immediate vengeance on the person who had reported him to the police. He was convicted of murder to life in prison (for a second time) and made an attempt on his own life by hitting his head violently against a wall (*Westernorrlands Allehanda* 1876). No skeletal evidence of head trauma was noted on his skull (No. 662), which is consistent with biomechanical studies of "head-butting" injuries, which have noted that the risk of bone fractures is relatively low (Adamec et al. 2013). In December 1875, Ulbl managed to escape but was quickly caught and returned to Karlau prison. He would live for an additional six years until he died of a stroke (*apoplexia cerebri*) on 11 December 1881.

Conclusions

The study of remains of individuals of known identity is a rare occurrence in bioarchaeological studies. They often derive from nineteenth-century anatomical collections, which have been a valuable resource for developing and refining methods such as sex and age-at-death estimations (e.g., Marinho et al. 2018). This study has shown that integrating osteological analysis with historical and archival records with skeletal remains from these collections also significantly helps to improve the theoretical and analytical approach to understanding social complexities in bioarchaeological research. It is evident, from the historical records, that the life experiences of the males incarcerated within Karlau Prison were diverse. These differences in life experiences are not reflected in the skeletal trauma record, which, however, may relate to the prison environment, which may have resulted in additional head trauma or injuries that obscure any patterns that may have been evident prior to incarceration.

The lack of evident direct links between the social variables selected and skeletal morphology (in this case, the evidence of trauma) on an individual level shows that the biocultural approach may not always capture social complexities when interpreting pathological changes in human skeletal remains, especially when historical biographical information is not available. Yet, this lack of social patterns within the prison

population—but high rates of head fractures compared to non-prison population groups—is telling in its own right. It may suggest that an assigned "othering" of people as criminals had more influence on the risk of exposure to head trauma than social conditions relating to age, ethnocultural identity, poverty, and socioeconomic status.

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Ethics Statement

The authors recognize the multilayered and culturally complex ethical circumstances relating to human remains, both historically and in the present time. Research ethics was assessed and approved by the School of History, Classics, and Archaeology Research Ethics Board (13 April 2021) and the Medical University of Graz Ethics Commission (36-241 ex 23/24).

Author Contributions

J. G. designed research, analyzed the data, and wrote the paper with input from the coauthor; N. H. provided analytical support and provided material resources and acquisition of data.

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