



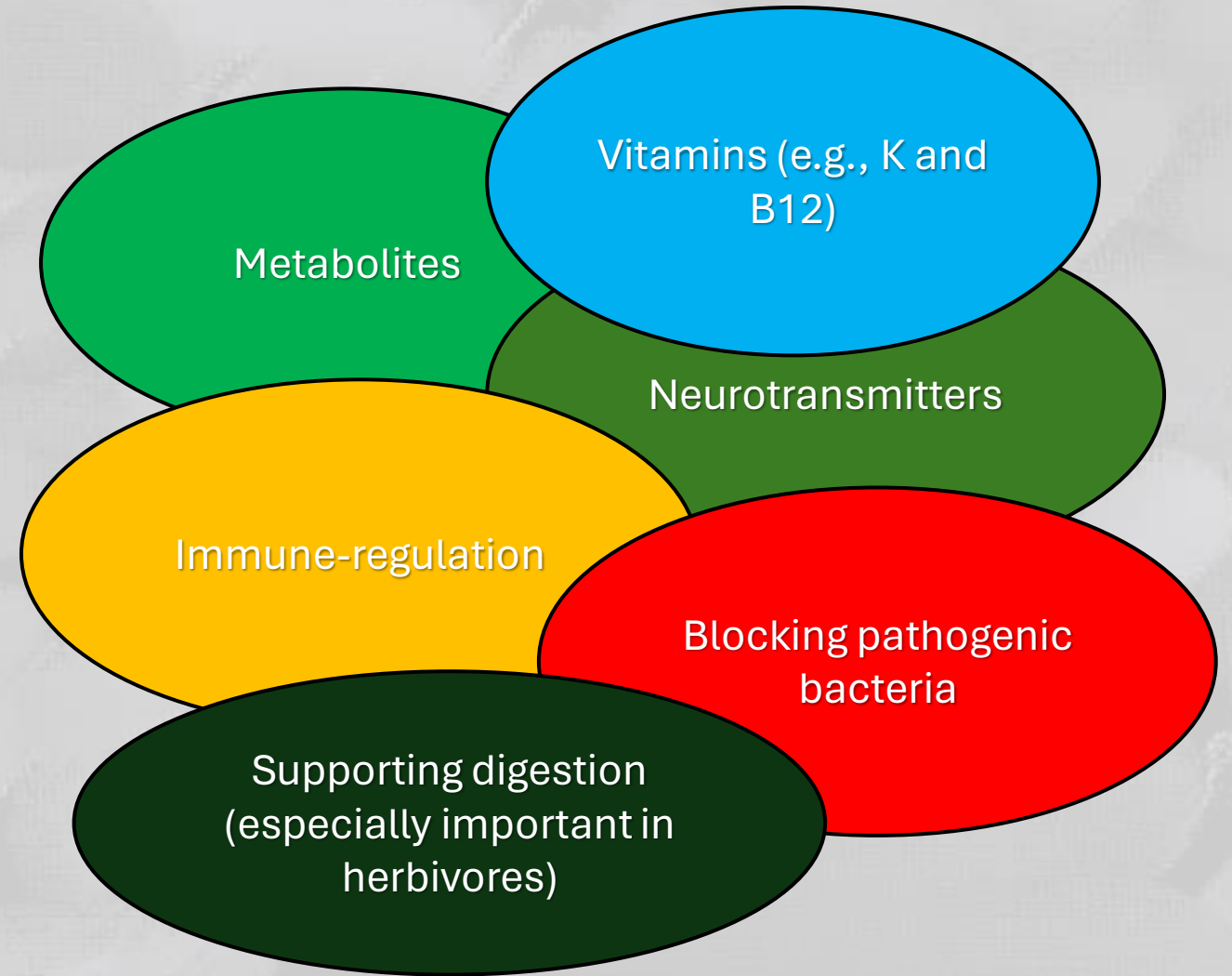
# The microbiome and the brain

**Dr. Sára Sándor**  
**05.31.2024.**

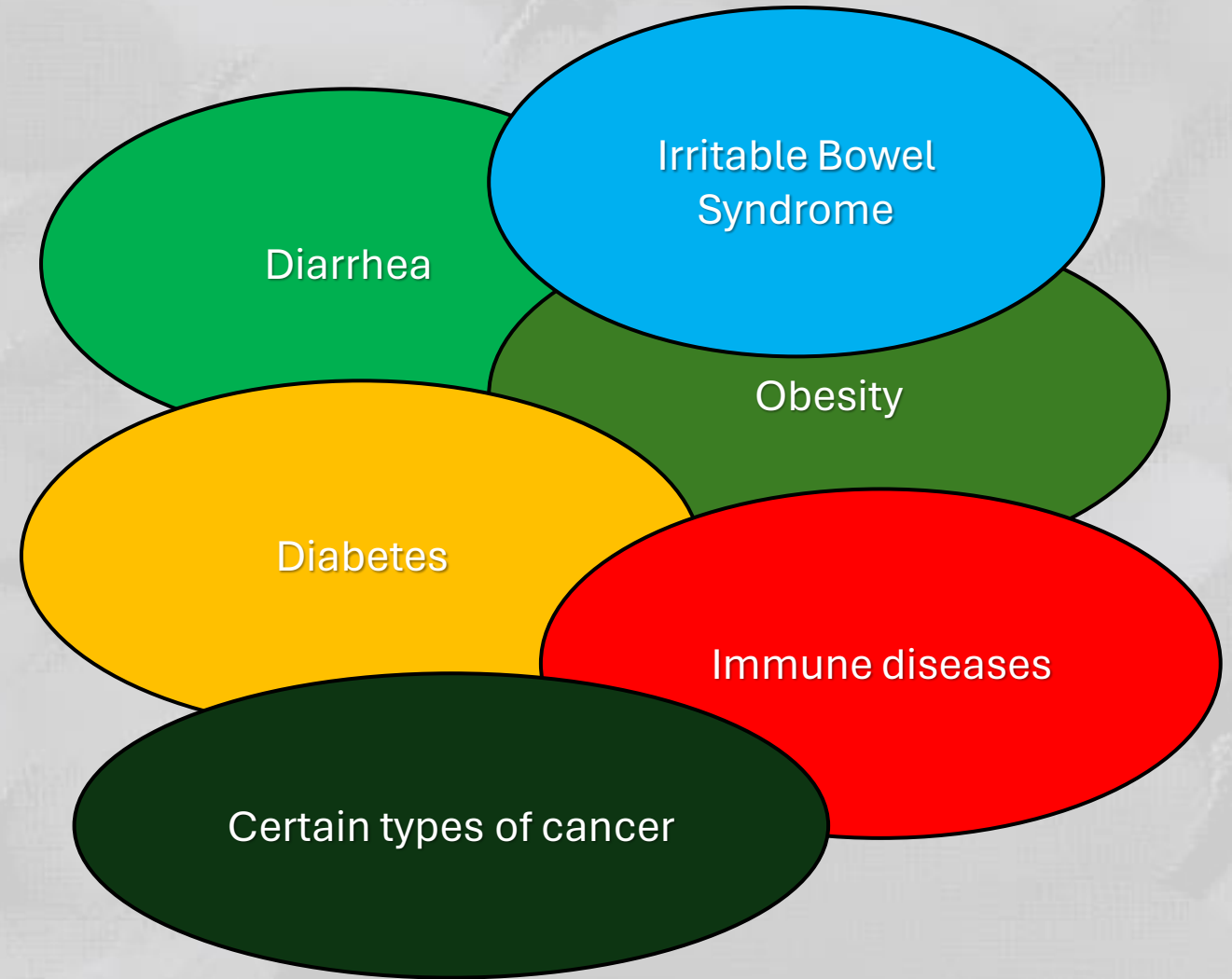
**Microbiome: a microscopic community of bacteria, viruses and others (e.g., protozoa, small parasites)**



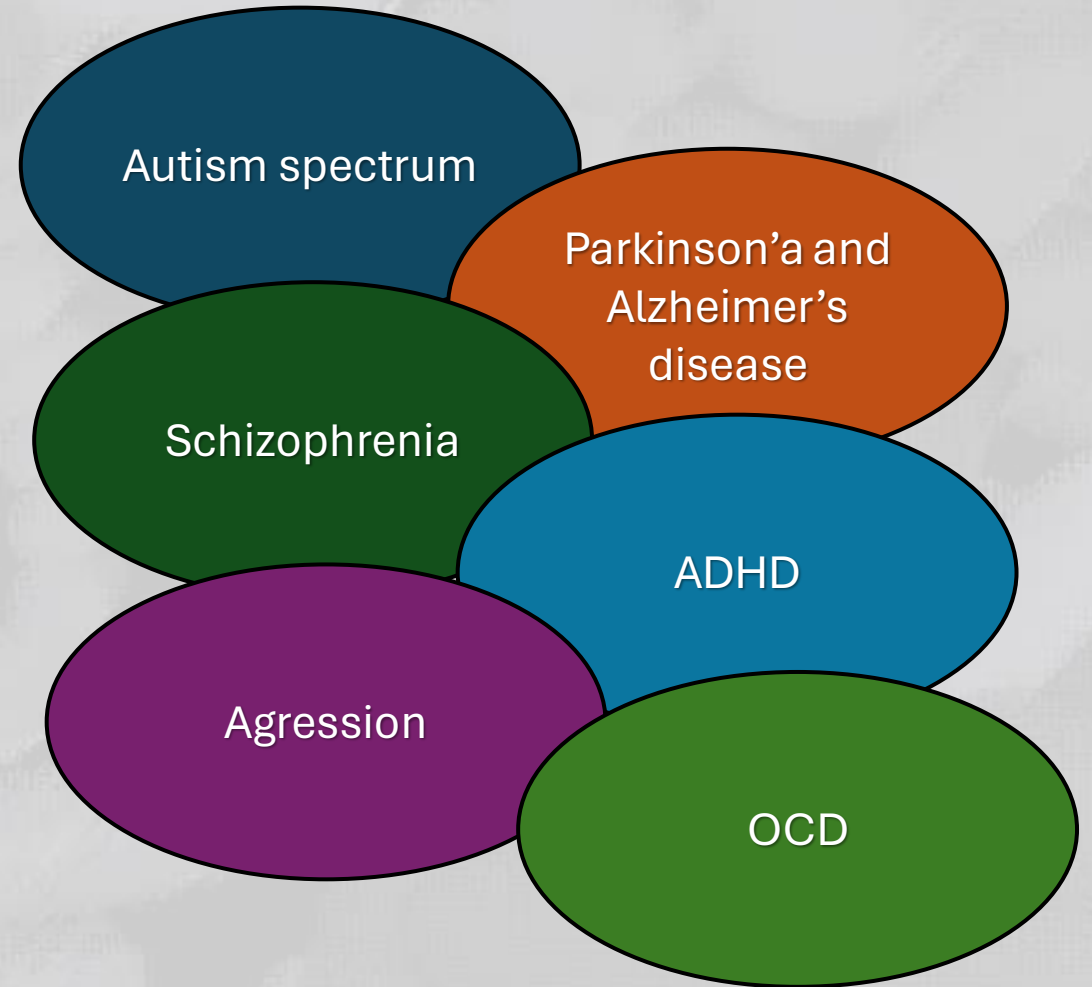
**An increasing body of scientific evidence indicates that the bacterial community living in our guts can fundamentally affect our health and wellbeing!**



# Correlation between the constitution of the bacterial communities and various health issues have been reported in humans (and in rodents)



**... including disorders affecting the central nervous system and variations in behavior.**

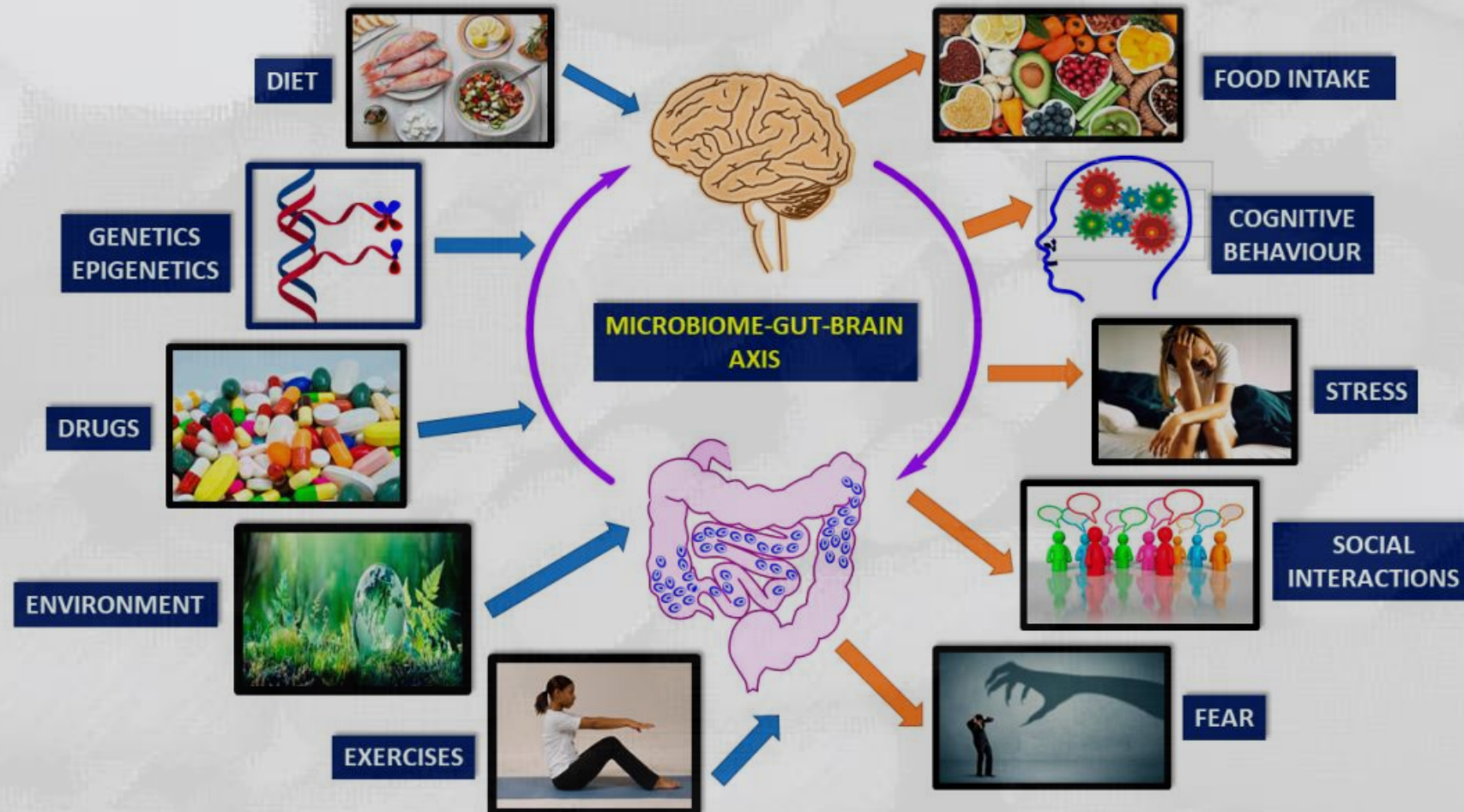


# The concept of the gut-brain axis has been recognized by the scientific community and medical experts

Review

## Gut-Brain-Microbiota Axis: Antibiotics and Functional Gastrointestinal Disorders

Tarkan Karakan <sup>1,\*</sup>, Ceren Ozkul <sup>2</sup>, Esra K peli Akkol <sup>3</sup>, Saniye Bilici <sup>4</sup>, Eduardo Sobarzo-S nchez <sup>5,6</sup> and Raffaele Capasso <sup>7,\*</sup>







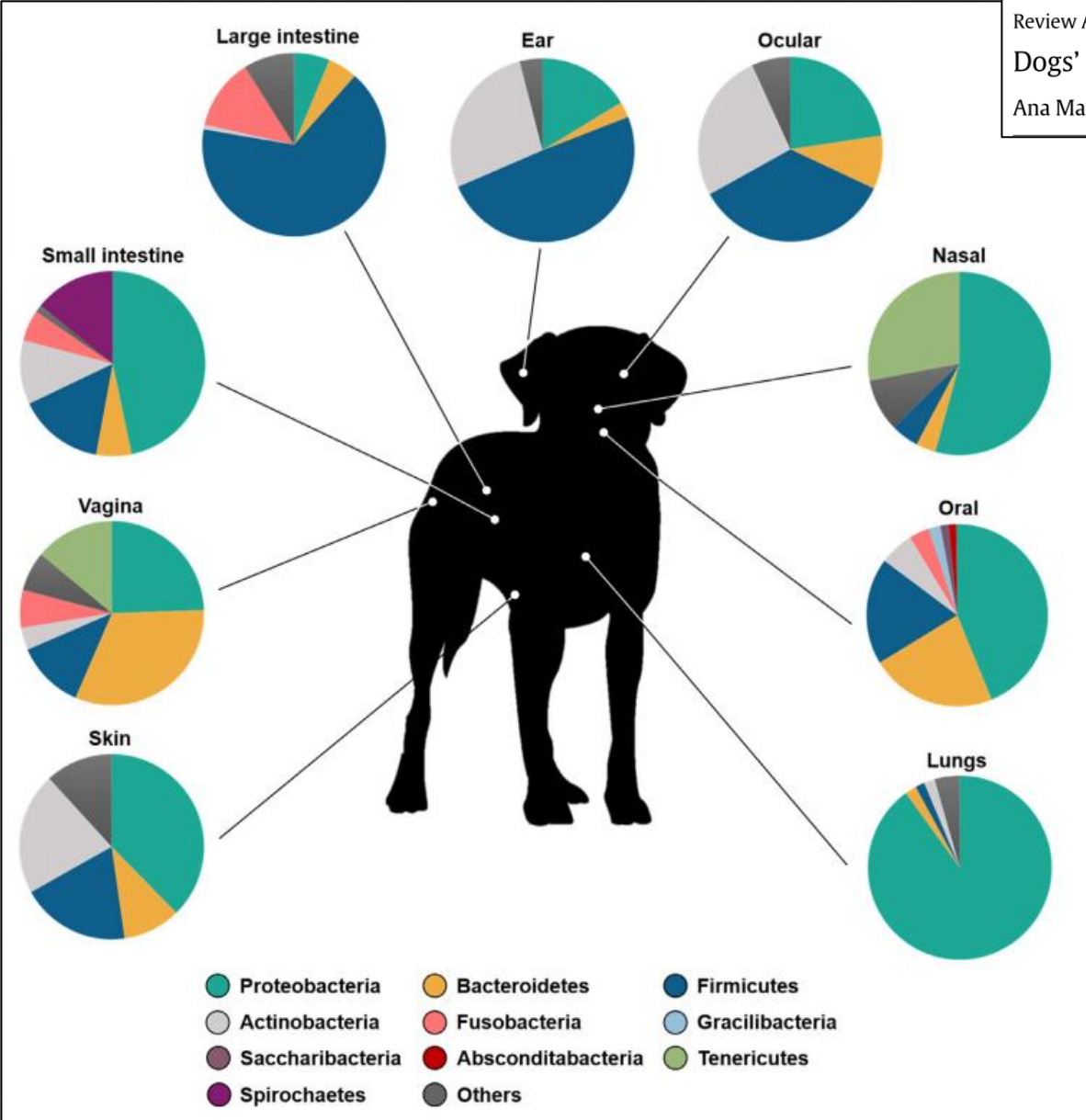


# Dogs also have their microbiomes around and inside their bodies

Review Article

## Dogs' Microbiome From Tip to Toe

Ana Margarida Pereira<sup>a,\*</sup>, Alfonso Clemente<sup>b</sup>

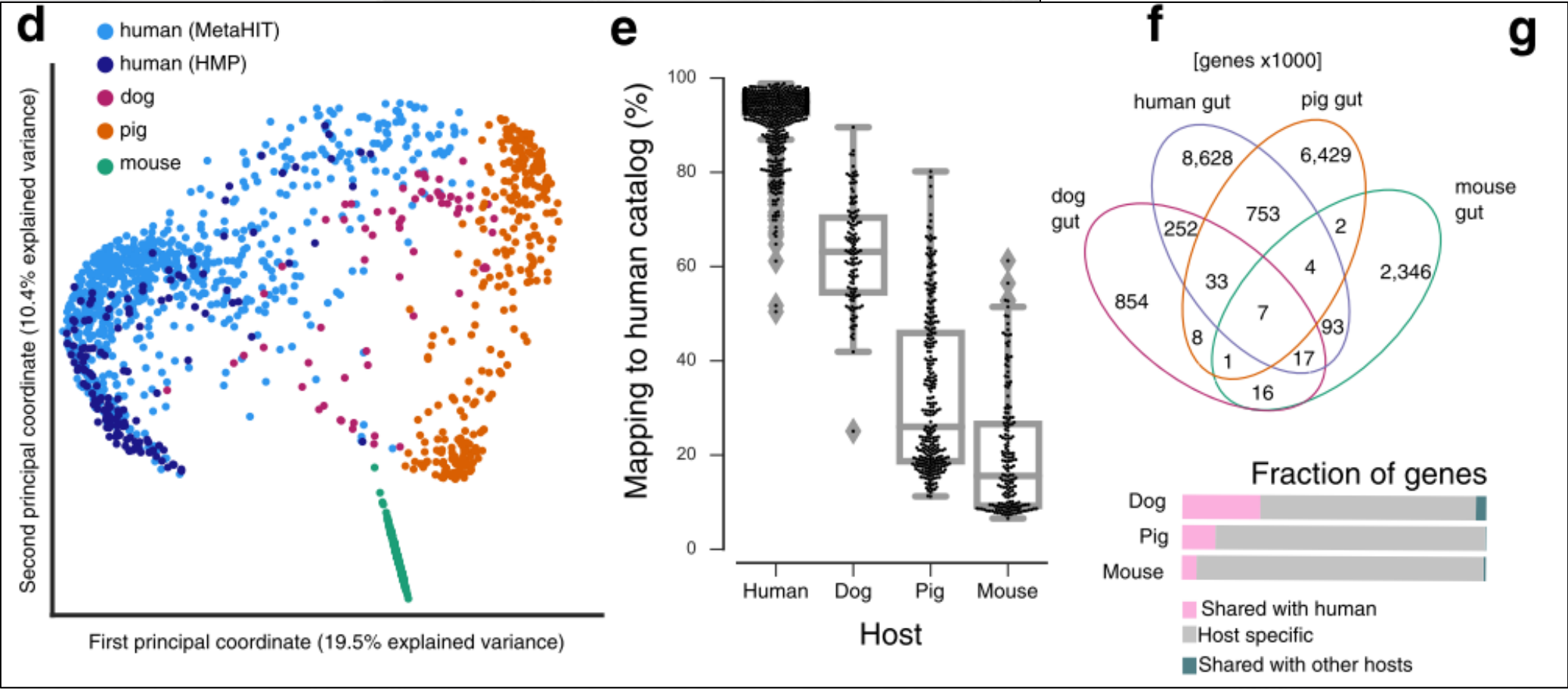


# The composition of the gut microbiome was found to be highly similar between dogs and humans relative to other species

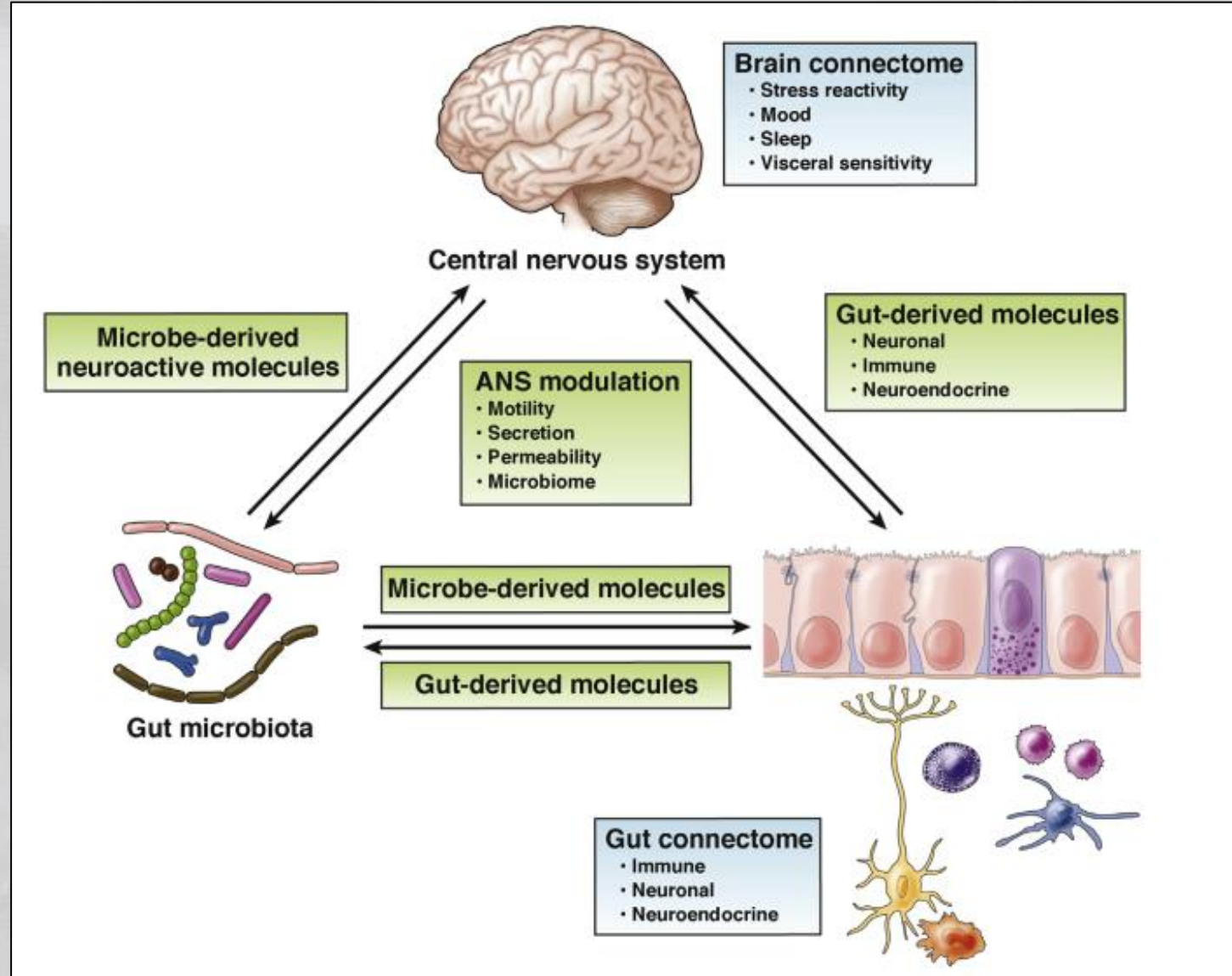


## Similarity of the dog and human gut microbiomes in gene content and response to diet

Luis Pedro Coelho<sup>1</sup>, Jens Roat Kultima<sup>1</sup>, Paul Igor Costea<sup>1</sup>, Coralie Fournier<sup>3</sup>, Yuanlong Pan<sup>2</sup>, Gail Czarnecki-Maulden<sup>2</sup>, Matthew Robert Hayward<sup>1</sup>, Sofia K. Forslund<sup>1</sup>, Thomas Sebastian Benedikt Schmidt<sup>1</sup>, Patrick Descombes<sup>3</sup>, Janet R. Jackson<sup>2</sup>, Qinghong Li<sup>2†</sup> and Peer Bork<sup>1,4,5†</sup>



# We can assume similar roles and mechanisms



# Various bacteria are linked to the production of several neurotransmitters

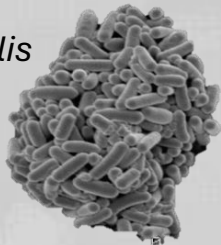
*Lactobacillus plantarum*



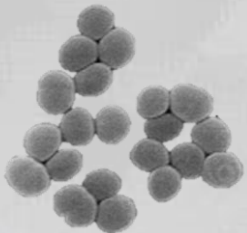
*Bifidobacterium spp.*



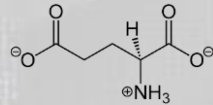
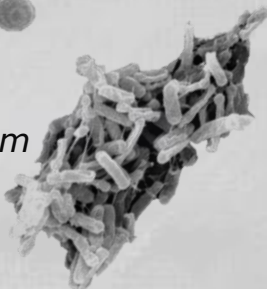
*Bacillus subtilis*



*Staphylococcus spp.*



*Clostridium spp.*



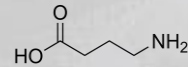
Glutamate

Acetate

*Lactobacillus plantarum* [36]  
*Bacteroides vulgatus* [36]  
*Campylobacter jejuni* [36]

Enteroendocrine cells [13]

Putative Functions in the Gut–Brain Axis  
 Transfer intestinal sensory signals to the brain through the vagus nerve [13]



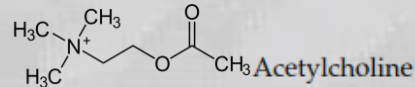
GABA

Acetate

*Bifidobacterium* [19]  
*Bacteroides fragilis* [19]  
*Parabacteroides* [19]  
*Eubacterium* [19]

Myenteric neurons [37]  
 Mucosal endocrine-like cells [38]

Modulate synaptic transmission in the enteric nervous system [37]  
 Modulate intestinal motility and inflammation [38]



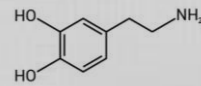
Acetylcholine

Choline

*Lactobacillus plantarum* [39]  
*Bacillus acetylcholini* [40]  
*Bacillus subtilis* [41],  
*Escherichia coli* [41]  
*Staphylococcus aureus* [41]

Myenteric neurons [42–44]

Produced by 33% myenteric neurons in human colon [44]  
 Regulate intestinal motility and secretion [42] and enteric neurotransmission [43]

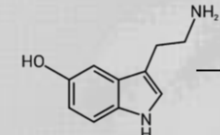


Dopamine

Tyrosine  
 L-DOPA

*Staphylococcus* [32]

Affect gastric secretion, motility, and mucosal blood flow [45]  
 Affect gastric tone and motility through nigro-vagal pathway in a Parkinson's disease (PD) rat model [46]



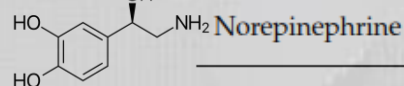
Serotonin

5-HTP  
 Tryptophan

*Staphylococcus* [32]  
*Clostridial species* [31]

Enterochromaffin cells [47]

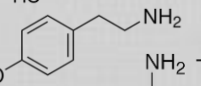
Promote intestinal motility [48]



Norepinephrine

Tyrosine

Modulate energy intake and thermal homeostasis [49]

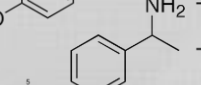


Tyramine

Tyrosine

*Staphylococcus* [32]  
*Providencia* [50]

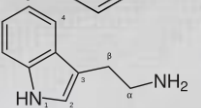
Precursor of octopamine [50]



Phenylethylamine

Phenylalanine

*Staphylococcus* [32]



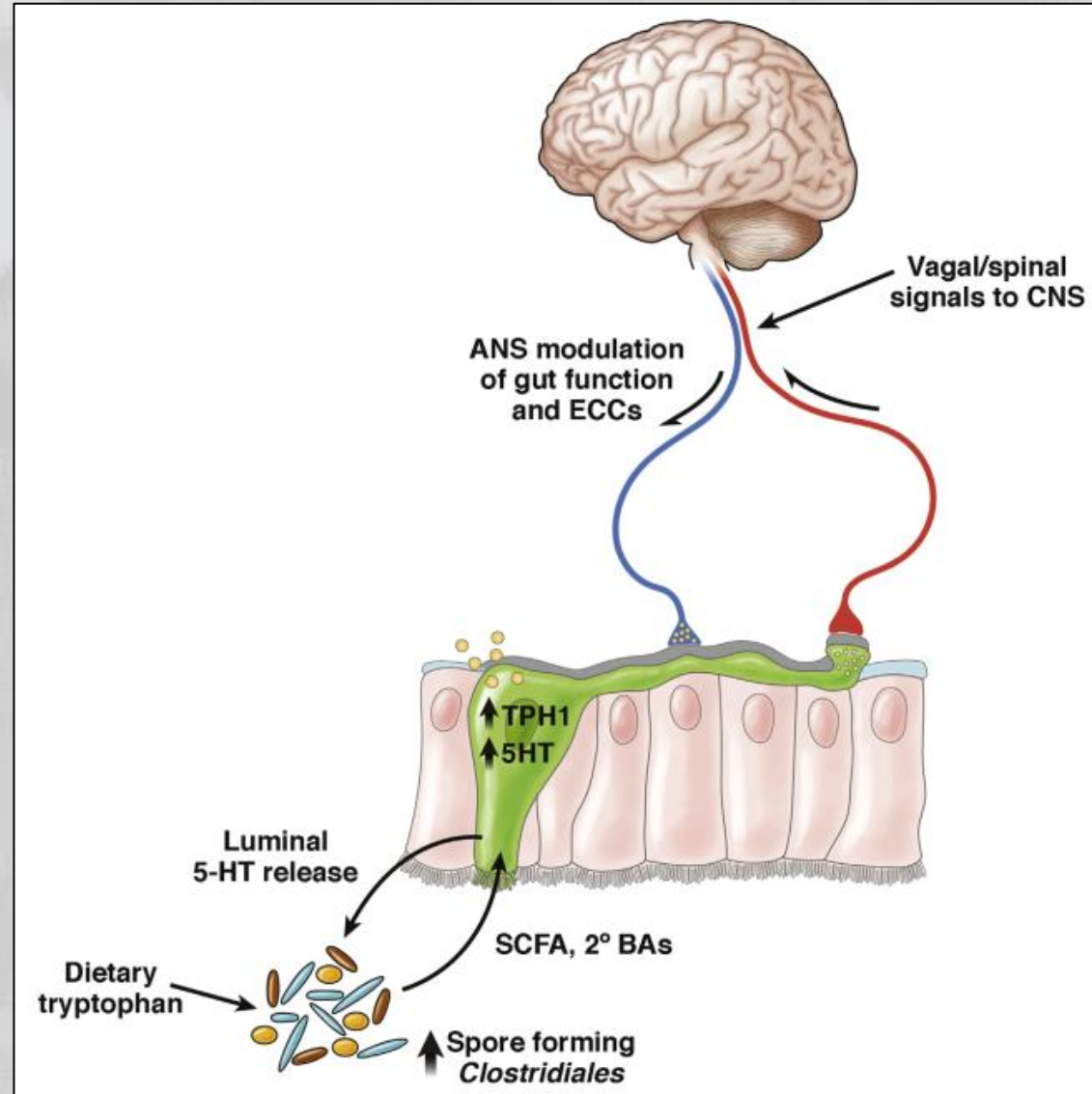
Tryptamine

Tryptophan

*Staphylococcus* [32]  
*Ruminococcus gnavus* [33]  
*Clostridium sporogenes* [33]

Induce serotonin secretion by enterochromaffin cells [51]  
 Promote gastrointestinal transit and colonic secretion [52]

# Example: most of the serotonin are produced in our guts, and this is affected by bacteria

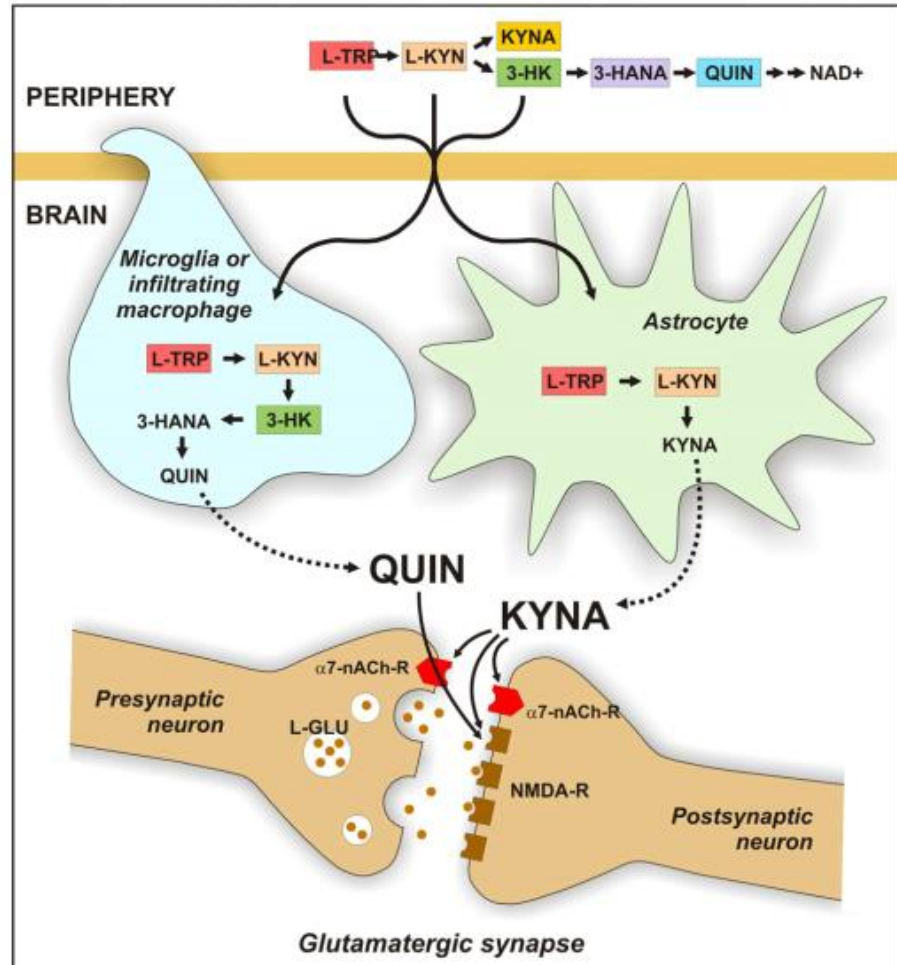


Review

### Serotonin, tryptophan metabolism and the brain-gut-microbiome axis

S.M. O'Mahony<sup>a,b,1</sup>, G. Clarke<sup>a,c,\*</sup>, Y.E. Borre<sup>a</sup>, T.G. Dinan<sup>a,c</sup>, J.F. Cryan<sup>a,b</sup>

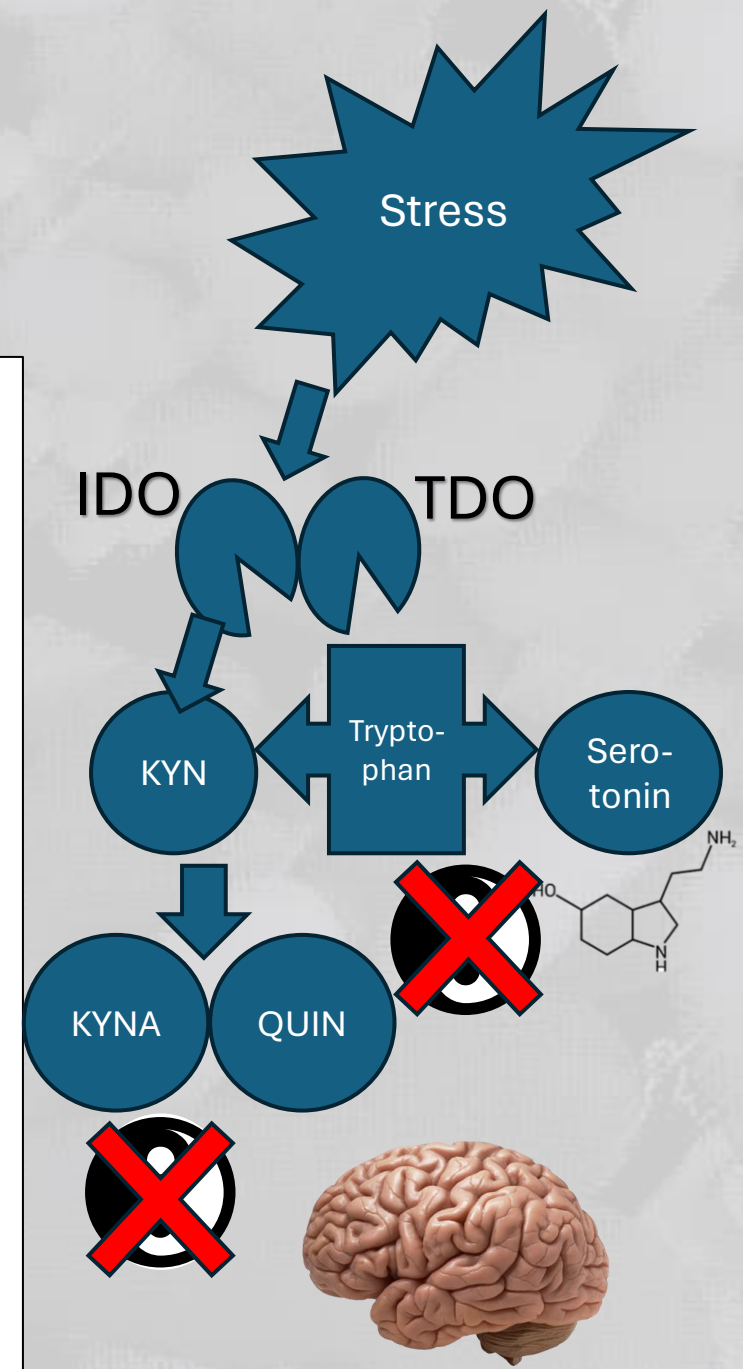
<sup>a</sup>Alimentary Pharmabiotic Centre, University College Cork, Cork, Ireland  
<sup>b</sup>Department of Anatomy and Neuroscience, University College Cork, Cork, Ireland  
<sup>c</sup>Department of Psychiatry, University College Cork, Cork, Ireland



### Altered TRP metabolism:

↑ Brain IDO  
 ↑ Brain/circulating kynurenes  
 ↑ L-kynurenine uptake  
 Altered levels of brain kynurenic and quinolinic acid  
 ↓  
**CNS alterations**  
 ↓  
**Cognitive deficit**

**Stress**  
 ↓  
 Inflammation    ↓    Glucocorticoids  
 ↓  
 Activation of IDO/TDO  
 ↓  
 ↓ TRP    ↑ KYN  
 ↓  
 Serotonergic deficiency  
 ↓  
**GI alterations**



# Example: correlation between aggression level and microbiome composition



The gut microbiome correlates with conspecific aggression in a small population of rescued dogs (*Canis familiaris*)

Nicole S. Kirchoff<sup>1</sup>, Monique A.R. Udell<sup>2</sup> and Thomas J. Sharpton<sup>1,3</sup>

<sup>1</sup> Department of Microbiology, Oregon State University, Corvallis, OR, United States of America

<sup>2</sup> Department of Animal and Rangeland Science, Oregon State University, Corvallis, OR, United States of America

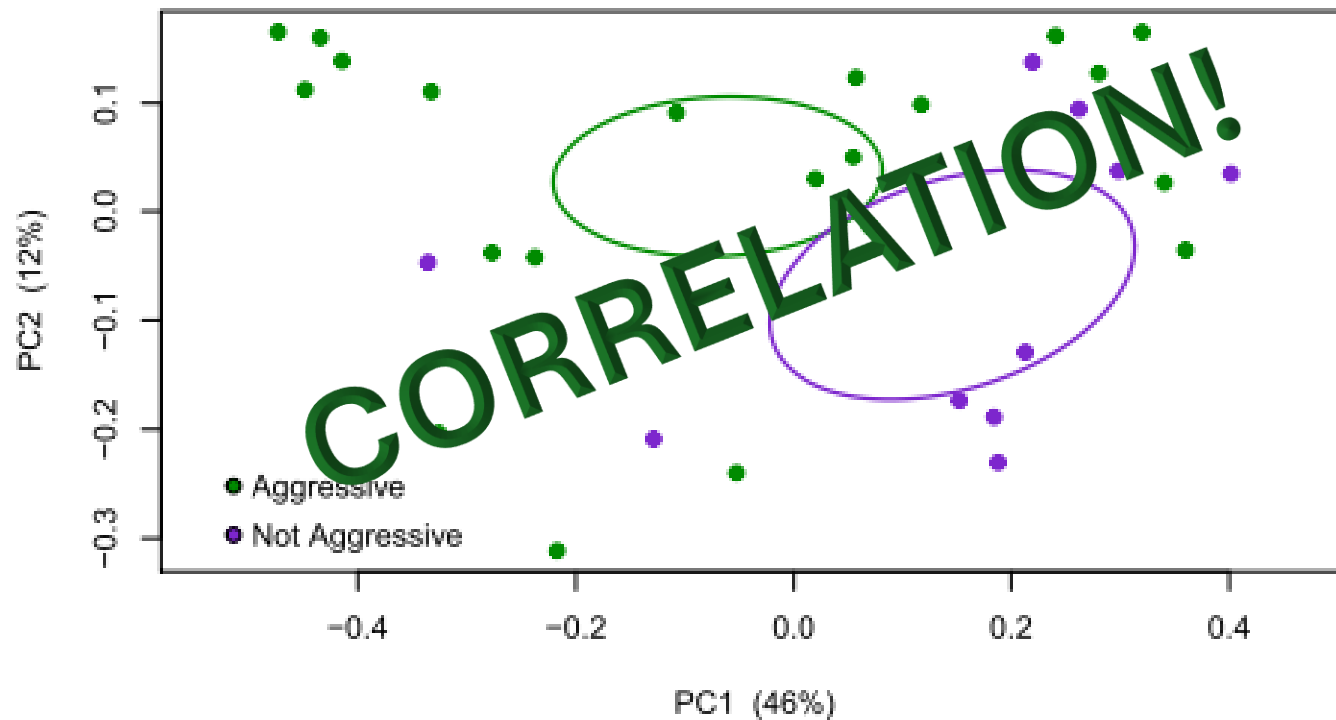
<sup>3</sup> Department of Statistics, Oregon State University, Corvallis, OR, United States of America

21 dogs showed aggression towards other dogs

10 did not show aggression towards other dogs



Fecal samples were collected from the dogs



**Figure 1** Aggressive and non-aggressive dogs differ in beta-diversity using the weighted UniFrac metric. Visualization of the phylogenetic differences in fecal microbiota of aggressive (green) and non-aggressive (purple) dogs using principal coordinates analysis (PCoA) of OTU abundances and weighted UniFrac distance. The separation between aggressive and non-aggressive samples in the PCoA plot was confirmed with an environmental fit analysis ( $p = 0.0250$ ,  $R^2 = 0.1297$ ), which supports aggression status as being a variable that is separating the microbial composition of the samples. The gut microbiome structure of aggressive and non-aggressive dogs is also significantly different with the weighted UniFrac metric using PERMANOVA ( $p = 0.0346$ ,  $R^2 = 0.0349$ ). Ellipses are based on 95% confidence intervals and standard error.



# Example: correlation between memory performance and microbiome composition in elderly dogs



Article

## Gut Microbiome Composition is Associated with Age and Memory Performance in Pet Dogs

Eniko Kubinyi <sup>1,\*</sup>, Soufiane Bel Rhali <sup>1,2,†</sup>, Sára Sándor <sup>1</sup>, Attila Szabó <sup>2</sup> and Tamás Felföldi <sup>2</sup>

<sup>1</sup> Department of Ethology, ELTE Eötvös Loránd University, 1117 Budapest, Hungary; belghalisoufiane@gmail.com (S.B.R.); sandorsara@gmail.com (S.S.)

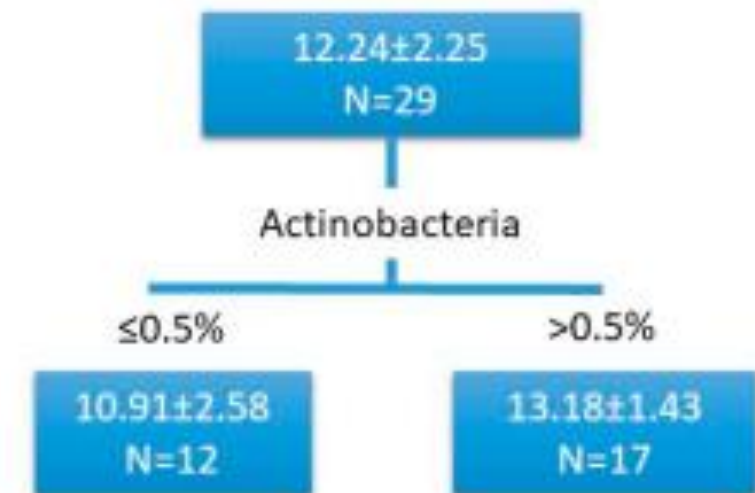
<sup>2</sup> Department of Microbiology, ELTE Eötvös Loránd University, 1117 Budapest, Hungary; attila.szabo.ttk@gmail.com (A.S.); tamas.felfoldi@gmail.com (T.F.)

\* Correspondence: eniko.kubinyi@ttk.elte.hu

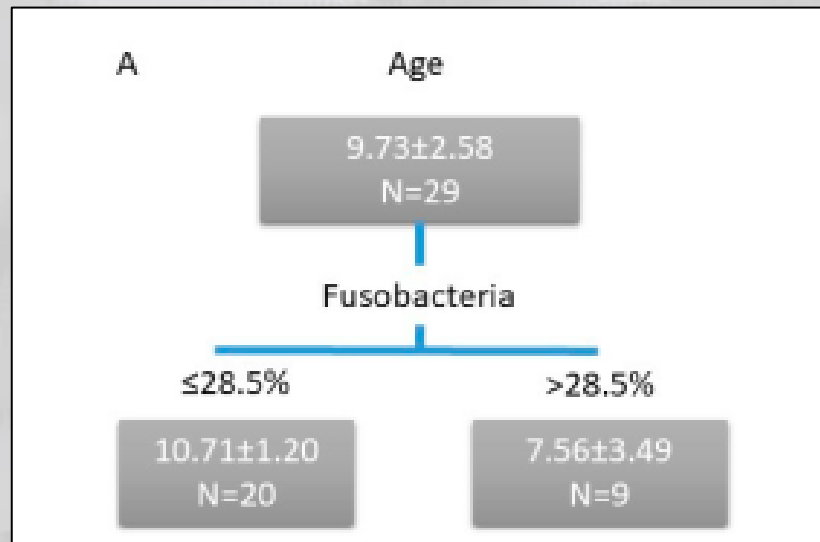
† These authors contributed equally to this work.



### B Memory test mistakes



# Example: correlation between age, memory performance and microbiome composition in elderly dogs



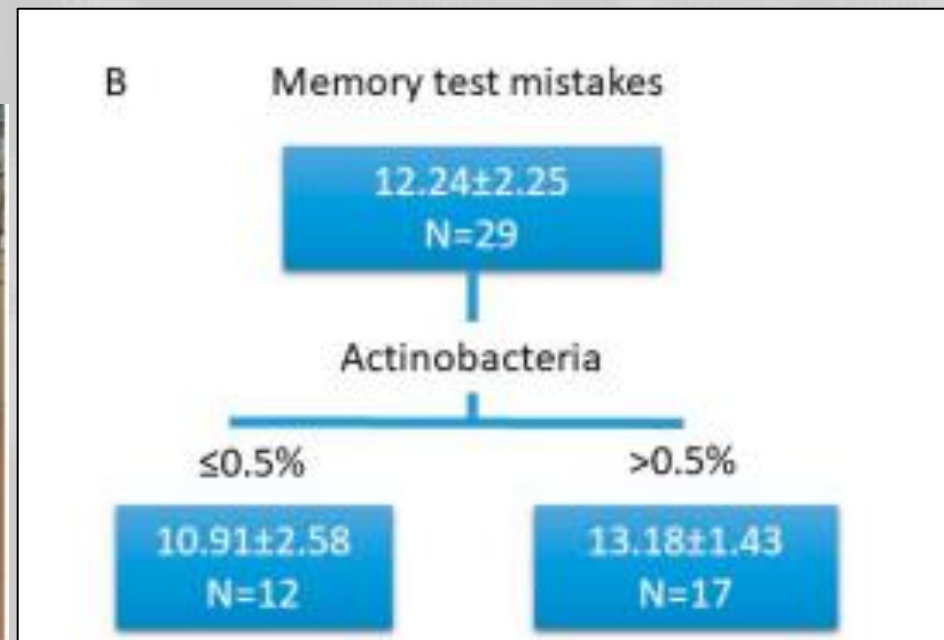
 **animals** 

Article

## Gut Microbiome Composition is Associated with Age and Memory Performance in Pet Dogs

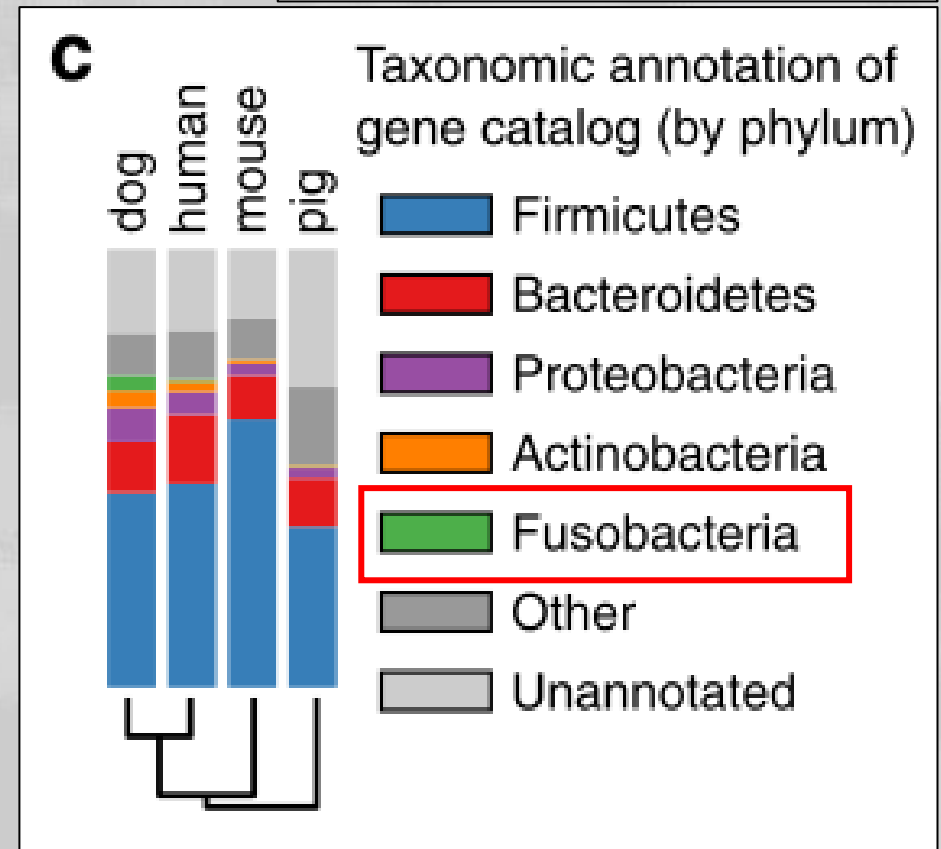
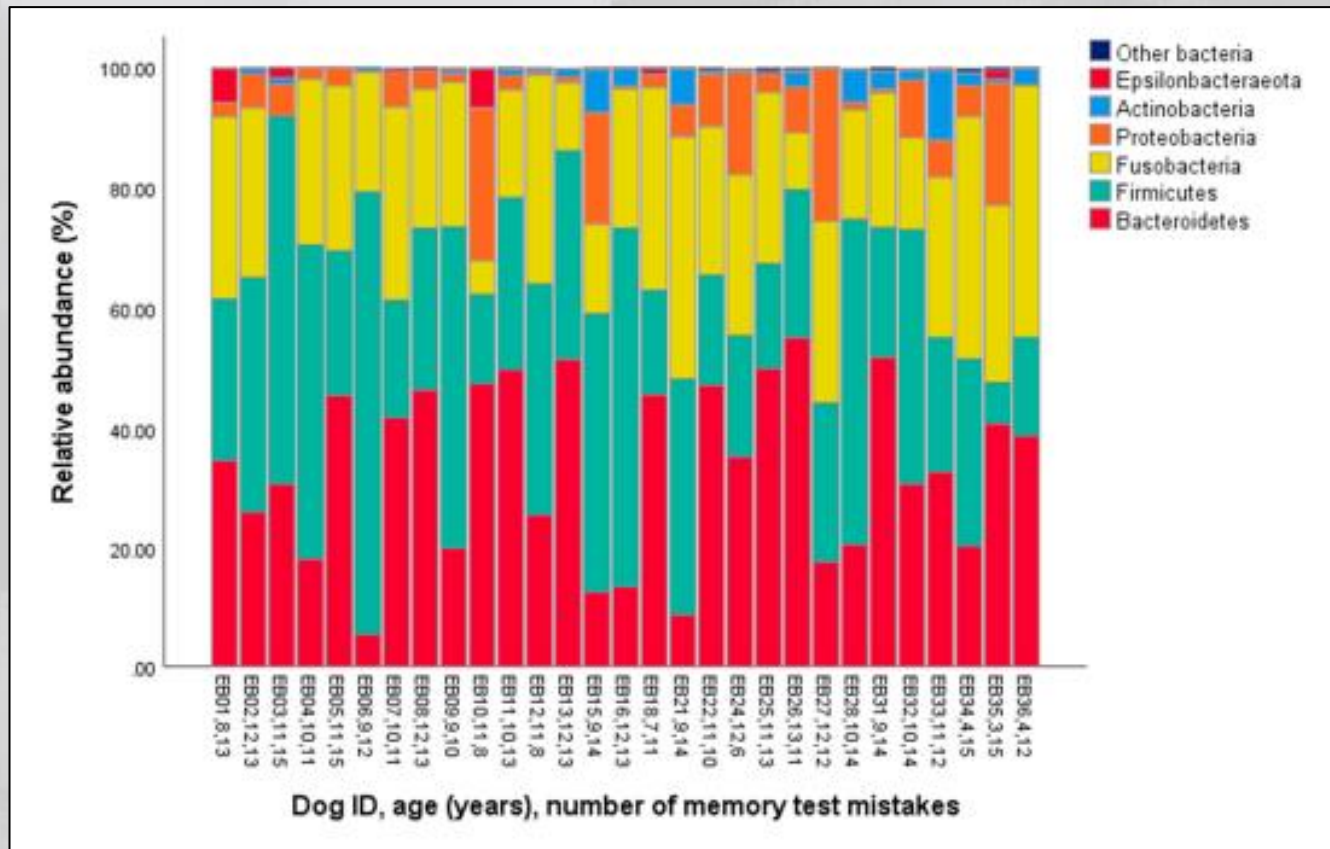
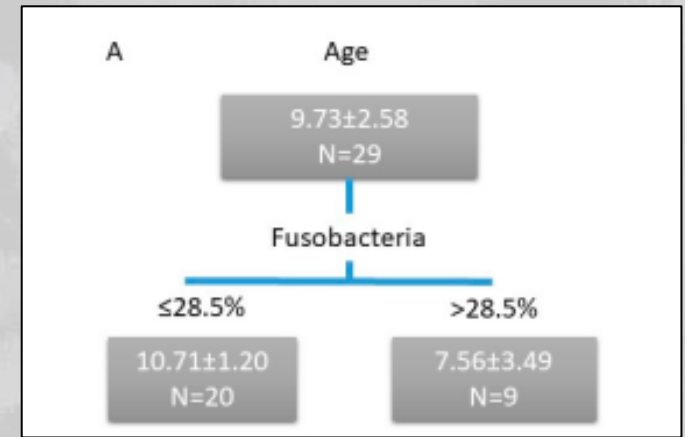
Eniko Kubinyi <sup>1,\*</sup>, Soufiane Bel Rhali <sup>1,2,†</sup>, Sára Sándor <sup>1</sup>, Attila Szabó <sup>2</sup> and Tamás Felföldi <sup>2</sup>

<sup>1</sup> Department of Ethology, ELTE Eötvös Loránd University, 1117 Budapest, Hungary; belghalisoufiane@gmail.com (S.B.R.); sandorsara@gmail.com (S.S.)  
<sup>2</sup> Department of Microbiology, ELTE Eötvös Loránd University, 1117 Budapest, Hungary; attila.szabo.ttk@gmail.com (A.S.); tamas.felfoldi@gmail.com (T.F.)  
\* Correspondence: eniko.kubinyi@ttk.elte.hu  
† These authors contributed equally to this work.

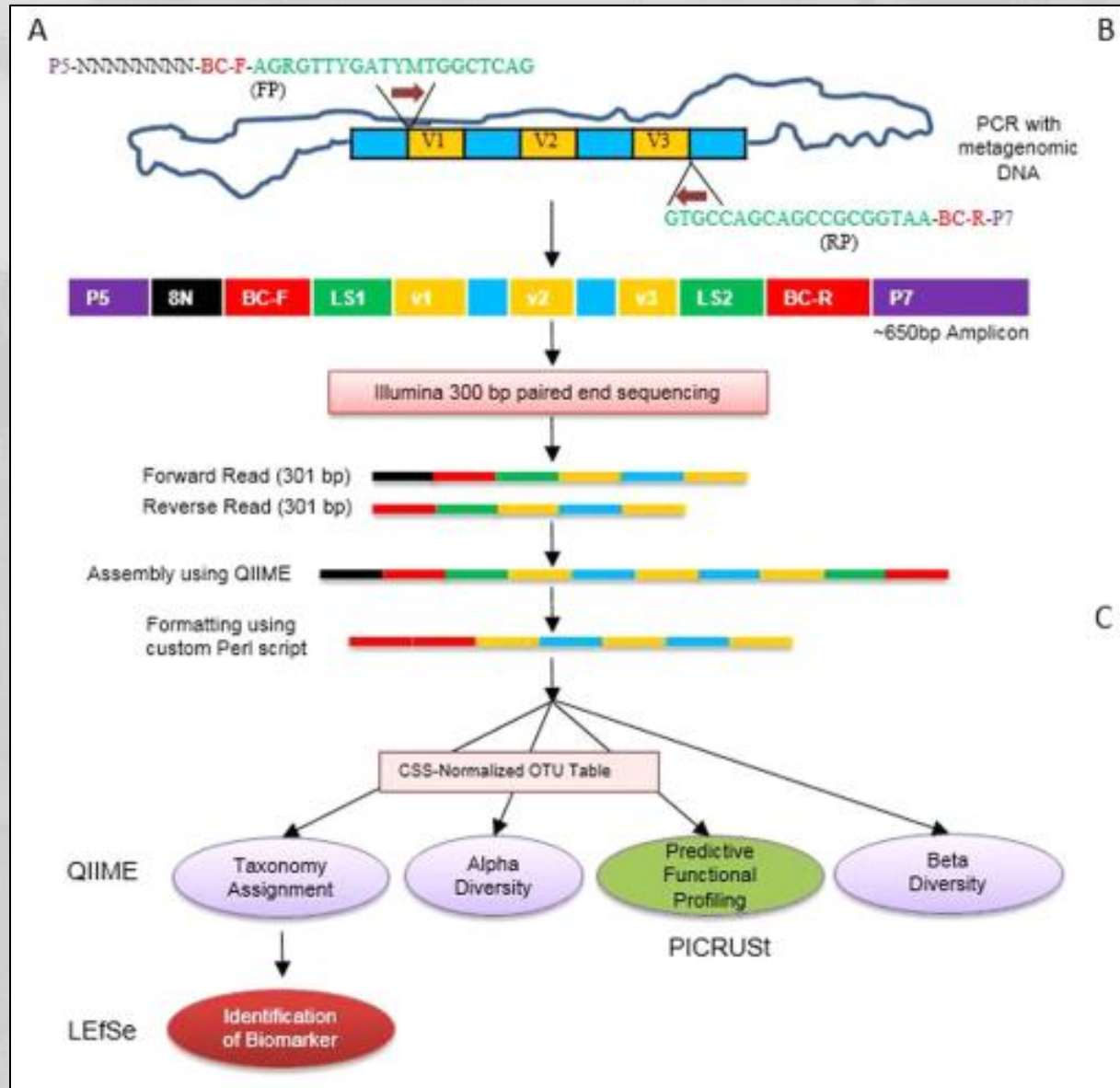
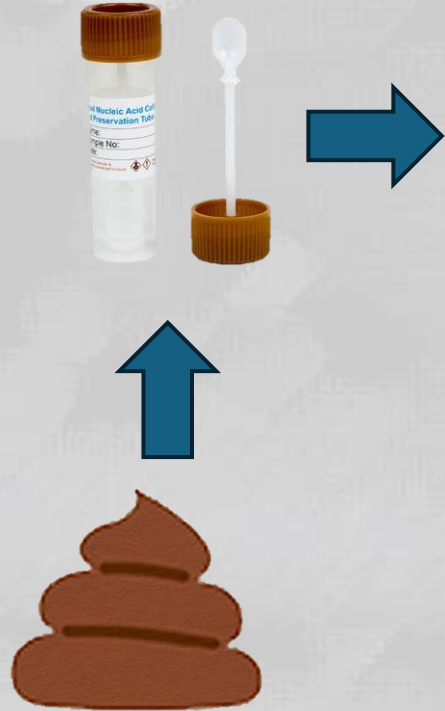


# Example: correlation between age, memory performance and microbiome composition in elderly dogs

**Note: Probiotics should be optimized for each species!**



# Data type 1: composition of the gut microbiome



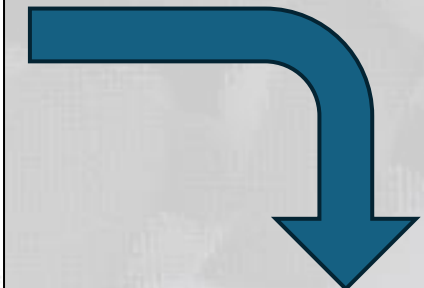
SCIENTIFIC REPORTS

OPEN

An investigation into blood microbiota and its potential association with Bacterial Chondronecrosis with Osteomyelitis (BCO) in Broilers

Received: 24 November 2015  
Accepted: 21 April 2016  
Published: 13 May 2016

Rabindra K. Mandal<sup>1</sup>, Tieshan Jiang<sup>1</sup>, Adnan A. Al-Rubaye<sup>2</sup>, Douglas D. Rhoads<sup>1</sup>, Robert F. Wideman<sup>1</sup>, Jiangchao Zhao<sup>1</sup>, Igal Pevzner<sup>3</sup> & Young Min Kwon<sup>1,2\*</sup>



## Data type 2: behavior, e.g. memory performance



# Correlation between dog dementia severity and periodontal disease severity!

Submitted: 27/01/2021

Accepted: 26/03/2021

Published: 19/04/2021

## Periodontal disease is associated with cognitive dysfunction in aging dogs: A blinded prospective comparison of visual periodontal and cognitive questionnaire scores

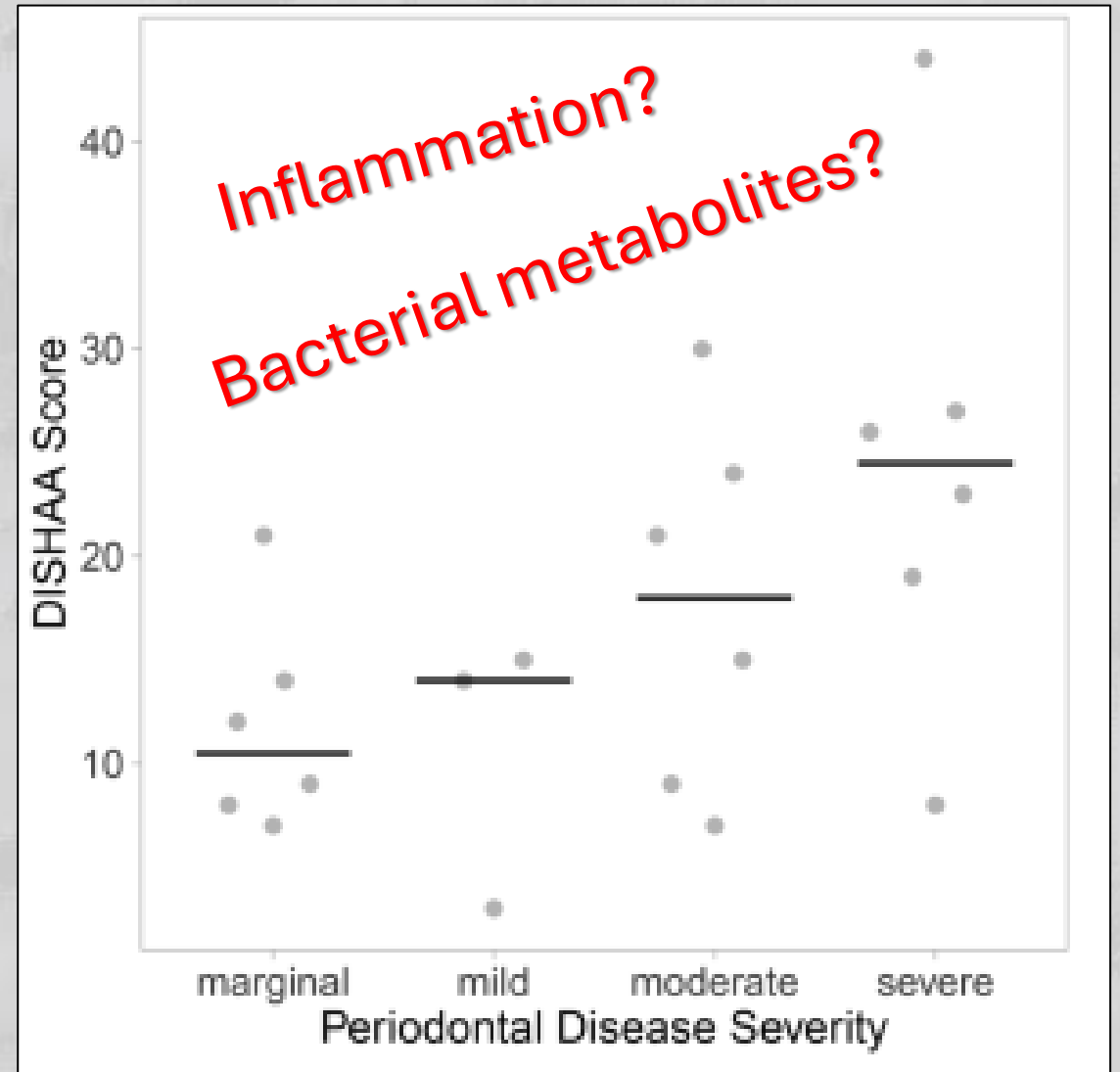
Curtis Wells Dewey<sup>1,2\*</sup> and Mark Rishniw<sup>3</sup>

<sup>1</sup>Elemental Pet Vets, PLLC, Freeville, New York, USA

<sup>2</sup>Chi University, Reddick, Florida, USA

<sup>3</sup>Department of Clinical Sciences, College of Veterinary Medicine, Cornell University, Ithaca, New York, USA

**CCD: Canine Cognitive Dysfunction Syndrome,**  
which is a neurodegenerative disorders similar to  
Alzheimer's disease



**What is this good for in the everyday practice?**

# What is this good for in the everyday practice?



Contents lists available at [ScienceDirect](https://www.sciencedirect.com)

Applied Animal Behaviour Science

journal homepage: [www.elsevier.com/locate/applanim](https://www.elsevier.com/locate/applanim)



Effects of *Lactiplantibacillus plantarum* PS128 on alleviating canine aggression and separation anxiety

Yu-Min Yeh<sup>a</sup>, Xin-Ying Lye<sup>b</sup>, Han-You Lin<sup>b</sup>, Jia-Yi Wong<sup>b</sup>, Chien-Chen Wu<sup>c</sup>, Chin-Lin Huang<sup>c</sup>, Ying-Chieh Tsai<sup>d</sup>, Lih-Chiann Wang<sup>b,\*</sup>

<sup>a</sup> Master Program of Green Technology for Sustainability, Nanhua University, Chiayi County, Taiwan

<sup>b</sup> School of Veterinary Medicine, National Taiwan University, Taipei, Taiwan

<sup>c</sup> Bened Biomedical Co. Ltd, Taipei, Taiwan

<sup>d</sup> Institute of Biochemistry and Molecular Biology, National Yang Ming University, Taipei, Taiwan

Probiotics

Prebiotics



Journal of Veterinary Behavior

Volume 42, March–April 2021, Pages 37–47



Effect of a novel nutraceutical supplement (Relaxigen Pet dog) on the fecal microbiome and stress-related behaviors in dogs: A pilot study

Simona Cannas<sup>a</sup> ✉, Barbara Tonini<sup>b</sup>, Benedetta Belà<sup>c</sup>, Roberta Di Prinzio<sup>c</sup>, Giulia Pignataro<sup>c</sup>, Daniele Di Simone<sup>d</sup>, Alessandro Gramenzi<sup>c</sup>



# What is this good for in the everyday practice?

## Fecal transplantation

Veterinary Medicine: Research and Reports

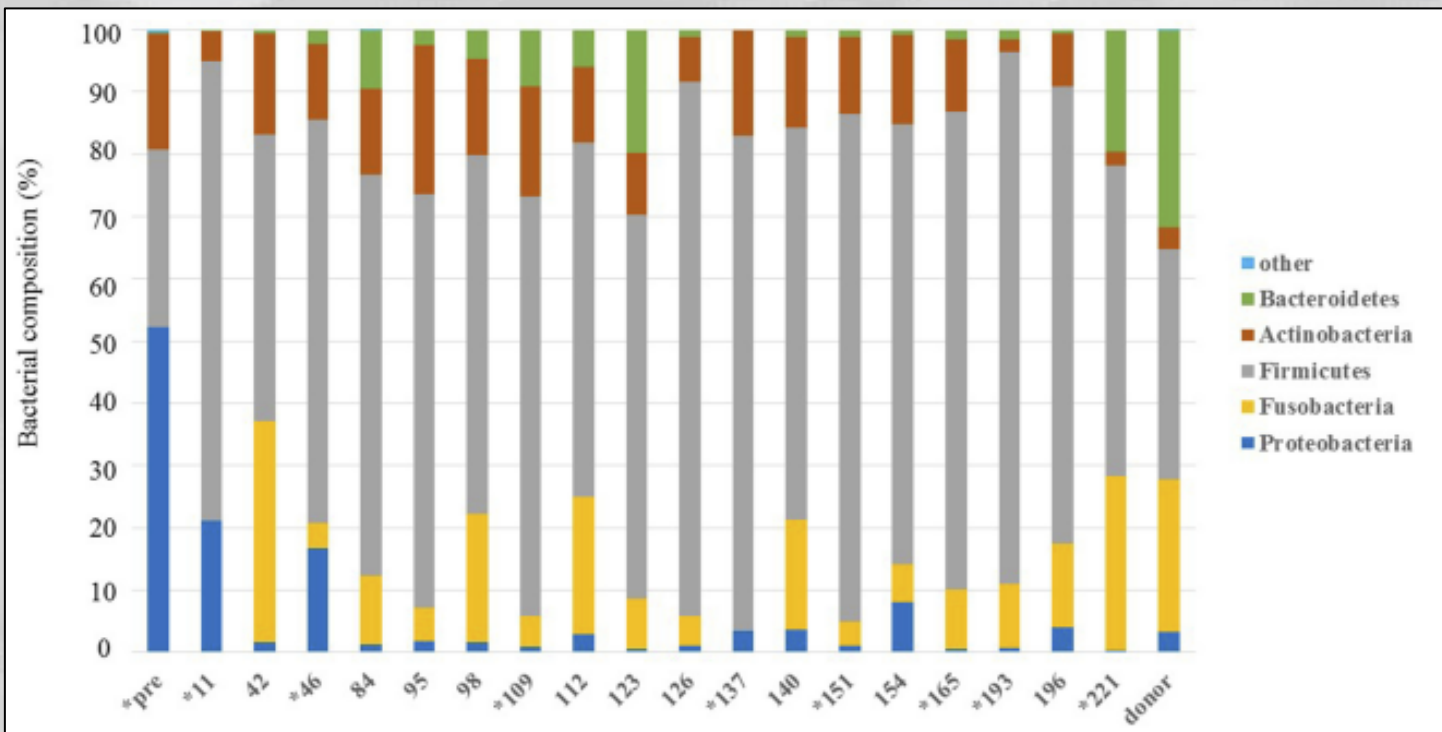
Dovepress

open access to scientific and medical research

Open Access Full Text Article

CASE REPORT

### Improvement in Clinical Symptoms and Fecal Microbiome After Fecal Microbiota Transplantation in a Dog with Inflammatory Bowel Disease



Applied Microbiology and Biotechnology (2024) 108:46  
<https://doi.org/10.1007/s00253-023-12935-0>

ENVIRONMENTAL BIOTECHNOLOGY



### Effects of fecal microbial transplantation on police performance and transportation stress in Kunming police dogs

Qiu-Ye Lin<sup>1</sup> · Jin-Jing Du<sup>2</sup> · Hu Xu<sup>3</sup> · Ming-Kui Lv<sup>2</sup> · Le Xu<sup>2</sup> · Jie Li<sup>3</sup> · Zhen-Hui Cao<sup>2,4</sup>

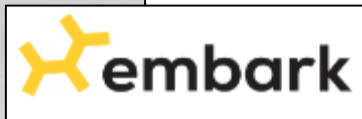
Received: 6 August 2023 / Revised: 6 November 2023 / Accepted: 17 November 2023  
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(Dogs have their own ways...)



# What is this good for in the everyday practice?

## Personalized medicine



# What is this good for in the everyday practice?

## The One Health Triad



source: wikipedia



Good or bad?

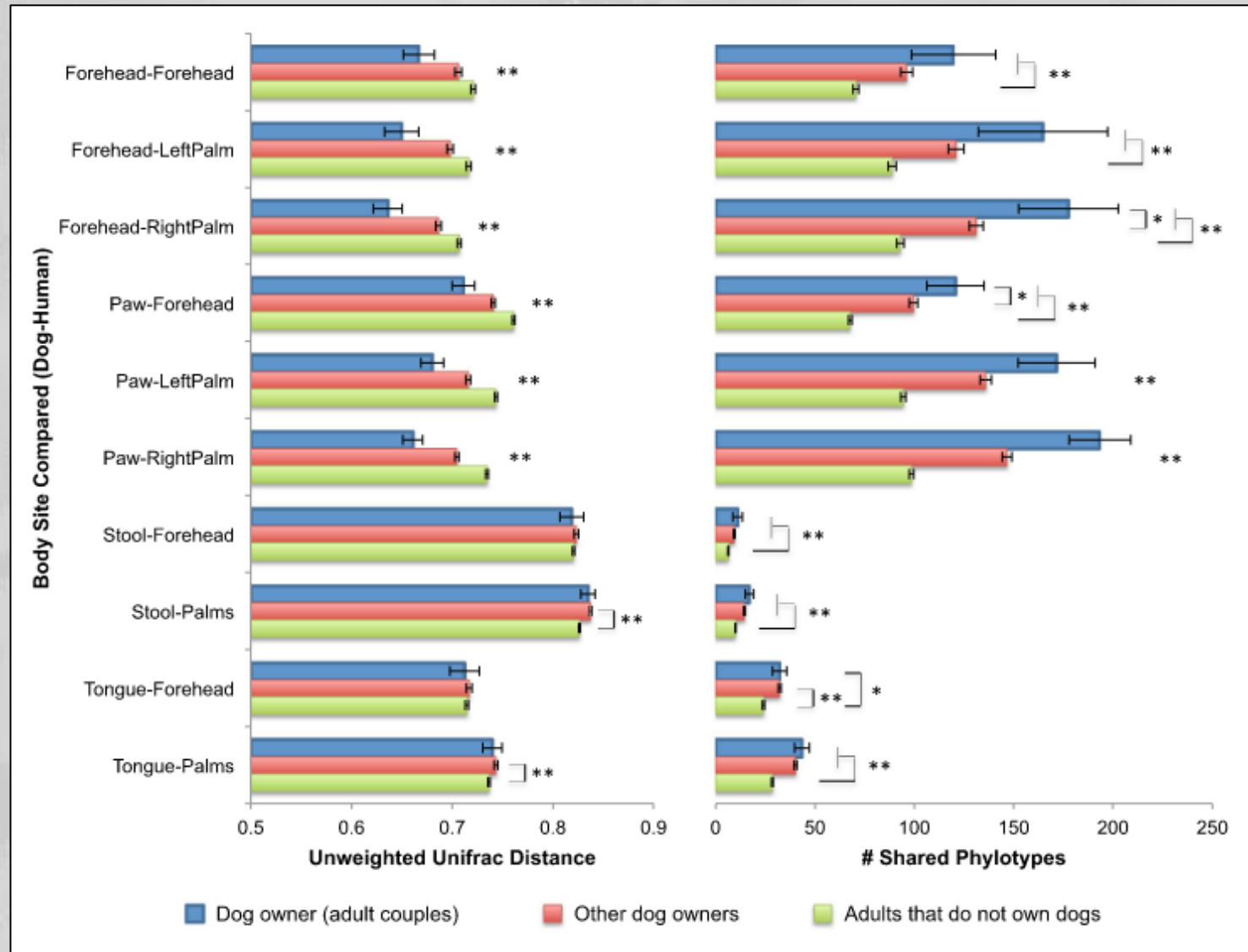


# What is this good for in the everyday practice?



## Cohabiting family members share microbiota with one another and with their dogs

Se Jin Song<sup>1</sup>, Christian Lauber<sup>2</sup>, Elizabeth K Costello<sup>3</sup>, Catherine A Lozupone<sup>4†b</sup>, Gregory Humphrey<sup>2</sup>, Donna Berg-Lyons<sup>2</sup>, J Gregory Caporaso<sup>5,6</sup>, Dan Knights<sup>7,8</sup>, Jose C Clemente<sup>4†a</sup>, Sara Nakielný<sup>9</sup>, Jeffrey I Gordon<sup>10</sup>, Noah Fierer<sup>1,2</sup>, Rob Knight<sup>11,12\*</sup>



**Thank you for your  
attention!**



I'm sorry, but the  
voices were telling me  
to eat that poop