



Digitization of the Nissen–Riesen chimpanzee radiological growth series

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Funding information

National Science Foundation SBE Office of Multidisciplinary Activities, Grant/Award Number: 1719432; Yerkes National Primate Research Center

Abstract

Longitudinal morphological growth data of apes are incredibly difficult to obtain. Long life histories, combined with practical and ethical issues of obtaining such long-term data have resulted in few longitudinal data sets in chimpanzees of known chronological ages. One classic, long-term growth study of chimpanzees was that of Drs Nissen and Riesen initiated at the Yale Laboratories of Primate Biology in 1939. Through that study, whole-body radiological images were taken on a regular basis from a “normative” group of chimpanzees from birth to adulthood. Here we have digitized the known remaining radiographs from that growth study, many of which are deteriorating, and uploaded the data set to the free, online database MorphoSource. The database comprises 3,568 X-ray images of 15 of the 16 chimpanzee subjects in the normative group and 1 individual from an experimental group. Herein, we briefly review the historical context of this study and specific details of the data set.

KEYWORDS

chimpanzee, database, growth, skeletal, X-ray, Yerkes

1 | MORPHOLOGICAL STUDIES OF CHIMPANZEE GROWTH

Precise longitudinal growth data are ideal for the study of life history in evolutionary anthropology, from estimating age in fossil hominins to understanding maternal investment and dominance. Chimpanzees (*Pan troglodytes*) have featured predominantly in studies concerning growth in humans and nonhuman primates. Indeed over the last 100 years, a number of cross-sectional and longitudinal studies have investigated their morphological growth.^{1–29} These studies have typically taken one of two forms: (a) longitudinal and/or cross-sectional studies of living captive chimpanzees of known age and (b) cross-sectional studies of individuals of differing ages via museum or wild skeletal collections, with or without known ages of individuals. Longitudinal studies of morphological growth of living chimpanzees are understandably difficult to undertake, yet provide information that

allows researchers to better understand growth patterns and levels of variation both within and between individuals over time.³⁰ Due to the logistical difficulty of conducting such long-term research on chimpanzees, direct metrical data of longitudinal somatic growth are typically only available from laboratory-, zoo-, or sanctuary-based studies, though some notable longitudinal field-based growth data exist as well.^{1,2} While variable in their duration, data collected, and sample sizes, much of the published longitudinal growth data have been collected in one of a limited number of locations: the Yale Laboratories of Primate Biology (YLPB),^{3–13} the Primate Research Institute, Holloman Air Force Base,¹⁴ the Primate Foundation of Arizona,^{15,16} the NYU Laboratory for Experimental Medicine and Surgery in Primates,^{17–20} the Stanford Outdoor Primate Facility,²¹ the Southwest Foundation for Biomedical Research,^{22–24} and the Kumamoto Primate Park and the Primate Research Institute of Kyoto University.^{25–29} Of these, the first center to begin collecting long-term longitudinal data

on chimpanzee growth and development was the YLPB (now the Yerkes National Primate Research Center).

As early as 1925, data on physical development were being collected in the first four chimpanzees of the YLPB.⁴ However, data on captive chimpanzee growth began in earnest in 1939, with the beginning of the Infant Studies Program at the YLPB, which entailed long-term longitudinal data collection on various aspects of morphological (as well as physiological and behavioral) growth.⁸ The study was originally funded by the Samuel S. Fels Fund, and headed by Dr. Henry W. Nissen and Dr. Austin H. Riesen.^{9,31} Original publications on the skeletal, dental, and overall body growth generated from the Infant Studies Program are still highly utilized and cited in Biological and Evolutionary Anthropology, and many of the data collected are irreplaceable. Of particular interest to Evolutionary and Biological Anthropology is that the chimpanzee subjects in the Infant Studies Program underwent regular radiological (X-ray) imaging as part of the standardized data collection schedule.^{8,11} X-ray imaging of live animals has only been possible in captive growth environments and provides a level of detailed measurements and quantitative information unique to many growth studies. Much of the data on chimpanzee growth from the original X-ray data set and Infant Studies Program have been published,^{5,7-13,32-36} yet the original X-rays continue to provide a wealth of other quantitative and qualitative information.

For the last several years a large portion of the original Infant Studies Program X-ray data set has resided in the Anatomical Sciences Museum of the Department of Anatomical Sciences at Stony Brook University.³⁷ Owing to its age, many of the original radiographs, in particular the earliest images, are damaged and deteriorating. Many of the early films are brittle, wrinkled, and display discolored or faded areas (Figure 1). Nevertheless, many of the later images are well preserved and even those that are damaged retain anatomically useful information. In order to preserve this collection, and to make it more readily available to researchers, we have now curated, digitized, and uploaded the remaining X-rays to the online database Morpho-Source³⁸ where they are freely available to researchers.

2 | DATA SET HISTORY AND STANDARDS

The Nissen–Riesen normative chimpanzee growth data set was a result of the Infant Studies Program which began in July 1939^{8,31} at what was then the YLPB in Orange Park, Florida. Sixteen individuals (nine males and seven females) born between July 1939 and January 1943 were originally included in the normative growth group.^{9,11,12,35,36,39} All infants in the study were of known parentage and were from one of eight mothers and one of three fathers (Table 1^{35,36,39,40}). Further individual biographical data including birthdates, photographs, and additional information regarding participation in experimental studies for the normative group of chimpanzees (as well as all of the first 100 chimpanzees at the YLPB) have been compiled from published and unpublished data by Dr Lori Gruen, and are available online.⁴¹

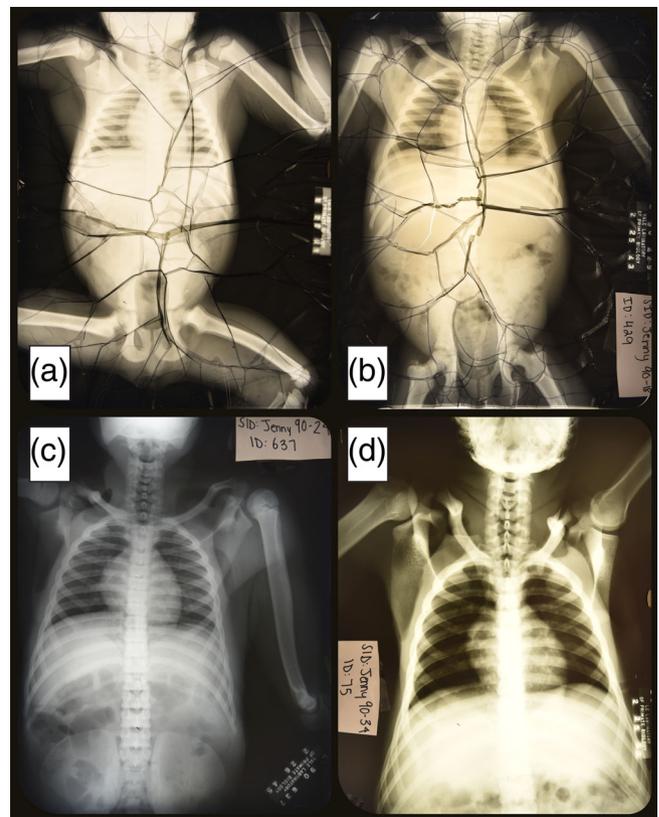


FIGURE 1 Trunk images of Jenny (YLPB-90) at different ages: (a) 1.5 years, (b) 3.0 years, (c) 5.0 years, and (d) 13.0 years. Many of the earlier images in the collection are damaged or degraded as in (a) and (b). For all images, scales are present on the light box but are cropped out here for clarity. YLPB, Yale Laboratories of Primate Biology [Color figure can be viewed at wileyonlinelibrary.com]

All 16 individuals in the normative group underwent largely the same experimental treatment, beginning with near immediate separation from the mother after birth. Most were separated within 48 hours and the median separation time for the first 14 individuals was 17 hours.^{8,36} All chimpanzees were then raised by human caretakers.^{8,36} While referred to as the “normative” group in publications,^{8,11} Nissen clarified that “No claim is made that these conditions have been ‘normal’ or ‘natural’; doubtless they have fallen short of being optimal even for our purposes. In so far as considerations of health permitted, however, they have been essentially constant for all individuals” (⁸, p. 160). Indeed the original design was intended to maximize experimental control of the group and provide a homogenous growth environment¹¹ as the normative group served as the basis of comparison for several experimental groups.⁴² Following separation, a suite of anatomical and physiological measurements were taken at regularly scheduled intervals (see⁸ for the complete list). For the radiological images (begun for all subjects in 1940), with some exceptions, subjects underwent X-ray imaging monthly during the first 2 years of life, tri-monthly during years 1–3, and yearly thereafter.¹²

Based on published descriptions of methodologies, X-ray films (at least until the age of 48 months) were made using a 1/10 or 1/20 s exposure, intensities of 32.2–54.1 kV peak at a constant

TABLE 1 Individuals, parentage, and numbers of radiographs digitized

Individual	ID number	Sex	MorphoSource identifier	Number of images	Date of birth	Age at last image	Mother	Father
Ken	YLPB-55	Male	S9427	221	July 9, 1939	14.0	Soda	Frank
Art	YLPB-57	Male	S9428	226	July 20, 1939	22.3	Fifi	Bokar
Alf	YLPB-59	Male	S9425	126	October 17, 1939	23.9	Alpha	Frank
Bard	YLPB-61	Male	S9429	233	February 22, 1940	14.0	Dita	Bokar
Scarf	YLPB-65	Male	S9420	164	November 24, 1940	10.0	Soda	Frank
Jed	YLPB-67	Male	S9426	243	April 16, 1941	20.3	Wendy	Jack
Jent	YLPB-71	Male	S9421	260	April 7, 1942	26.1	Bentia	Jack
Web	YLPB-79	Male	S9249	115	January 16, 1943	18.9	Wendy	Bokar
Jenny	YLPB-90	Female	S9422	387	February 24, 1940	31.9	Wendy	Jack
Jojo	YLPB-94	Female	S9424	242	April 23, 1940	22.2	Josie	Jack
Banka	YLPB-98	Female	S9423	236	January 2, 1941	13.1	Bimba	Frank
Flora	YLPB-100	Female	S23126	348	January 28, 1941	34.9	Alpha	Frank
Fanny	YLPB-102	Female	S23127	290	August 16, 1941	28.1	Nana	Frank
Falla	YLPB-104	Female	S23128	211	April 29, 1942	12.0	Alpha	Frank
Karla	YLPB-106	Female	S23129	215	May 26, 1942	8.6	Bula	Frank
Alfalfa ^a	YLPB-120	Male	S23130	51	March 29, 1945	5.0	Fifi	?
Total				3,568				

Note: Parentage data from References 36 and 40

^aAlfalfa is the only individual who was not part of the “normative” group.

10 mAs, and with a tube-film distance of 41 in.³⁶ However, these parameters were reported for X-rays taken during the first 4 years of growth, and they likely changed in the later films when chimpanzees reached adult size. A complete set of X-ray images included images of the trunk, head, and the left upper and lower limbs.³⁶ While the left side was the standard side to image,³⁶ and it typically is labeled as such on the X-rays, many experimental days have images of both right and left extremities. The vast majority of images are labeled with a radiopaque image tag containing the subject number (see below), the imaging date, and the limb side (“L” or “R”).

In the years during which the Infant Studies Program was ongoing, a number of publications utilized the “normative” growth to investigate weight changes,^{7,11,43} timings of tooth eruption,^{9,10,32} appearance and fusion of ossification centers,^{13,36,43} and long bone growth,^{11,12} all with an eye toward comparisons with humans and other primates (e.g.,^{32–34}). By 1966, many of the original 16 normative individuals were no longer alive.^{13,41} The final image in our possession dates to 1975. At some point following the conclusion of the normative group data acquisition, the X-ray collection moved from the Yerkes Research Center and into the possession of Dr Elizabeth S. Watts. Watts collaborated on a comparative study on adolescent growth of chimpanzees and rhesus macaques with Dr James A. Gavan,³⁴ who himself had utilized the data set for his dissertation⁴⁴ and subsequent publications.^{11,12,32,33} Watts later collaborated with Dr Daris R. Swindler and one of the current authors (R. L. A.) on a study of dental development using the radiological data set.⁵ Following Watts' death in 1994, the collection was given by Watts' husband to Dr John G. Fleagle. The collection has resided in the Department of

Anatomical Sciences' museum at Stony Brook University since then, where it has received infrequent use.³⁷

Of the 16 original normative chimpanzees, we have digitized and uploaded data on 15 individuals. The 16th individual, Spratt, died after 12 months and none of his data remain in the collection.¹¹ For five of the individuals, the original radiographs are no longer housed with the main collection and their whereabouts are unknown, however they were previously photographed and converted to 35 mm slides by R. L. A. In addition to the normative individuals, we also possess 35-mm slides of the original X-rays of one individual from an experimental group (Alfalfa, #120) who was raised in near-complete darkness for the first 20 months of life.⁴²

3 | CURATION, ORGANIZATION, AND USE OF THE DATA SET

Each chimpanzee at the YLPB possessed a name and a unique identification number which were consistently utilized across all publications (e.g.,^{11,45}). Here we utilized those individual identification numbers, with the prefix “YLPB” denoting the Yale Laboratories of Primate Biology. Within each individual, the radiological collection is divided into folders, where each folder is assigned a number, and generally includes all images of a single imaging session. Each image further possesses an image identification number between 1 and 999. In most cases, the subject identification number, date of imaging, and image identification number are identified on the radiopaque tag on the X-ray itself, though in some cases this original information was

missing from the X-ray and identified from the original notes on the folders. In cases where the identification number of the image could not be positively established, we assigned it a number within the range of image identification numbers listed on the folder and prefixed the image number with "N-." Thus, each image can be uniquely identified by the subject identification number, folder number, and image identification number. For the 35-mm slides, no folder number is present; instead they are demarcated with the letter "S."

Each radiograph was placed on a lightbox with an identification tag and scale bar and photographed with a Nikon D750 or D60 camera and saved as .TIFF images. This method was preferred over an X-ray digitizer both due to the prohibitive cost of a digitizer, but also because many of the original films are wrinkled, warped, and/or deteriorating, and thus not suitable for an X-ray digitizer. As not all images took up the original 14" × 17" radiography film area, we zoomed in on the relevant area for each radiograph. Each image contains a scale bar positioned on the light box for users' reference and we have also provided the relevant scale factor (in cm/pixels) for each image in Table S1. For the 35-mm slides, we used an Epson Perfection dual-lens flatbed scanner to digitize all slides as high-quality .JPEG images which were then converted to .TIFF images.

In total, we digitized 3,568 images for 16 individuals, 15 of which are part of the normative group, and 11 of which represent the remaining physical X-ray collection in our possession (Table S1). There were between 51 and 387 images for each individual (Table 1 and Figure 2). Each image is accompanied by a brief description of the elements fully contained in each image, side (if known), and the scale factor (cm/pixel) for measurements. The side labels for some X-rays were missing, and in some cases the X-rays were too damaged to read the labels, in which case we have omitted a side classification. However, it is worth noting that the vast majority of radiographs were taken on the left extremities, and as reported by Nissen and Riesen,³⁶ the standard set of extremity X-rays was taken on the left side. In some cases, the left side is also evident based on geometric positioning of the limbs. Regardless, unless the body side was explicitly recorded and evidently correct on the X-ray, we omitted the side attribution. An index of all images is provided in Table S1, and an approximate breakdown of the number of images for anatomical regions is provided in Table S2.

All 3,568 images were then uploaded to MorphoSource (<https://www.morphosource.org/>³⁸), Project 414. The hierarchy of the collection is as follows. First, each subject is included as an individual specimen, identified by its YLPB prefix and identification number. Within

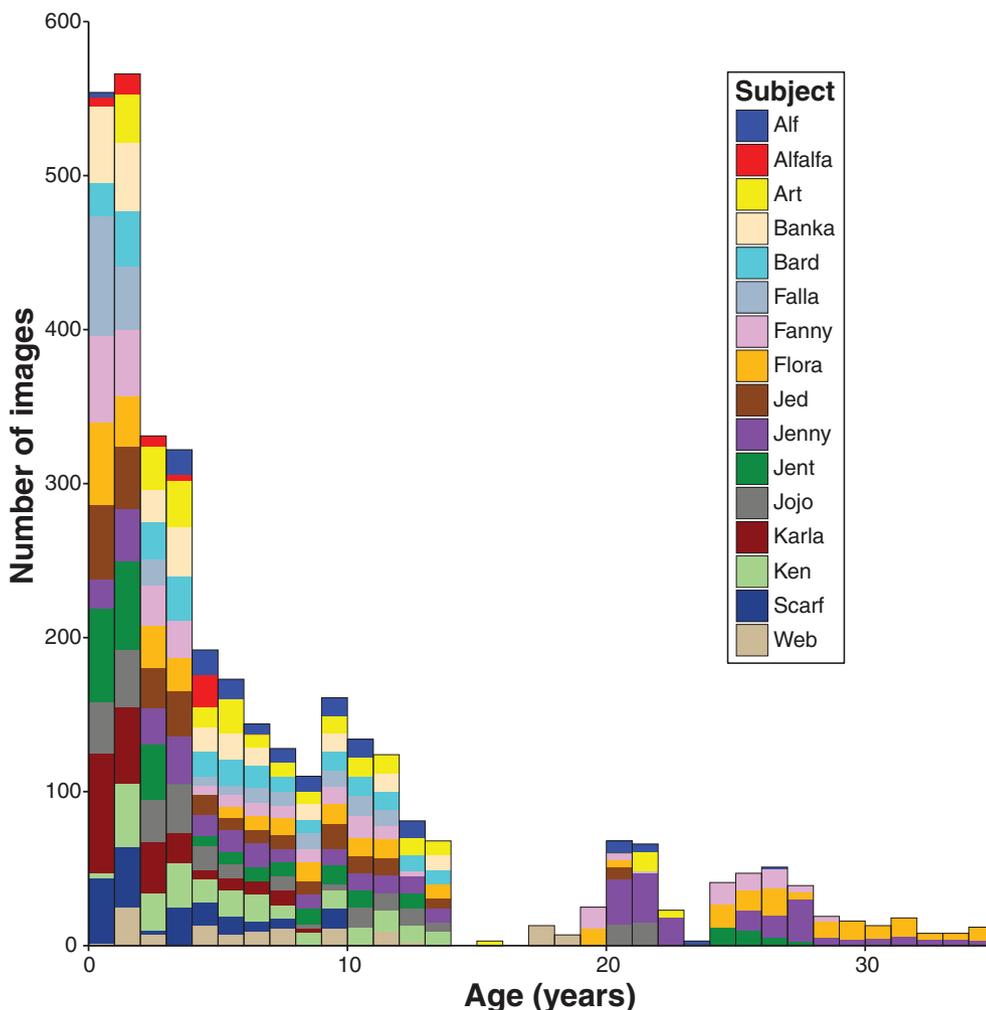


FIGURE 2 Number of radiological images by chimpanzee subject and age [Color figure can be viewed at wileyonlinelibrary.com]

each specimen, a separate “media group” exists representing each individual date of imaging typically representing a single folder of images. Each media group then contains all individual X-rays from that particular experimental day as individual media files. In addition to the previously described individual and image ID numbers, MorphoSource assigns its own unique identifier to each individual (Table 1), as well as a unique identifier to each media group and individual media (.TIFF) file.

For researchers interested in using data on the normative group, we advise users to first revisit those studies published during the duration of the initial study, in particular those studies by Nissen, Riesen, and Gavan.^{9–13,33,36,43,44} These studies contain a wealth of data directly measured from X-rays of the normative group, in addition to various other additional data from the Infant Studies Program that are no longer associated with this X-ray data set (e.g., body mass data and anthropometric measurements,^{11,12} gestation lengths,^{11,35,36} and birth weights³⁶), though much of these data are species- or sex-averaged. Finally, we encourage and remind users of this data set to bear in mind the captive conditions in which these chimpanzees were raised. Several studies have demonstrated that captive chimpanzees tend to display accelerated development and growth, particularly in the postcranial skeleton, compared to free-ranging chimpanzees.^{1,7,25,26} The YLPB chimpanzees may therefore exhibit accelerated growth trajectories and/or larger skeletal elements than wild populations of chimpanzees at a given age, though their growth curves are similar to other captive populations (e.g.,⁶). In addition, as the chimpanzees at the YLPB were hand-reared, social influences such as rank likely had little influence in nutrition and growth. While this was the original intent of the study,⁸ both of these factors can affect growth and developmental milestones in captive and wild chimpanzees.^{28,29,46} When using this data set, we urge users to consider how these factors may influence the ability to address specific research questions.

4 | PRESERVATION AND PROLIFERATION

With the curation and digitization of this unique data set, we not only hope to preserve it, but also bring it out of the shadows and increase its utilization. Much quantitative and qualitative data remain to be extracted from these radiographs, and we hope that they can continue to be utilized in evolutionary anthropology and comparative biology for baseline data on comparative growth, studies of musculo-skeletal configuration, and aging of fossil hominins and apes. The Infant Studies Program at the YLPB was the result of decades of dedicated work by researchers, caretakers, and staff members,³¹ and the data collected through these efforts are irreplaceable. By preserving this data set we ensure that these efforts, and this unique data set, continue to be fruitful for anthropologists.

We further hope that by disseminating and increasing the utilization of the X-ray data set in our possession, other data from the Infant Studies Program may come to light. Notably, based on the original radiographic schedule^{8,11,36} and data present in previous studies

(e.g.,^{11,12}), large portions of the data set are still missing. For instance, conspicuously absent from the collection in our possession are nearly all radiographs documenting Years 15–20 in all subjects (Figure 2). Perhaps coincidentally, this corresponds to a period from mid-1954 to mid-1960, a period of turnover for the, then-named, Yerkes Laboratories of Primate Biology, including the death of both the founder of the YLPB, Dr Robert M. Yerkes, and the head of the Infant Studies Program, Dr Henry W. Nissen, as well as the transfer of ownership of the facility from Yale University to Emory University.³¹ In addition to missing X-rays, much original data on daily dietary intake, body mass and size measurements, and various physiological measurements of the normative chimpanzee group (see⁸ for details) are no longer associated with the radiological data set, nor are they available in the archives of the Yerkes National Primate Research Center (Dr R. Paul Johnson, personal communication). Nevertheless, the present data set of over 3,500 images serves as an invaluable and irreplaceable source of data on chimpanzee growth, and any future inclusion of data from this study will increase its utility.

We will continue to update the radiological data set on MorphoSource as new or higher quality images become available, and any request for higher quality images or retakes of images can be made to the corresponding author (N. E. T.).

ACKNOWLEDGMENTS

We thank Dr John G. Fleagle for having adopted this collection, Dr Susan G. Larson for her continued curation of the Anatomical Sciences Museum at Stony Brook University, and both Dr Fleagle and Dr Larson for their support in uploading this data set to MorphoSource. We also thank R. Graves who conducted initial inventories of the radiological data set, as well as three anonymous reviewers and the associate editor who helped to improve the manuscript. We would further like to thank Dr R. P. Johnson and the Yerkes National Primate Research Center (in both its current and previous incarnations), and all those involved in the Infant Studies Program without whom open access to such a data set would not be possible. The digitization of this collection was supported in part by the National Science Foundation (NSF SMA 1719432 to N. E. T.).

CONFLICT OF INTEREST

The authors declare no potential conflict of interest.

DATA AVAILABILITY STATEMENT

All 3,568 images were then uploaded to MorphoSource (www.morphosource.org), Project 414.

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SUPPORTING INFORMATION

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

How to cite this article: Thompson NE, Ahmed L, Celebi TB, et al. Digitization of the Nissen–Riesen chimpanzee radiological growth series. *Evolutionary Anthropology*. 2020; 1–7. <https://doi.org/10.1002/evan.21836>