The Visible Ape Project: A free, comprehensive, web-based anatomical atlas for scientists and veterinarians designed to raise public awareness about apes

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The Visible Ape Project: A free, comprehensive, web-based anatomical atlas for scientists and veterinarians designed to raise public awareness about apes

Nicole Barger[1,2,3] | José Saúl Martín[4] | Eve K. Boyle[1] | Marli Richmond[2] | Rui Diogo[1,2]

[1]Anatomy Department, Howard University College of Medicine, Washington, District of Columbia

[2]Center for the Advanced Study of Human Paleobiology, The George Washington University, Washington, District of Columbia

[3]Anthropology, The George Washington University, Washington, District of Columbia

[4]Biology Department, University of Aveiro, Aveiro, Portugal

Correspondence
Nicole Barger, Anatomy Department, Howard University, College of Medicine, Washington, DC.
Email: nicole.barger@howard.edu

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Abstract

The Visible Ape Project (VAP) is a free online platform providing unprecedented access to a suite of resources designed to comprehensively illustrate and educate about the anatomy of our closest relatives, the apes. It contains photographs, magnetic resonance images, and computed tomography scans, as well as three-dimensional models that can be manipulated to explore homologies and variations in soft and hard tissues in hylobatids, orangutans, gorillas, chimpanzees, and bonobos. Based at Howard University, a historically black university, it aims to reach communities underrepresented in anthropology and evolutionary biology, providing educational materials appropriate for K-12 and college classrooms in both English and Spanish. Accordingly, VAP incorporates outreach activities to disseminate science and promote awareness of apes, forming partnerships with veterinarians and conservationists in Africa and Asia. In this paper, we present an introduction to the website to illustrate how this accessible, evolving resource can support evolutionary anthropology and related disciplines.

KEYWORDS
anatomy, awareness, biological anthropology, human evolution, muscles, outreach, STEM education

1 | INTRODUCTION

Human evolutionary biology cannot be understood without referencing our closest relatives, the apes. These can be divided into lesser apes (hylobatids, including gibbons and siamang) and great apes, including orangutans, gorillas, bonobos, and common chimpanzees. Evolutionary anthropology arose as a discipline largely through the exercise of comparing humans and apes, e. g., their anatomy, locomotion, and behavior. Today, we understand that the markedly distinct phenotypes characterizing each ape species result from only minor variation in the protein coding genome.[1,2] Yet, considerable effort has been spent cataloguing ape genomic variation through public databases, while resources on ape anatomy remain available only to a proportionately smaller number of specialists. The open-source platforms that do exist, like MorphoSource (www.MorphoSource.org), provide excellent access to raw data but do not provide detailed information about anatomical structures or homologies for most specimens, particularly soft tissues such as muscles, nerves, and blood vessels, or anatomical variation. Given the rare and precious nature of ape samples, resources required to further interrogate these data are often expensive and less accessible. In fact, a major problem of texts focusing on a single species, or even a single specimen as in some previous atlases, is that they often do not illustrate homologies across apes nor variations within a certain ape genus, while papers addressing homologies are largely limited in their anatomical scope. The paucity of information on soft-tissues is exemplified by the fact that, of the soft-tissues catalogued in the human in *Nomina Anatomica*,[3] only 10% have been well described in apes.[4] This complicates efforts not only to translate variations in genotype to anatomical phenotype but also to isolate morphological correlates of behavioral phenotypes unique to the human lineage, for example, bipedalism, complex tool use, or language.[5] More broadly, it encumbers instruction in human evolutionary biology, especially in challenging pedagogical environments outside of universities where active learning is key.[6]

The Visible Ape Project (VAP) (www.visibleapeproject.com) is a major project funded by NSF-HBCU-EiR (Historically Black Colleges and Universities - Excellence in Research) with various related aims. One is to fill this scientific gap by providing a common, intuitive, web-based, public reference atlas presenting two-dimensional (2D) and three-dimensional (3D) resources for visualizing ape anatomy (Figures 1–6), including musculoskeletal, cardiovascular, nervous, and digestive systems. All great ape genera—common chimpanzees (*Pan troglodytes*), bonobos (*Pan paniscus*), gorillas (*Gorilla gorilla*), and orangutans (*Pongo pygmaeus*)—are included in addition to gibbons (*Hylobates sp.*) and siamang (*Symphalangus syndactylus*). Drawing on

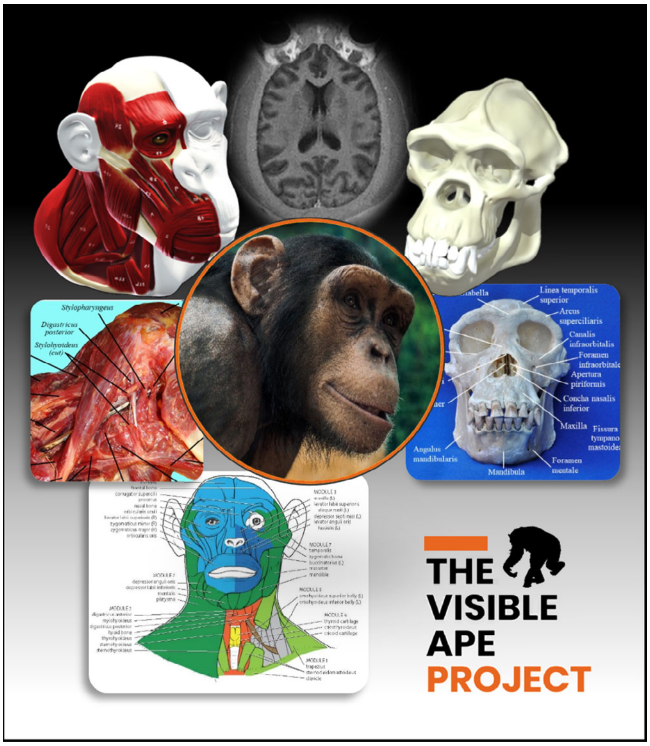

FIGURE 1 The Visible Ape Project provides multiple ways to view anatomical information for each ape. For example, for chimpanzee crania, we provide MRIs (top), 3D models of the musculature and skull (upper left and right), detailed soft tissue and osteological photographic atlases (middle left and right), and artists' illustrations (bottom left)

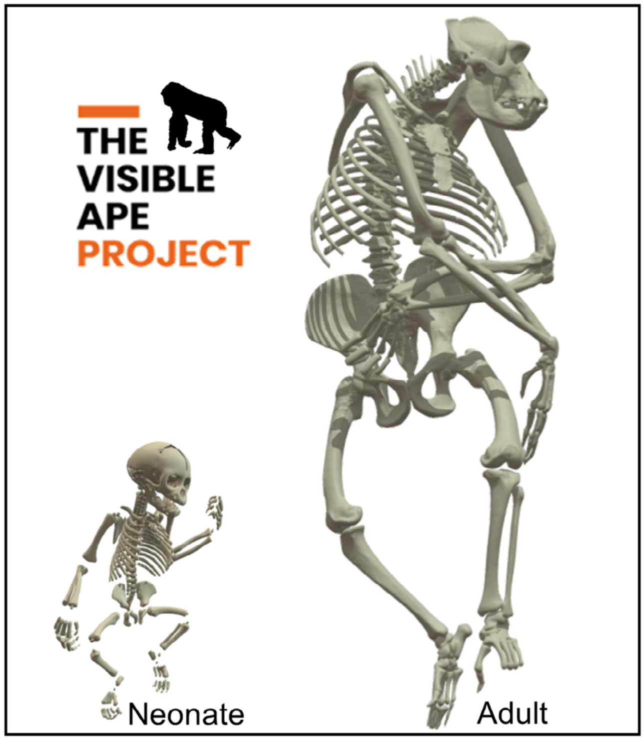

FIGURE 3 The Visible Ape Project contains rare developmental specimens. CT-based 3D models, like these neonatal and adult gorillas, can be used to appreciate skeletal variation through development

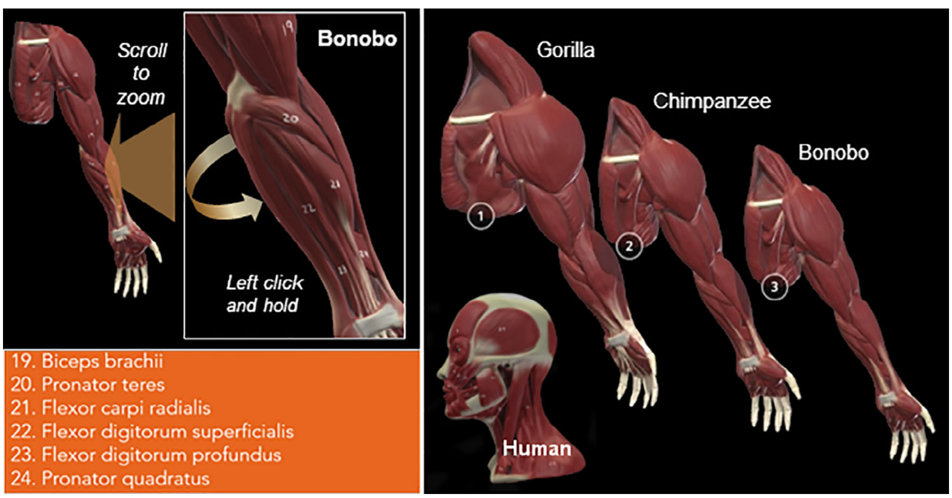

FIGURE 2 3D models can be manipulated in the webpage (left). Use scroll to zoom and left click and hold to rotate; small numbers on musculoskeletal models refer to individual muscles. 3D models are designed to facilitate comparison of homologous structures across species (right). Some models incorporate multiple species to simplify comparing variation across ape species (upper right). In these models, large numbers identify species. Models of human anatomy may be used to address evolutionary variation between humans and apes (lower right)

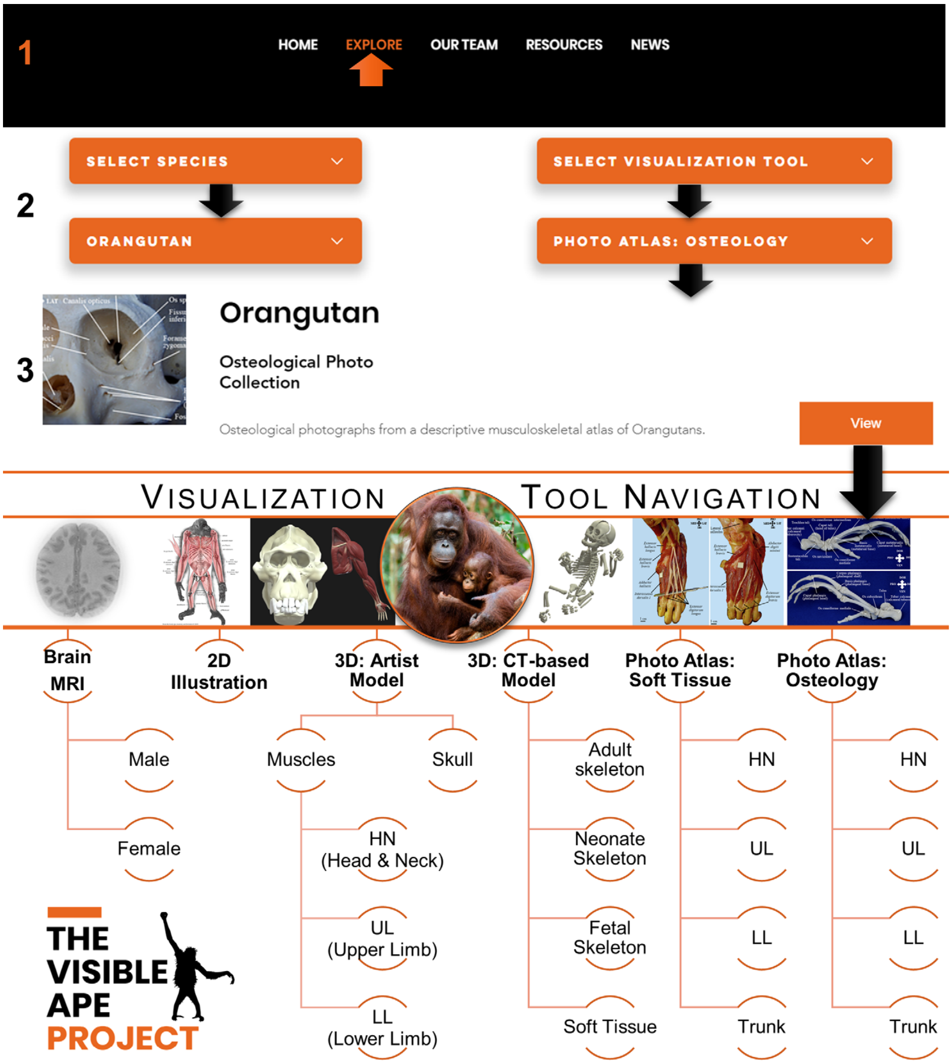

FIGURE 4 Accessing the resources is simple. (1) From the explore page on the header, (2) select the species and visualizations of interest, (3) which will present the visualization tool and the View button. Clicking on the View button will take you to the visualization of interest. The bottom half of the image details the visualization tools currently available and their associated resources

the expertise of an international group of collaborators,[7–12] VAP is the first freely available, detailed multispecies ape anatomical atlas. As such, it should prove an essential tool for researchers seeking to identify and analyze homologous anatomical regions across hominoids, substantially increasing information available for these rare species. To bridge to human anatomy and evolutionary biology, VAP includes 3D anatomical models of *Homo sapiens*, designed to complement, and in a way inspired by, the Visible Human Project (https://www.nlm.nih.gov/research/visible/visible_human.html). Integrating this diverse data under one framework, VAP is positioned to be a transformative tool for research in evolutionary anthropology and related fields like genomics—including research about the links between phenotype and genotype—developmental biology—including information about ape fetuses, neonates, infants, juveniles/subadults and adults—anatomy, systematics, biomechanics, physiology, and neuroscience.

A second, major aim of VAP is to help educators in STEM fields increase scientific literacy in human evolutionary biology and raise public awareness and appreciation of our diverse and imperiled evolutionary relatives. The Visible Human Project recognized that 3D anatomical models greatly improve the understanding of anatomical concepts in education.[13] That project has proven extremely useful to the scientific community and popular with the general public, underscoring the utility of this approach. VAP capitalizes on this emphasis, incorporating 3D anatomical models to provide a more intuitive format for understanding the relationship between anatomical structures presented in 2D atlases (Figure 1) and for visualizing homologies across hominoids (Figure 2). This, in turn, highlights that, despite the ecological and morphological diversity of hominoid species, the gross internal anatomy of apes is strikingly similar, in general, to that of humans. This has two important implications for the general public: it emphasizes that we evolved from apes, promoting inclusion in STEM disciplines related to biological and human evolution, and stresses that apes are very similar to us on the inside and thus deserve to be respected and protected. As such, it has pragmatic value as a pedagogical tool in K-12, university, and graduate education, including veterinary training, as well as a tool for scientific dissemination to underrepresented communities in the United States and globally.

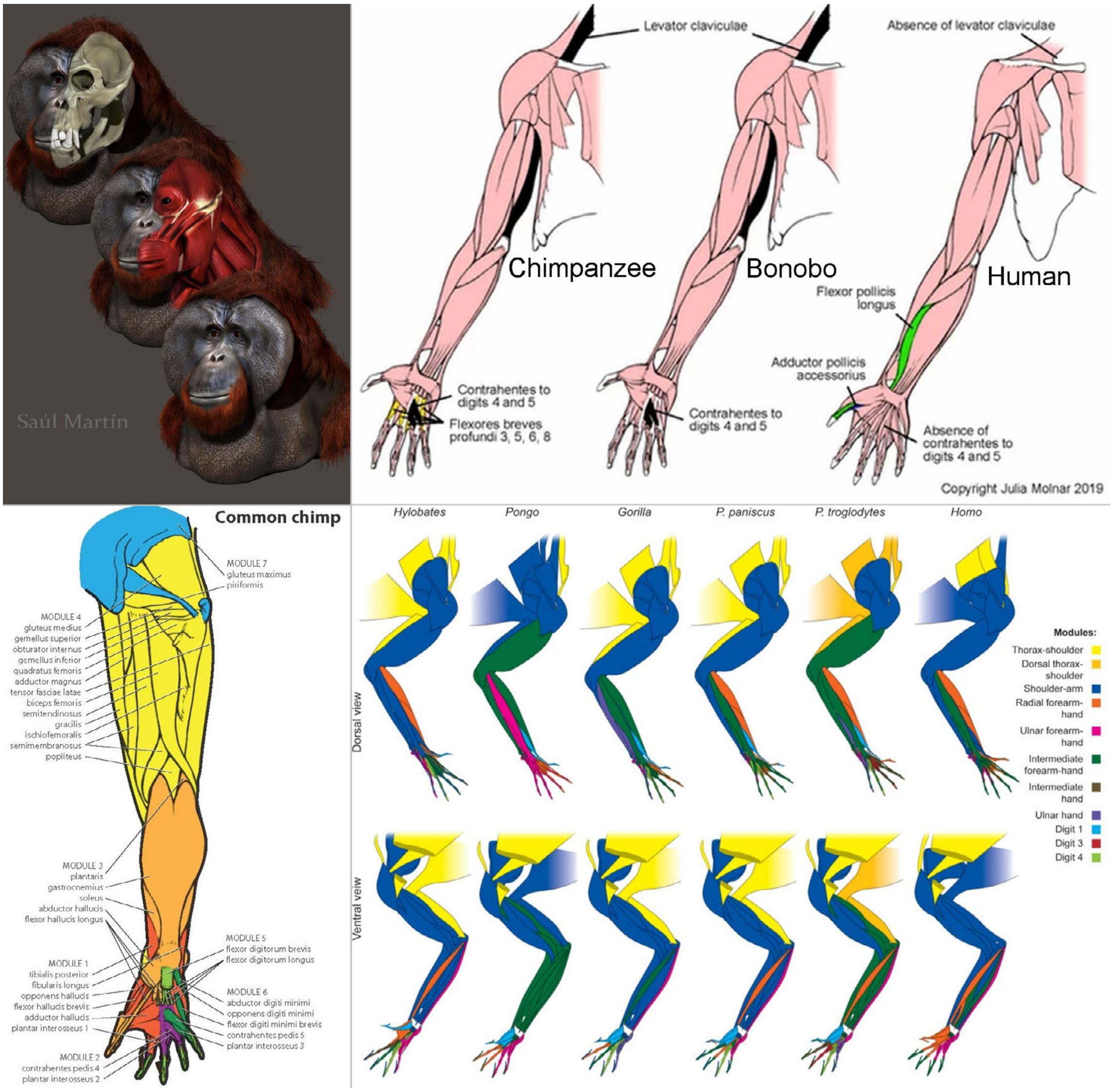

FIGURE 5 The site incorporates a diverse array of illustrations. For individual species, some illustrations reveal the association between hard and soft tissues (upper left) or provide detailed illustrations incorporating anatomical terminology (lower left). Inter-species illustrations (upper and lower right) indicate shared and derived features across ape species

Based at Howard University, the most renowned HBCU (historically black colleges and universities), VAP especially aims to increase engagement with and participation in anthropology and biology by groups that are underrepresented in these fields, particularly African-American and Latina/o communities.[14] To reach broader audiences within and outside of the United States, many resources are presented in both Spanish and English. Providing free resources appropriate for K-12 education can help to increase early educational exposure to these concepts across diverse communities in the US and globally, promoting and extending the scope of audiences interested in our discipline. VAP includes STEM outreach to further advance this goal.

In its first year (March 2020 to March 2021), the VAP website hosted approximately 6,000 visits in total from over 60 countries representing all inhabited continents (Figure 7). VAP was accessed by users across the globe and in nearly all US states (43 states and the District of Columbia). Designed to be inclusive to Spanish-speaking communities, it has received high use in Spanish-speaking countries and states with large Latina/o populations (e.g., California, New York, Texas, and Florida). Academic institutions accessing resources were diverse, including universities, museums, and community colleges. Many of these visits have already led to practical outcomes, for example, veterinarians using VAP data in US zoos, conservationists in ape sanctuaries in Africa establishing outreach collaborations, and science dissemination projects that 3D-printed and used VAP's 3D models for interactions with young kids. Below we present a brief overview of the site and its resources to formally introduce VAP to researchers and educators in evolutionary anthropology, comparative anatomy, and related fields of science.

2 | BRIEF DESCRIPTION OF METHODS

2.1 | Collection

VAP collates anatomical resources obtained from long-term projects detailing homologous hard and soft-tissues across ape species,[10–12,15,16] augmenting them with complementary open-source data. It integrates magnetic resonance images (MRI), photographic data, 3D models based on computed tomography (CT) scans, and 2D and 3D renderings by anatomists and anatomical illustrators (Table 1; Figures 1–6). Currently, there are 642 anatomical resources from 56 individual nonhuman apes, including 9 bonobos, 17 chimpanzees, 8 gorillas, 10 orangutans, 9 gibbons, and 3 siamang (Table 2) and 20 resources representing humans for a total of 662. The site contains 537 cadaver dissection photographs, 53 anatomical illustrations, 48 3D musculoskeletal models, 10 3D CT whole skeleton models, one 3D CT of the cardiovascular system, and 13 brain, head, and neck MRIs. Developmental stages span fetal ($n = 2$), neonate ($n = 4$), infant ($n = 7$), juvenile/subadult ($n = 6$), and adult ($n = 34$) periods (Table 2; Figure 3). It includes 30 males, 22 females, and 4 apes of unknown sex (CT models). All cadaver specimens were obtained after their natural death from zoos or research institutes. *Atlas images* are full color and were taken at high resolution (36.3 M) with a Nikon D-800 camera equipped with micro and macro lenses, providing clear visualization of fine detail. Most dissections were performed on fresh frozen specimens to ensure optimal preservation of soft tissues. *CT scans* of ape cadavers were mainly performed using a Somatom multislice Sensation 64 CT-system at the University of Vallidolid—courtesy of Francisco Pastor—or were obtained from MorphoSource (Table 2). *MRIs* were collected in vivo and were sourced from the National Chimpanzee Brain Resource (www.chimpanzeebrain.org), provided courtesy of J. K. Rilling.[17–19] *3D models* of whole skeletons were created with Avizo 7.1.0 (ThermoFisher, Inc.) from CT data from ape cadavers, stored as PLY files, and cleaned with Geomagic 2017 (3D Systems). 3D muscle reconstructions—done by coauthor J. S. Martin—are based primarily on dissections from atlases authored by Diogo and colleagues[10–12,15,16] (Table 1) as well as on work from other groups obtained through comprehensive literature review[10] to approximate what is the most typical phenotypic configuration for each species. In the 3D editor Zbrush (Pixologic, Inc.), sculpting tools (brushes) were used to build and transform all surface elements of the musculoskeletal system. To build organized and uniform 3D structures, a dynamic, interactive mesh subdivided into polygons was sequentially updated to recalculate polygons that were initially deformed, achieving a compact base allowing continuity and detail improvement until the correct form was reached. A standard color was added and elements such as light, shadow, material, and position were configured before rendering. Each render act as a "photograph" of the model, an accurate scientific illustration as it was "drawn" in 3D. This method was

FIGURE 6 CT scan of a siamang injected with radiopaque material to reveal the cardiovascular system, from the Museums at the Royal College of Surgeons

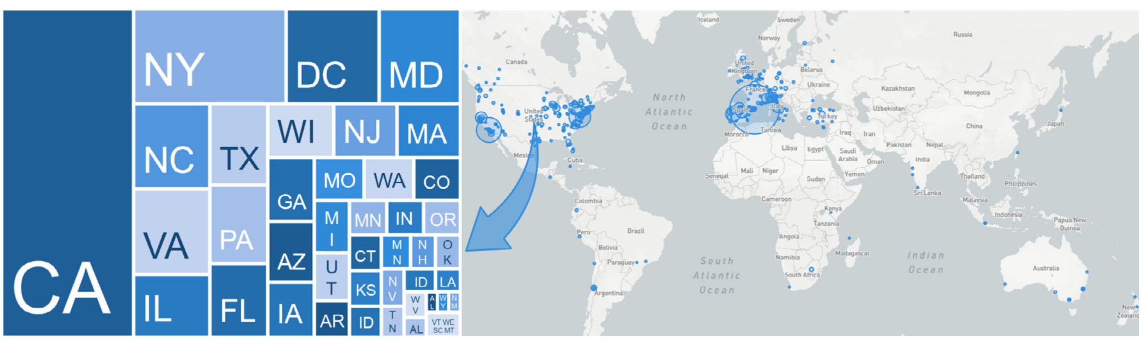

FIGURE 7 The Visible Ape Project is accessed by users across the globe and in nearly all US states. Designed to be inclusive to Spanish-speaking communities, it has received high use in Spanish-speaking countries and states with large Latina/o populations (e.g., CA, NY, TX, and FL)

TABLE 1 Inventory of resources

Species	Media	HN	UL	LL	T	W	Total
Bonobo	MRIs	2					2
	Illustrations	3	5	2			10
	Photographs	25	67	56	12		160
	3D model	2	2	2		1	7
Chimpanzee	MRIs	2					2
	Illustrations	3	4	2			9
	Photographs	35	23	14	6		78
	3D model	3	2	2	0	3	10
Gorilla	MRIs	2					2
	Illustrations	2	3	1			6
	Photographs	27	46	20	36		129
	3D model	3	2	2	0	2	9
Orangutan	MRIs	3					3
	Illustrations	2	3	1			6
	Photographs	31	21	36	8		96
	3D model	3	2	2	0	1	8
Gibbon	MRIs	2					2
	Illustrations	1	1	1			3
	Photographs	14	10	38	12		74
	3D model	2	2	2	0	1	7
Siamang	3D model					2	2
Human	MRIs	2					2
	Illustrations	3	6	4			13
	3D model	2	0	1	0	2	5
Species comparison	Illustrations	2	3	1			6
	3D model	9	1	1			11
Grand total							662
Non-human ape total							642

Abbreviations: C, cranium; UL, upper limb; LL, lower limb; T, thorax; W, whole body.

successively used to achieve realistic 3D musculoskeletal models of heads, upper, and lower limbs.

2.2 | Nomenclature

Anatomical structures are defined based on extensive, long-term analyses of homologies across ape species published by Diogo and colleagues in several atlases.[11,12,15,16] Latin terms similar to those used in modern human anatomy[3] are used to label musculoskeletal structures. English names are provided when Latin does not easily translate.

3 | SITE DESIGN

To facilitate access by diverse users, the interface is designed to be easily navigated by researchers and members of the public. Anatomical resources may be accessed from the EXPLORE link on our webpage banner (Figure 4). Use the left drop-down menu, SEARCH BY SPECIES, to select the species of interest and the right menu, SEARCH BY VISUALIZATION TOOL, to further refine the results. To access each resource, select the orange View button. A quick navigation menu is also provided in the footer. A description of each resource currently in the archive follows.

3.1 | Atlas photographs

Each species is documented in over 70 atlas photographs (Figure 4). Clicking on View for each tool provides an overview of the photographs organized by anatomical region: Head and Neck, Upper Limb, Lower Limb, and Trunk. Left clicking on an individual photograph increases the image to full size. Each image includes the names of major anatomical features with lines indicating their position on the gross specimen and anatomical orientation.

TABLE 2 List of apes and associated anatomical resources on the current website build. *Visualization type*: OA, osteological atlas; STA, soft tissue atlas; 3DS, 3D skeleton model; 3DM, 3D muscle model; 3DC, 3D cardiovascular model. *Source Institution*: AMNH-M, American Museum of Natural History via MorphoSource; AZ, Antwerp Zoo; BV, Bioparc Valencia; CMN, Canadian Museum of Nature; DU, Duquesne University; HU, Howard University; NCBR, National Chimpanzee Brain Resource; PFA, Primate Foundation of Arizona; RSCOM, Museums at the Royal College of Surgeons; VU, Valladolid University; YPM-M, Yale Peabody Museum via MorphoSource; YNPRC, Yerkes National Primate Research Center. ARK identifiers are provided for data accessed on MorphoSource.org

Name	Age group	Sex	*Species*	Visualization	Source institution/copyright
CMS GG1	Adult	Male	*Gorilla gorilla*	STA, 3DM	CMN
GGN1[a]	Neonate	Male	*Gorilla gorilla*	3DS, OA, STA, 3DM	VU/BV
KEKLA	Juvenile	Male	*Gorilla gorilla*	MRI	NCBR
KINYANI	Subadult	Female	*Gorilla gorilla*	MRI	NCBR
VU GG1	Adult	Female	*Gorilla gorilla*	STA, 3DM	VU
VU GG2	Adult	Female	*Gorilla gorilla*	OA, STA, 3DM	VU
VU GG3	Adult	Male	*Gorilla gorilla*	STA, 3DM	VU
YPM MAM 014998	Unknown	Unknown	*Gorilla gorilla*	3DS	YPM-M ark:/87602/m4/M56407
VU HG1[b]	Infant	Male	*H. gabriellae*	STA, 3DM	VU
VU HG2[b]	Adult	Male	*H. gabriellae*	STA, 3DM	VU
M-201742	Unknown	Male	*H. hoolock*	3DS	AMNH ark:/87602/m4/M25860
VU HK1[b]	Adult	M	*H. klossii*	3DM	VU
BUDDY	Adult	Male	*H. lar*	MRI	NCBR
CLEO	Adult	Female	*H. lar*	MRI	NCBR
GWU HL1	Juvenile	Female	*H. lar*	STA, 3DM	GWU
HU HL1[c]	Adult	Male	*H. lar*	STA, 3DM	HU
DU HM1[d]	Adult	Male	*H. muelleri*	STA, 3DM	DU
ARJU	Adult	Unknown	*Pan paniscus*	OA	AZ
ANO	Fetus	Female	*Pan paniscus*	STA, 3DM	AZ
BOSONDJO	Adult	Male	*Pan paniscus*	MRI	NCBR
ETJE	Infant	Male	*Pan paniscus*	STA, 3DM	AZ
FOYO	Infant	Male	*Pan paniscus*	STA, 3DM	AZ
JASIRI	Juvenile	Female	*Pan paniscus*	STA, 3DM	AZ
KIDOGO	Adult	Male	*Pan paniscus*	STA, 3DM	AZ
LOREL	Adult	Female	*Pan paniscus*	MRI	NCBR
M-202870	Subadult	Male	*Pan paniscus*	3DS	AMNH-M ark:/87602/m4/M38741
GWU-ANT PT1	Adult	Female	*Pan troglodytes*	STA, 3DM	GWU
GWU-ANT PT2	Adult	Female	*Pan troglodytes*	STA, 3DM	GWU
HU PT1	Infant	Male	*Pan troglodytes*	STA, 3DM	HU
MARV	Adult	Male	*Pan troglodytes*	MRI	NCBR
MARY	Adult	Female	*Pan troglodytes*	MRI	NCBR
PFA 1009	Adult	Female	*Pan troglodytes*	STA, 3DM	PFA
PFA 1016	Adult	Female	*Pan troglodytes*	STA, 3DM	PFA
PFA 1051	Infant	Female	*Pan troglodytes*	STA, 3DM	PFA
PFA 1077	Infant	Female	*Pan troglodytes*	STA, 3DM	PFA
PFAU[a]	Infant	Male	*Pan troglodytes*	STA, 3DM	PFA
PTN1	Neonate	Male	*Pan troglodytes*	3DS	VU
RCSOM/OH/W099	Fetus	Unknown	*Pan troglodytes*	3DS, CT	RCS OH
VU PT1[e]	Adult	Male	*Pan troglodytes*	STA, 3DM	VU
VU PT2[f]	Adult	Male	*Pan troglodytes*	STA, 3DM	VU
VU PT3[b]	Adult	Female	*Pan troglodytes*	OA, 3DM	NCBR
YERKESU	Adult	Male	*Pan troglodytes*	STA, 3DM	YNPRC

(Continues)

TABLE 2 (Continued)

Name	Age group	Sex	*Species*	Visualization	Source institution/copyright
YPM MAM 015939	Adult	Male	*Pan troglodytes*	3DS	YPM-M ark:/87602/m4/M58004
GWU PP1	Adult	Male	*Pongo pygmaeus*	STA, 3DM	GWU
HATI	Adult	Female	*Pongo pygmaeus*	MRI	NCBR
HU PP1	Neonate	Male	*Pongo pygmaeus*	STA, 3DM	HU
MENTUBAR	Juvenile	Male	*Pongo pygmaeus*	MRI	NCBR
MOLEK	Adult	Male	*Pongo pygmaeus*	MRI	NCBR
PPN1	Neonate	Male	*Pongo pygmaeus*	3DS	VU
VU PA1	Adult	Female	*Pongo abelli*	OA	VU
VU PA2	Adult	Female	*Pongo abelli*	OA	VU
VU PP1	Adult	Female	*Pongo pygmaeus*	STA, 3DM	VU
VU PP2	Adult	Female	*Pongo pygmaeus*	OA, STA, 3DM	VU
DU HS1[d]	Adult	Male	*Symphalangus syndactylus*	STA, 3DM	DU
M-202326	Unknown	Unknown	*S. syndactylus*	3DS	AMNH ark:/87602/m4/M24479
RSCOM-OH-W098	Neonate	Unknown	*S. syndactylus*	3DC	RSCOM

[a]Uncatalogued specimen.
[b]Originated from the Bioparc Fuengirola.
[c]Yerkes Regional Primate Center number YN87-134.
[d]Originated from the Cleveland MetroParks Zoo.
[e]Originated from the Fundación Mona.
[f]Originated from the Zoo-Aquarium of Madrid.

3.2 | 3D models

3D models of hard and soft tissues are provided for each species (Figure 1). Whole skeletons are derived from CT scans (Figure 3; Table 2). Models of the musculature are separated into head and neck, upper limb, and lower limb for each species (Figure 4). They incorporate a numbering system to identify muscles visible on the model surface (Figure 2). Clicking the View button will open a window with an embedded object linked to the 3D hosting platform Sketchfab (https://sketchfab.com). Click on the model to load it. Once loaded, left click and hold to rotate the model or use scroll to zoom in and out (Figure 2). The right mouse button can be used to pan, changing the position of the model. Model meshes can be downloaded in .obj or .ply format from the FILE DOWNLOADS AND DATASETS option on the SEARCH BY VISUALIZATION menu (Figure 8) and shared through the buttons in the upper right corner of the screen. They can also be directly accessed from our Sketchfab page: https://sketchfab.com/VISIBLEAPEPROJECT.

3.3 | Scientific illustrations

Detailed line drawings primarily illustrating myological anatomy are available for each ape (Figure 5). These drawings present anatomy in a way that is easy to parse, visually, and many are color-coded to help discriminate muscle groups.

3.4 | MRIs and CTs

We currently profile MRIs for one male and one female per species (Figure 4). Selecting View opens these two MRIs in the same browser page. Clicking on the MRI will start the navigation. Clicking on the image or the left arrow advances forward in the image stack and the right arrow, backward. We provide a variety of CT scans, mostly of skeletons, but also of a vessel injected body of a siamang (Figure 6). Raw data can be accessed through the FILE DOWNLOADS AND DATASETS menu option (Figure 8).

3.5 | Inter-species comparisons

While separate browser pages can be used to compare species, the website also incorporates several visualizations that include multiple species accessible via the INTER-SPECIES option on the pull-down menu in SEARCH BY SPECIES. Some 3D myological models incorporate multiple species to facilitate direct comparison (Figure 2), while many scientific illustrations indicate the relationship between groups of muscles and specify known variation across hominoids (Figure 5).

3.6 | Educator resources

Under the Resources page, the "Educator Resources" button provides the primary material meant for education, including several lesson

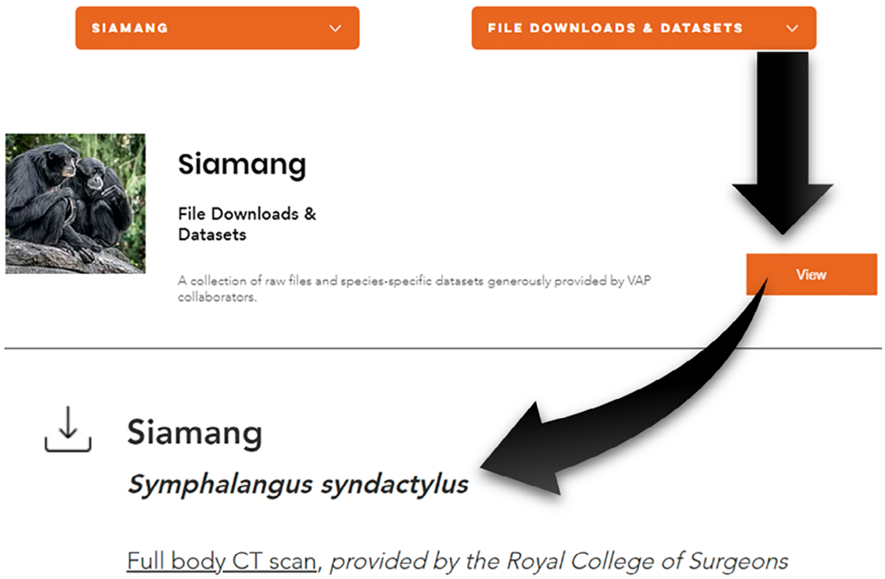

FIGURE 8 From the FILE DOWNLOADS AND DATASETS menu item, raw radiographic image series and 3D mesh files can be accessed

plans for using the site tools to explore evolutionary and developmental anatomy. Each provides a lesson and an answer key in Spanish and in English. Additionally, a glossary of evolutionary and anatomical terms can be accessed from the resources tab in both languages. An informational overview of each ape, explaining the species' habitat, conservation status, behavior, lifespan, locomotor habits, and size, is accessible from the home page. These summaries are succinct and designed to be easily understood by young readers. Because illustrations and models are suitable for younger children, we expect the site to be useful for educators in diverse environments. Atlas material is also designed to augment instruction in human evolutionary biology. 3D models are freely available and are saved in a format that is compatible with 3D printers. Additional models with no numbering are included and could be used to test anatomical concepts. Sketchfab-hosted material can be viewed in virtual reality to provide an alternative, "hands on" experience.

4 | APPLICATIONS AND OUTREACH

The website is built with various audiences in mind: researchers, students, and educators from K-12 to higher education, people who are responsible for the health and well-being of primates, conservationists that aim to promote awareness of apes, and the general public, including underprivileged and underrepresented minorities in Western countries and rural communities in African and Asian countries. Because VAP is the sole free 2D and 3D atlas of extant ape anatomy documenting homologies and variations across genera of all major ape groups, it should aid anthropologists and biologists who rely on comparative anatomy to make inferences about extinct taxa. For example, VAP could inform models of fossil hominoid musculature which require the use of methods like the extant phylogenetic bracket[20] and artistic reconstructions based on such models. Comprehensive data on soft tissues will similarly be valuable in systematic biology. Evolutionary developmental biologists can better understand developmental variation across the hominoid clade, directly comparing apes at different developmental stages within and between species. Hypotheses about the significance of genetic variation observed over hominin evolution and about the links between the phenotype and genotype can be better interrogated with phenotypic information catalogued in VAP, as the know genotypes of each ape can be studied/compared with the phenotypes illustrated in the VAP. Broadly, we believe VAP benefits researchers from any field who wish to perform comparative and evolutionary studies of apes, including humans, that require anatomical precision.

VAP resources should aid teachers and students of general biology, biological anthropology, comparative anatomy, mammalogy, and zoology. Active learning can promote better understanding of anatomical concepts,[21] but few students have the opportunity to appreciate ape anatomy through gross dissection, given the limited availability of ape cadavers and infrastructure required. VAP attempts to overcome this barrier by making the information widely available to students, teachers, and the general public. Our educational resources have already been accessed by universities and community colleges. During the COVID-19 pandemic, we shared them with local elementary school students and their families through a virtual event with the DC outreach organization, Turning the Page (https://turningthepage.org/). To educate the broader public, we introduced visitors at the National Museum of Natural History to VAP. In Portugal, the governmental ciencia-viva (live-science) project will use printed 3D models to promote awareness of both our evolution and ape conservation. Several African-American students in the College of

Medicine and undergraduate students in the Biology Department of Howard University have been actively engaged in the project, with the aim of bridging the gap between medical education and human evolutionary biology which can hinder medical appreciation of variations, anomalies, and pathology of human structures.[9,10]

Other vital groups VAP is designed to support are veterinarians and other caretakers of apes, both wild and captive. Currently, there are limited resources to understand ape anatomy in the detail needed to inform medical procedures or evaluate injuries. Surgeons at George Washington University and Hospital are already using our 3D models and 2D photographs to undertake hand surgery of an orangutan at the Smithsonian. Moreover, we will engage in collaborative activity with the Gorilla Doctors of the Mountain Gorilla Veterinary Project in Rwanda. Thus, the suite of information provided by VAP will aid the care and management of both captive and wild apes. In this regard, VAP could contribute both to the health of individual apes in addition to broader conservation efforts. So far, it can be said that in just 1 year, the VAP has been particularly active and successful in terms of its applications and outreach.

5 | ACADEMIC AND SOCIETAL ACTIVITIES

Within academia, VAP's applications and goals concern the promotion of research and development in evolutionary anthropology, comparative biology, and other fields to open avenues for interaction and collaboration by providing free access to extensive documentation of ape anatomy. For the general public, we hope to increase literacy in evolutionary anthropology by providing free access to material for education and exploration. A major objective of VAP is to increase awareness of the remarkable similarities between ourselves and our closest living relatives who risk extinction. Showing how similar humans and apes are can draw attention to our close relationship with other apes, highlighting the need for their conservation. Finally, we are committed to increasing representation of historically underrepresented groups in evolutionary anthropology. African-Americans are especially underrepresented in ecology and evolutionary biology (EEB) departments, receiving less than 2% of all PhDs awarded in EEB related subfields in 2014.[14] Lack of exposure to evolutionary concepts has been associated with a lower sense of belonging in EEB among African-American students, while Latina/o students also report lower exposure to evolutionary biology relative to their white counterparts.[14] Thus, VAP's broader benefits to public education, providing a free, accessible platform to explore human evolutionary biology, may be magnified in these groups. As a research project of Howard University, a premier MSI (minority serving institution), VAP incorporates and is, in part, built by African-American undergraduate students who are profiled on the "Our Team" page. Moreover, this resource in evolutionary anthropology will be housed permanently at Howard University, reinforcing the position of this HBCU within EEB research and the association of MSIs with work in EEB. We aim to be inclusive of mono- and bilingual Spanish speakers. Strikingly, last year, approximately a third of all non-US visitors to VAP were from countries where Spanish is the primary language. Within the United States, many users were located in states which have large Latina/o populations like California, New York, and Texas (Figure 7). Ultimately, we would like to make VAP open to contributions from diverse research communities to comprehensively represent anatomical variation among the apes and to encourage its use in educational outreach globally and in underserved communities in the United States.

6 | FUTURE DIRECTIONS

We envision VAP to be a "living document" of ape anatomy, increasing in breadth over time. In the first year, we have focused on building visualizations primarily of the musculoskeletal system, with some atlas pages devoted to soft tissues like those of the digestive system. Our current objective is to address the nervous system, including the nerves of the body and the brain, while continuing to expand the available musculoskeletal visualizations, and to incorporate raw CT and MRI scans in the site. Plans are in place to perform more detailed dissections and 3D renderings of the arteries, veins, and nerves. We are partnering with the American Museum of Natural History to perform whole body CT and MRI scans. These scans, in addition to scans used to create some of the skeletal models for the site, will be made freely available to researchers through the download page. We would like to pursue in-person outreach within the Washington, DC, public, private, and charter school systems and hope to expand the scope of this work, especially through collaborations in Rwandan and other African communities living near ape habitats. Additionally, we plan to hold workshops to increase visibility of VAP among relevant professional organizations, for example, the American Associations of Physical Anthropologists, Anatomists, and Zoo Veterinarians. We are also establishing partnerships with conservationists and ape sanctuaries in Africa and Asia. In fact, one of the main objectives for the next year is to have much more visibility and activity in non-Western countries, something that we could not fully engage in yet because of the current pandemic.

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DATA AVAILABILITY STATEMENT

The data that support this study are openly available from the Visible Ape Project at www.visibleapeproject.com and Morphosource at www.morphosource.org (see Table 2 for direct links).

ORCID

Nicole Barger https://orcid.org/0000-0003-4731-873X

Rui Diogo https://orcid.org/0000-0002-9008-1910

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AUTHOR BIOGRAPHIES

Nicole Barger is project manager of the Visible Ape Project at Howard University and Assistant Research Professor in Anthropology at The George Washington University, affiliated with the Center for the Advanced Study of Human Paleobiology. Her research addresses comparative and developmental variation in ape brains through an evolutionary anthropological framework.

José Saúl Martín is a biologist and scientific illustrator with experience in biological and anatomical illustrations for papers, guides, and scientific communication projects. He provided 3D illustrations for the Visible Ape Project. He is currently a master's student in applied biology with a specialization in scientific illustration at Aveiro University in the Scientific illustration laboratory (lic dBio).

Eve K. Boyle is currently an AAAS Science & Technology Policy Fellow serving at the National Science Foundation. As a postdoctoral fellow at Howard University in 2019 to 2020, she was the first project manager for the Visible Ape Project. She is an evolutionary anthropologist with expertise in informal science education, public engagement, project management, and broadening participation activities.

Marli Richmond serves as the Visual Designer for the Visible Ape Project. She combines a research background in biological anthropology with training in user experience design, user interface design, and education-based media development. Marli created and implemented the website's primary design system and digital strategy.

Rui Diogo, Associate Professor at Howard University, is a multi-awarded researcher known for his multidisciplinary approach to address broader societal issues using state-of-the-art empirical data. He participated in about 150 papers and 20 books, including "*Learning and understanding human anatomy and pathology*" and "*Evolution driven by organismal behavior*," often listed among the top-10-best 2017 evolutionary books.

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