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Layla Aberman April 8, 2022

Localizing Cognitive Regions Involved in Juvenile Facial Recognition in Dogs Using fMRI

by

Layla Aberman

Gregory Berns
Adviser

Psychology

Type adviser's name here

Adviser

Philippe Rochat

Committee Member

James Rilling

Committee Member

(if you have more than three committee members, add lines for them)

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Layla Aberman

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An abstract of
a thesis submitted to the Faculty of Emory College of Arts and Sciences
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Research has shown that dogs have brain regions that recognize and respond to human faces. However, little research has been done to examine how dogs respond to juvenile faces both within and outside of their own species. Humans show significant activation in the lateral premotor cortex, supplementary motor area, middle cingulate gyrus, anterior insula, thalamus, and fusiform gyrus, which are associated with preparedness to act and speak, social and emotional responsiveness, and parental attachment respectively. Thus, we scanned awake, unrestrained dogs that are trained for fMRI studies while viewing images of adult and infant humans and dogs. In our study, we found greater activation in the ectolateralis posterior within the dog face area at a significance level of $p<0.05$ in response to adult stimuli, a novel finding that we discuss potential reasoning for. This study gives us a better understanding of the relationship dogs have with humans and their ability to care for and bond with humans, and sheds insight into our understanding of dogs' ability to form familial relationships outside of their species.

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Abstract: Research has shown that dogs have brain regions that recognize and respond to human faces. However, little research has been done to examine how dogs respond to juvenile faces both within and outside of their own species. Humans show significant activation in the lateral premotor cortex, supplementary motor area, middle cingulate gyrus, anterior insula, thalamus, and fusiform gyrus, which are associated with preparedness to act and speak, social and emotional responsiveness, and parental attachment respectively. Thus, we scanned awake, unrestrained dogs that are trained for fMRI studies while viewing images of adult and infant humans and dogs. In our study, we found greater activation in the ectolateralis posterior within the dog face area at a significance level of $p<0.05$ in response to adult stimuli, a novel finding that we discuss potential reasoning for. This study gives us a better understanding of the relationship dogs have with humans and their ability to care for and bond with humans, and sheds insight into our understanding of dogs' ability to form familial relationships outside of their species.

1. Introduction

Human infants are born with limited cognitive and physical capabilities. They have a large amount of brain growth postnatally compared to many species (DeSilva & Lesnik, 2006). To ensure infants' survival with these limited capabilities they require a lot of care from adults until they can develop further (Rosenberg, 2021). The baby schema, known as Kindchenscema, is made up of neonatal features such as a large head, round face, and big eyes and have been proven to elicit caretaking in others (Glocker et al., 2009). This response is not only found in related family members, but is also seen in unrelated adults.

Humans are cooperative breeders in that birth givers require help from other individuals when raising children (Bogin et al., 2014). When that care is provided to infants by individuals other than their biological parents, it is known as alloparenting. This behavior has been seen in humans back to early foraging populations and is present today in cultures across the world (Emmott, 2017). In many species of non-human primates we see similar behaviors of cooperative breeding and alloparenting within their social groups (Cerrito & DeCasien, 2021) (Ginther & Snowdon, 2009). Free-ranging dogs and their closest relative, the grey wolf (Canis lupus), have both shown promising behavioral evidence for alloparenting within their own species (Paul & Bhadra 2018) (Thurston, 2002). However, little is known about the cognitive mechanisms that go on behind these behaviors.

There are several neural mechanisms that underlie our response to juvenile faces. These mechanisms are involved with preparedness to act and speak, social and emotional responsiveness, and parental attachment. When viewing novel infant faces, humans show activation in the lateral premotor cortex (PMC), middle cingulate gyrus (mCG), thalamus, supplementary motor area (SMA), anterior insula (AI), and fusiform gyrus. The fusiform gyrus in humans, while being a critical area for facial perception, has also been associated with complex planning and social emotional and empathetic responsiveness. The thalamus and mCG in humans are known to be a part of the reward system and are related to motivation. Activation in the thalamus has also been associated with parental attachment and facial perception. The PMC has shown increased activation with preparation to move. The SMA and AI are involved in the preparation and intention to communicate (Caria et al., 2012).

Domesticated dogs provide a unique population to understand how alloparenting can occur in non-human mammals as about 38.4% of American households own at least one dog. The modern domesticated dog has been selectively bred for favorable traits to humans. A large amount of this genetic modification occurred in the Victorian era when the number of recognized dog breeds increased by over 15-fold due to the creation of dog shows pushing selective breeding (Worboys et al. 2018). More recently we have seen neural evidence of dogs attending to human faces (Dilks & Cook, 2015). Given that dogs respond to human faces, have been selectively bred for favorable traits, and are the most common pet in the U.S., it is possible they have developed a neural capacity to respond to human infants.

In this study, we scanned unrestrained, awake dogs that are trained for fMRI studies while viewing images of adult and infant humans and dogs. We expected to see activation in the dog face area (DFA) which is analogous to the Fusiform Face Area (FFA) in humans. We also expected to see increased activation in the PMC, mCG, and thalamus when the dogs were viewing infant dogs and infant humans as compared when they were viewing adult dogs and adult humans. While we see activation in the SMA and the AI in humans when viewing infants, we did not expect to see these regions activated in dogs, as these regions are involved in human communication. Activation in these regions in response to juvenile stimuli could indicate a neural mechanism in domesticated dogs that are precursors of alloparenting. A response to both human and dog juvenile stimuli would provide evidence for cross-species alloparenting.

2. Material and methods

2.1 Participants

Participants were (N=4) awake, unrestrained dogs from the Atlanta community. 9 dogs participated in the experiment however, data were only retained for 4 of them. Participants included 2 males and 2 females, all spayed/neutered, ranging in age from 7 to 12 years old. Breeds included 1 boxer mix, 1 Boston terrier mix, 1 lab-golden mix, and 1 pit mix. Prior to testing, all dogs completed a training program that prepared them to be comfortable within the scanner environment and had participated in prior scan sessions. All dogs had previously demonstrated an ability to lie awake and unrestrained during scanning while viewing stimuli on a projection screen prior to this experiment.

2.2 Stimuli

There were 4 conditions consisting of adult human, infant human, adult dog, and infant dog. Stimuli consisted of 320 black and white images with 80 images within each condition. All stimuli included the face including chin but not neck, hair, and ears only as applicable. Stimuli were presented on a black background and the edges of the stimuli’s features were slightly blurred so as to not have sharp edges to avoid images looking unnatural. Adult human images were taken from the FEI Face Database (Thomaz & Giraldi, 2010). Infant human images were taken from the City Infant Face Database (Webb et al., 2018). Adult dog images were taken from the Stanford Dog database and were chosen from 80 different breeds and were selected based on quality and the presence of a full-frontal view of the face (Khosla et al., 2011). Infant dog images were taken from Petland adoption websites as images had clear views of the dogs' faces. Infant dogs chosen were between 2 and 5 months old (Figure 1). All images were novel to the participants.

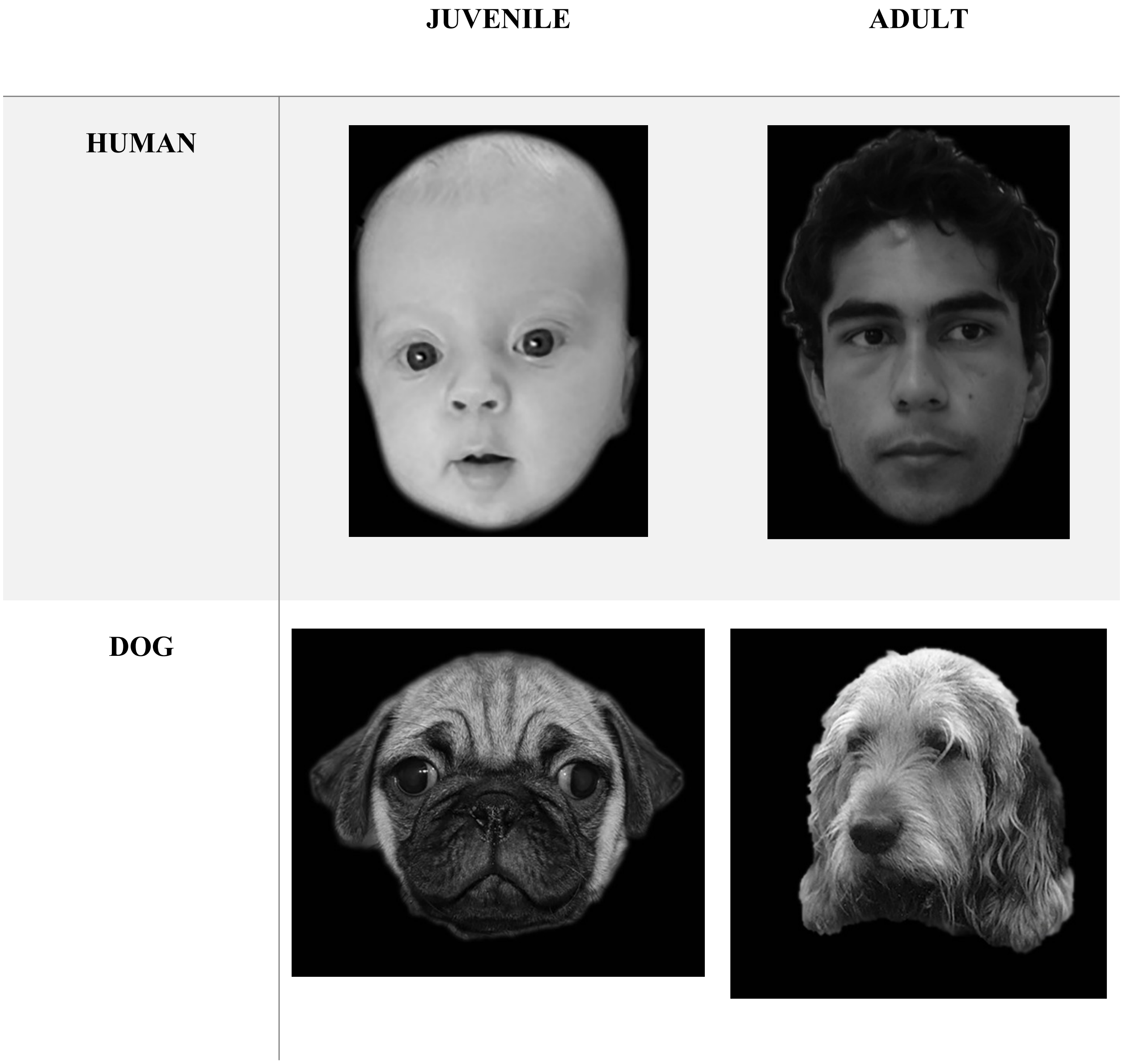

Figure 1. *Stimuli examples*

2.3 Block design

During scanning, dogs actively viewed image stimuli presented on a screen placed in the scanner bore. Stimuli were separated into 2 runs with a total of 160 images per run (40 images from each condition). Stimuli were split into blocks with 10 images all from the same condition. Each run contained 16 blocks (randomly ordered prior to scanning) and lasted approximately 5 min. Stimuli were presented using PsychoPy software. An experimenter standing at the end of the scanner bore manually initiated each block to ensure that dogs remained still in a suitable position within the scanner. Block onset times were recorded using an MRI-compatible button box. The interstimulus intervals lasted approximately 10 seconds. To maintain focus throughout each run, dogs were rewarded food during the inter-block interval as needed.

2.4 MRI scan acquisition

Dog training and fMRI protocol were consistent with the procedures previously used in awake dog fMRI studies. For stimuli presentation, a translucent screen was placed in front of the participants, and images were presented in the following block design. Dogs laid down in a sphinx position to watch stimuli. The scans were obtained using a Siemens 3T Trio MRI scanner. To acquire functional scans, a single shot, echo-planar imaging (EPI) sequence was used to acquire volumes of 22 sequential 2.5 mm slices with a 20% gap (TE = 25ms, TR = 1260 ms, flip angle = 70°, 64 x 64 matrix, 2.5 mm in-plane voxel size, FOV = 192 mm). For each individual, approximately 360 functional volumes were acquired for each dog over the course of one to two runs. For each dog, the total scan session lasted for a maximum of 30 minutes.

2.5 Preprocessing

AFNI (NIH) was used for both preprocessing and statistical analysis. Preprocessing of the fMRI data included motion correction, censoring, and normalization. Censoring was performed based on both signal intensity and motion. Volumes with either more than 2 mm of scan-to-scan movement or more than 1% of voxels flagged as outliers were censored from further analysis. To improve signal-to-noise ratio, the remaining data were spatially smoothed with a 6 mm Gaussian kernel. Additionally, a mask was drawn in functional space for each dog in the cerebellum, which was used to censor the data further by removing volumes where the beta values extracted from the cerebellum were assumed to be beyond the physiologic range of the BOLD signal (|signal change| > 3%) for each trial.

Task related regressors for each experiment were modeled using AFNI’s dmUBLOCK and stim_times_IM functions and were as follows: (1) adult human; (2) infant human; (3) adult dog; (4) infant dogs. This function created a column in the design matrix for each trial, allowing for the estimation of beta values for each trial. Data were censored for outliers as described above for the contrasts of interest. A series of contrasts were pre-planned to assess the main effects of adult versus juvenile and whether they differed between human and dogs. The contrast [all adults—all juveniles] was performed to identify regions that differentially respond to all adults versus all juveniles, independent of human or dog conditions. The contrast [all human – all dog] was performed to identify regions that respond differentially to human and canine stimuli, independent of adult or infant conditions.

2.6 Region of interest analysis

To localize the ROIs for each dog, we overlaid the contrasts of [all adults—all juveniles] and [all human – all dog] onto each of individuals’ mean image in AFNI. We then looked at the contrasts in group space using the CCI as the underlay and varied the voxel threshold to $p < 0.05$ and excluded regions along the edge of the brain were excluded from analysis as motion artifacts to select clusters (Gillette et al., 2022).

3. Results

We identified a region in the ectolateralis posterior as defined by the Johnson atlas within what we believe is the DFA in the adult-juvenile contrast (Johnson et al., 2020). This region is overlayed on the CCI atlas in Figure 2 below. The cluster was defined by its voxel size of 114 at $p<0.05$. Average and individual beta values in this region are displayed in Table 1. No clusters were identified for the human-dog contrast so no further analysis was done.

Dogs that retained fewer than 50% dicoms were excluded from further analysis, leaving 4 dogs remaining. These dogs had a lot of movement during their scanning which interferes with the BOLD response. Dogs that remained retained an average of 79.3% of volumes from scanning after preprocessing.

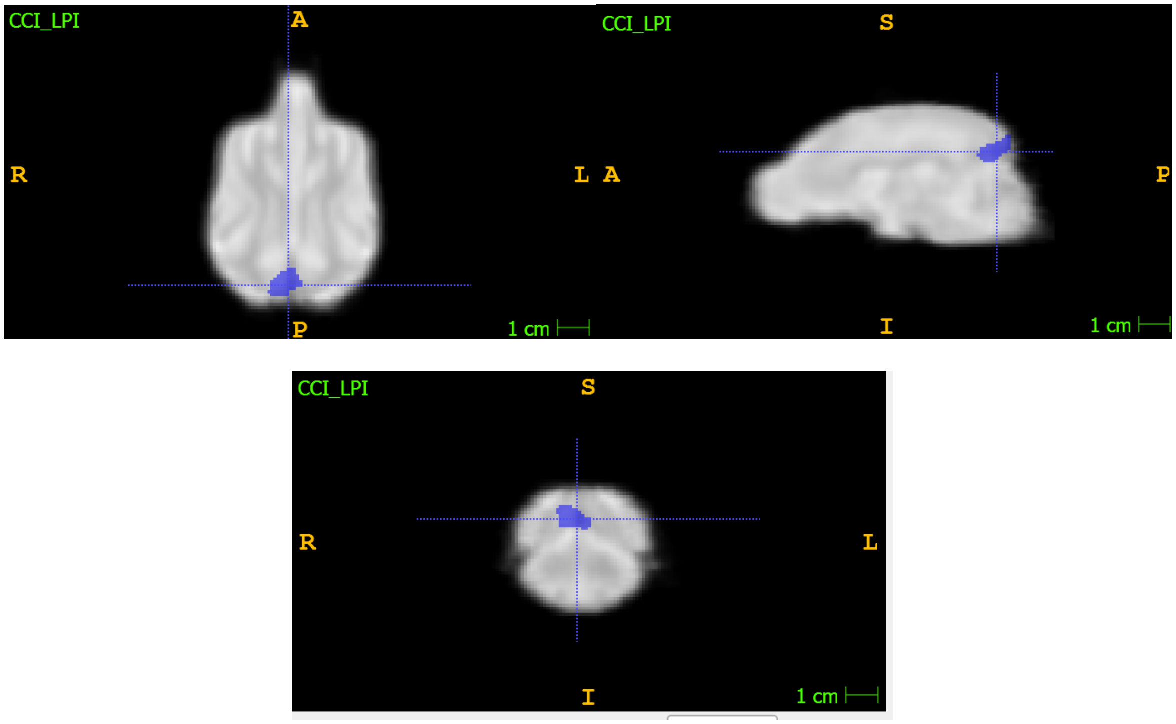

Figure 2. *Adult-Juvenile Contrast*. Greater activation in the ectolateralis posterior within the DFA was found in response to adult stimuli

Contrast	*Area*	*p-value*	*Dogs*	*Betas* (β)	*Beta Means* ($\bar{\beta}$¿	*Beta SE* (SE_{β})
[adult-juvenile]	DFA	0.05	Bhubo	2.2762	1.042222	0.488762
			Daisy	-0.02875		
			Eddie	1.26377		
			Koda	0.65767		

Table 1. *Region of interest statistics.*

4. Discussion

In summary, we scanned dogs while viewing adult and juvenile stimuli and found a significant neural response in the ectolateralis posterior within in the DFA. As the dogs viewed adult stimuli, both human and canine, there was greater activation in this region than when they viewed adult stimuli. While there is not much research on this area in humans or domesticated dogs, the region appears to be part of the DFA which is analogous to the fusiform face area (FFA) in humans. This is surprisingly incongruent with previous neural evidence in humans. We have seen that when humans view juvenile stimuli, they have increased activation in the fusiform gyrus. This increased activation in the critical face processing region may indicate increased visual attentiveness for adult features.

These findings could be due to the dogs' increased attentiveness to adult faces due to their capabilities for training. All dogs that participated in this experiment have spent much of their lives rewarded for attentiveness and responsiveness to their adult trainers. Future studies should try to limit the involvement of adult faces in their training or investigate the effect of juveniles giving rewards during training or scanning.

We are limited in our ability to generalize these findings due to a small sample size. Our retention ratio for this study was just under 50%. Those that did provide data were all above the age of 7 and had previously participated in other fMRI studies and specialized training. With their age and experience in research the participants may apply more salience and neural activation to facial stimuli. The dogs that we scanned are not representative of all modern domesticated dogs and have displayed an aptitude for responsiveness in attention demanding tasks.

While visual cues did not indicate an alloparenting response to juveniles, further research should examine the effect of odor and sound cues on this response. There is evidence for a neural system in humans that responds to the sound of a baby's cry and given the high sensitivity of the canine auditory system this could also be a significant mediator in dogs' responsiveness to juveniles. Additionally, the caudate has shown discriminatory activation to familiar scents and could be worthwhile to investigate when dogs are provided scents of adults and juveniles (Berns et al., 2015).

The neural response could also be uneven between dog and human stimuli. Modern domesticated dogs have neotenized features when compared to those of wolves. Given that many breeds of dogs maintain these juvenile features into adulthood the comparative age effect could be minimized in dog stimuli when compared to humans. A replication of this study should consider additionally showing wolve stimuli to see if dogs respond differentially to them.

5. Conclusion

The present work explores domesticated dogs' neural response to juvenile and adult stimuli. We saw activation in the ectolateralis posterior within the DFA increase when dogs viewed adult stimuli as compared to juvenile stimuli. More work should be done to further investigate the neural responses of dogs to juveniles to better understand this activation and its implications on alloparenting.

Institutional Review Board Statement: Dog studies were approved by the Institutional Animal Care and Use Committee of Emory University (PROTO201700572), and all owners gave written consent for their dog's participation in this study.

Conflicts of Interest: The authors declare no conflict of interest.

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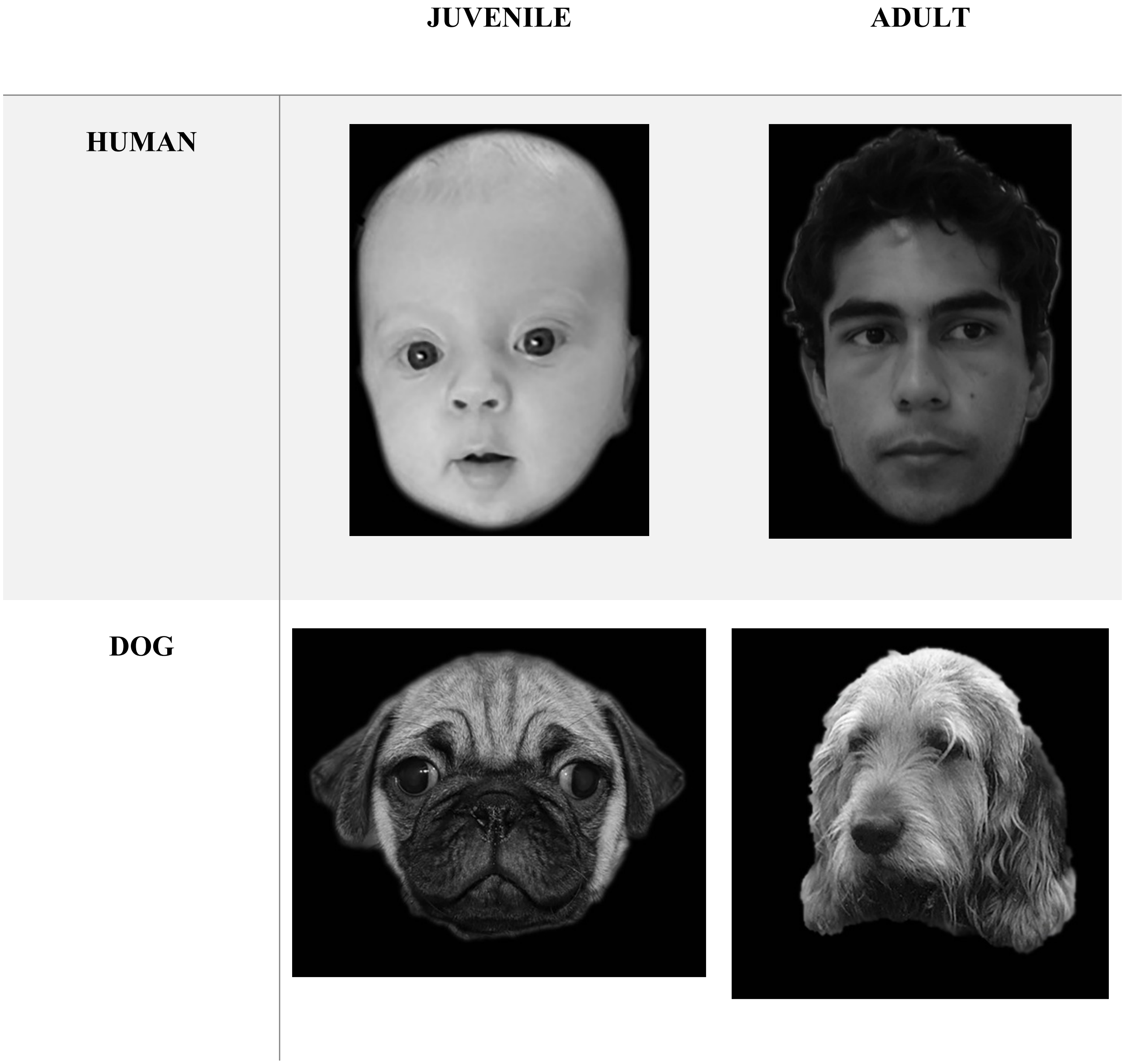
Figures and Tables



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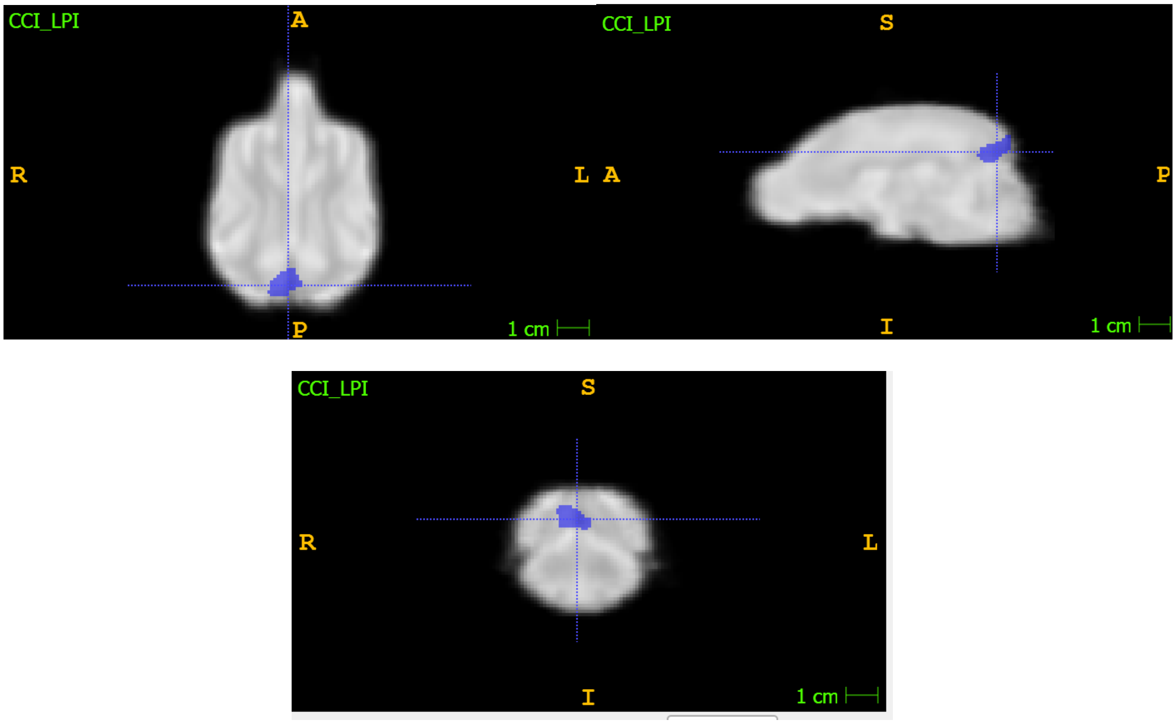

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