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Actualistic research into dynamic impact and its implications for understanding differential bone fragmentation and survivorship

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ABSTRACT

The relationship between bone mineral density and archaeological bone survivorship has played a critical role in zooarchaeological and taphonomic studies in recent decades. Numerous studies have suggested that higher-density skeletal element portions survive more frequently than lower-density element portions when archaeological assemblages are affected by some taphonomic processes. Interpretations of density mediated destruction have become commonplace in the archaeological literature, and are often used to explain the absence of certain bone elements and element parts in zooarchaeological assemblages. This study explores the effects of rockfall on bovid elements in varied environmental conditions and the differential survivorship of their element parts, and has implications for understanding the taphonomic processes through which bones are subjected to dynamic loading. Actualistic rockfall experiments conducted on twelve samples of frozen, fresh, and semi-dried bovid bones reveal that the generally low-density epiphyseal ends of bone elements resist fracture and analytical deletion with more frequency than the higher-density diaphyses. This evidence suggests that bone density does not correlate with likelihood of breakage or effective archaeological "destruction" when rockfall and other processes that result in dynamic impact are in action. While this research does not question the relationship between bone mineral density and the likelihood for archaeological survivorship as the result of some taphonomic processes, it presents one specific set of taphonomic processes that result in the differential survivorship of low density bone elements parts and the fragmentation and destruction of higher density element parts. This research presents evidence that shows that dynamic impact is a process capable of fragmenting and sometimes destroying high-density elements while low-density elements survive.

1. Introduction

This study tests the survivorship of different parts of bones broken through events of dynamic impact, as demonstrated by actualistic rockfall experiments. Little previous work has addressed the nature of processes that result in dynamic impact on bones and the differential rates of survivorship that can be observed as a result. Previous work regarding rockfall is scant, and is particularly lacking in actualistic research. In one instance, Dixon (1984) studied deposits in natural cave environments in Alaska in an attempt to better understand bone fracture patterns produced by rockfall and taphonomic processes that alter bones. His work focused principally on the capacity for natural processes to produce specimens that resemble evidence of cultural bone modification. Little other research directly addresses the nature of rockfall as a taphonomic process or attempts to understand the differential bone breakage patterns produced by rockfall, though many experiments have been conducted to test the effect of hammerstone impact on bone assemblages (e.g. Alcántara García et al., 2006; Blumenschine, 1988; De Juana and Domínguez-Rodrigo, 2011; Galán et al., 2009; Karr and Outram, 2012).

Though early scholars occasionally noted differential patterns of element part survivorship, work conducted by Guthrie (1967), Brain (1969), Behrensmeyer (1975), Binford and Bertram (1977), and Lyman (1984) initiated modern studies aimed at understanding the likelihood of bone survivorship based upon the measured density of different portions of bone elements. An important distinction must be made between the fracture and fragmentation of bones and bone element parts, and their "destruction," or effective analytical deletion, in archaeological contexts. Many processes are capable of fracturing and fragmenting bones, but the resultant fragments often remain identifiable to element. The destruction or analytical deletion of bones only occurs when a bone or an element part has undergone such extensive

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fracture and fragmentation that it can no longer be identified to element. The concept of density mediated attrition lies in the assumption that low-density portions of bones are more likely to be destroyed than high-density portions of the same bones when certain taphonomic processes are at work. This assumption has been broadly accepted in the archaeological community, and some actualistic research has demonstrated a positive correlation between bone density and survivorship when certain taphonomic processes, such as carnivore gnawing and fluvial transport, are in action (Marean, 1991; Marean and Spencer, 1991; Voorhies, 1969).

Though clear evidence for a relationship between bone density and archaeological survivorship has not been demonstrated for some taphonomic processes, the near universal acceptance of density-mediated destruction among scholars is manifest through the near-exclusive application of density-related interpretations of zooarchaeological assemblages. A large body of literature has been created centred around attempts at measuring bone density, devising methods for measuring density more accurately, and interpreting archaeological assemblages based upon density (Binford and Bertram, 1977; Elkin and Zanchetta, 1991; Enloe, 2004; Faith et al., 2007; Gaudzinski, 2000; Grayson, 1989; Ioannidou, 2003; Kreutzer, 1992; Lam et al., 1998; Lam et al., 1999; Lam and Pearson, 2004, 2005; Lam et al., 2003; Lyman, 1984, 1994; Marean and Frey, 1997; Marshall and Pilgram, 1991; Stiner, 2004; Symmons, 2005; Ugan, 2005). Early studies (Lyman, 1984, 1994) focused on measuring bulk densities of bones, which resulted in imprecise measurements because of the inclusion of the marrow cavity of long bones. Other methods (Lam et al., 1998) improved the accuracy of bone density studies by removing the marrow cavity from consideration when measuring density, and demonstrated a more dramatic difference in density between epiphyses and diaphyses. For the purposes of the experiments detailed in this article, extraordinarily precise density data of the type widely available in the literature are not required. Instead, this research demonstrates that in the case of the taphonomic process of rockfall (and in other situations where dynamic impact on bones occurs), density is not the principal factor mediating element part destruction, and that a negative correlation between density and archaeological survivorship exists. The experiments detailed in this article suggest that an inverse relationship between density and survivorship, whereby the lowest density elements exhibit the greatest resistance to fracture and fragmentation, and experience the greatest likelihood of survival.

Bone density and its relationship to archaeological survivorship remained relatively unchallenged in the archaeological literature until very recently, and served as a primary analytical tool for the interpretation of many assemblages (e.g. Binford and Bertram, 1977; Gaudzinski, 2000; Marean, 1991; Marean and Frey, 1997; Lyman, 1994:234–293). Recent research, however, has demonstrated that when certain taphonomic processes are in action, density is not the principal factor mediating bone destruction. A recent study by Pante and Blumenschine (2010) has demonstrated that density is not the critical factor in the fluvial transport of broken bone elements, suggesting that bone destruction caused by the movement of elements in flowing water does not necessarily correlate with the density of those elements. Stiner (2002, 2004) has utilized the methods of both Lyman (1984, 1994) and Lam et al. (1998) to demonstrate that her methods for bone identification circumvent the problems of density variation among element parts when constructing body part profiles. Stiner (2002) suggests that body part profiles are less affected by variations in bone density when certain identification methods are employed, contradicting the other scholars who suggest head-and-foot dominated assemblages may be methodological artifacts (see Marean and Frey, 1997 for an extended discussion). Conard et al. (2008) demonstrate that the processes of heating and cooling, and wetting and drying, lead to the disproportionate fragmentation of high-density diaphyses, while epiphyses tend to resist fracture and fragmentation when the same processes are at work. To date, similar attempts at understanding rockfall as a taphonomic process and the relationship between bone density and survivorship have not been published. This study is designed to provide actualistic data relevant to understanding rockfall and other taphonomic processes that produce dynamic impact on bones, as well as to provide for a clearer understanding of the role of density in the destruction of some element portions and the survival of others. A set of experiments utilizing fresh, frozen, and semi-dried bones provides a means for understanding the effect of these taphonomic processes on the differential fragmentation of large mammal long bones.

2. Methods

The cattle (*Bos taurus*) bones used in these experiments were obtained from a local butcher. As a result of the nature of modern butchering practices, cattle bones generally available for the purposes of archaeological experimentation are sourced from animals approximately 18 months in age. In order to ensure that age-bias was minimalized for the purposes of this experiment, special effort was made such that the cattle bones used in this experiment were sourced from animals between 24 and 36 months in age, as indicated by epiphyseal fusion stages and direct conversation with the butchers that provided the bone material. All bones used for these experiments had been refrigerated while still fleshed for two weeks immediately following the death of the animals. Bones in this condition exhibit negligible levels of degradation when compared to truly fresh bones (Karr and Outram, 2012).

In total, 96 cattle long bones were used. These were divided into twelve samples of eight bones each. Two samples of eight bones each were prepared to simulate each of the environmental condition detailed in Table 1.

Frozen and fresh samples, both with and without flesh, exhibit fracture morphologies consistent with fresh bones, while bones artificially dried for periods of several days to several weeks exhibit fracture morphologies consistent with moderately dry (but not completely mineralized) bones (Karr and Outram, 2012). The different environmental conditions allow for samples that represent bone assemblages ranging from fresh to partially dried, but do not include completely dried or mineralized bones. These experiments, then, address the period of time when humans and carnivores are most likely to interact with bones (when they were fresh)

Table 1
Environmental conditions simulated by each experiment and the processing methods for bones in each of those samples.

Prepared condition	Methods for processing
Frozen cleaned bones	Bones cleaned with modern knives to remove all meat, fat, and periosteum, then frozen for 15 days at −20 °C.
Fresh cleaned bones	Fresh bones cleaned with modern knives to remove all meat, fat, and periosteum. Fractured within one day of being cleaned.
Frozen bones with some tissues intact	Bones frozen for 15 days at −20 °C with a small amount of meat, fat, and periosteum intact.
Fresh bones with some tissues intact	Fresh bones with a small amount of meat, fat, and periosteum intact. Fractured within one day of being obtained from a butcher.
Cleaned, dried bones	Bones cleaned with modern knives to remove all meat, fat, and periosteum, then air-dried at 40 °C for 40 h in an adapted drying cabinet.
Bones dried with some tissues intact	Bones with a small amount of meat, fat, and periosteum intact that were dried at 40 °C for 20 days in an adapted drying cabinet.