Evolution of interactions between cognitive abilities and emotions in primates: Contributions of Artificial Intelligence

1) Contexte

In humans, most cognitive processes (perception, attention, reasoning, decision making, learning) have been shown to be affected by emotional state (De Houwer & Hermans, 2010). The links between emotions and cognition are thus well known in humans, in contrast to non-human primates. Rare studies in primate species (baboons, chimpanzees, japanese macaques, rhesus macaques) show that individuals tend to have their cognitive functions modified during learning tasks that include stimuli with negative emotional value. For example, japanese macaques (Macaca fuscata) are faster to detect threatening stimuli (snakes) than neutral stimuli (flowers) in a visual search task (Shibasaki & Kawai, 2009). A study on baboons (Papio papio) showed that the emotional value of mental representations, in the absence of physical stimuli, can also impact their cognitive processing (Blanchette et al., 2017). Furthermore, non-human primates have their own personality (Freeman & Gosling, 2010) and this is now known, as in humans (Bar-Haim et al. 2007), to affect cognition. Thus, the way in which animals' cognition is affected by emotions is likely to differ according to the personality of individuals (Carere & Lacurto, 2011).

The studies on the relation between emotion and cognition in primates are carried out on too few species not representative of the phylogeny. This prevents us from discussing the evolution of this interaction between emotion and cognition. In a previous study (Mortessagne et al., in prep.), we demonstrated that the interaction between emotion and cognition is already present in lemurs. Indeed, in a learning task, the performance of grey mouse lemurs (representative of primates' ancestors) is significantly modified by the nature of the cues presented (i.e., negative, positive, or neutral). The question is how this interaction evolved?

2) Objectives

Thus, the goal of this PhD project is to study the evolution of interactions between cognitive abilities and emotions in primates by exploring these interactions in controlled captive conditions. An exploratory study will also be conducted in the field condition to provide additional information on the interaction between emotion and cognition among individuals subjects, for example, to predation and competition for resources (food, sexual partner, etc.). Emotion will be quantified with a unique system based on the use of artificial intelligence (AI, collaboration with Raphaël Cornette, UMR 7205) using facial recognition algorithm. Our preliminary data in mouse lemur show very promising results with this algorithm which is already able to distinguish animals in stressful compared to non-stressful situations.

Such an innovative approach will allow us to address these questions:
1) how emotions impact primates' cognition according to their phylogenetic proximity?
2) what is the evolution of these interactions?
3) how these emotions and interactions with cognition differ according to the habitat (captive vs field)?

3) Methodology

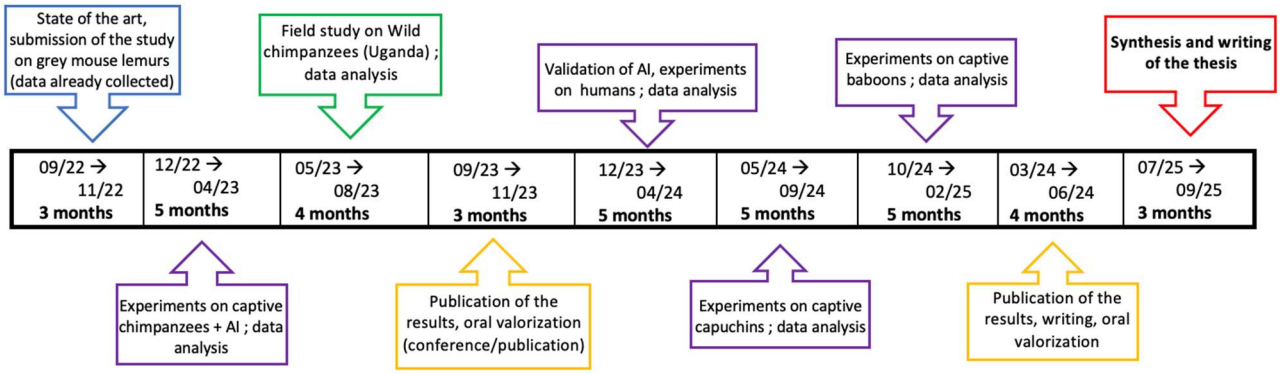
For this project, we will work on 5 species representatives of primates' phylogeny: lemurs, represented by the Microcebus murinus, a small prosimian primate with characteristics close to primate ancestors (Ezran et al., 2017), capuchins (Cebus capucinus), guinea baboons (Papio papio), chimpanzees (Pan troglodytes), and humans. We will work in collaboration with the station of Rousset, the zoological parks "La vallée des singes" and "Beauval" and the laboratory of psychology of the University Paris 8 (Jean-Luc Picq) for the studies on human subjects. Thus, to evaluate the direct link between emotional state and cognitive performance, learning and memory tests with cues of various emotional value will be conducted. The tests will be adapted according to the characteristics of each primate species. In parallel, tests and observations will be conducted to attest the personality of the individuals. For lemurs and capuchins, arboreal species, we will use cognitive tests allowing them to express their choice by jumping towards a target (which is in accordance with the ecology of the species). For the largest non-human primates, we will use screen-based cognitive tests in which their ability to identify the correct item according to its emotional value (positive or negative) will be evaluated. In addition, we will conduct a field study in Uganda to study chimpanzees (in collaboration with Sabrina Krief), in which we will carry out behavioral observations. We chose chimpanzees for our field study for several reasons: they are very expressive, are our phylogenetically closest relatives, are accessible for us in the wild (Uganda) due to long-time settled collaboration with Sabrina Krief, one of the leading chimpanzee specialists in Uganda. For this part of the project, we will carry out behavioral observations and identify the context in which these behaviors are observed. This will give clues about the emotional state of the individuals. We will then be able

to look at how emotions can influence activities requiring cognitive abilities such as social relationship, foraging... and thus study the interaction between emotion and cognition in the natural environment.

Finally, for humans, screen-based cognitive tests similar to those of the great apes will be conducted (Lacreuse et al., 2013). To assess personality, we will conduct the "Big Five" personality test, based on five major personality factors that define human personality and explain individual differences (openness, conscientiousness, extraversion, agreeableness, neuroticism) (McCrae & John, 1992).

For the exploratory part of this project, we will continue to develop the device based on AI to quantify the emotions of both captive and wild chimpanzees. For the individuals present in laboratory or in zoological parks we will present them with items with a negative, positive, or neutral emotional value. A camera will record movements of the mouth, eyes and ears and a deep learning AI based on facial recognition of emotions will be applied. For the wild individuals we will carry out observations of their behavior and will make video recordings with cameras. We will then apply the AI to detect possible emotional changes of primates in their natural habitat that we will relate to the behavioral observations.

The general organization and feasibility of the PhD project is summarized in the timeline below:



4) Expected results

Based on the existing literature and our hypotheses, we expect to quantify effects of personality and emotions on cognitive performance. For example, we expect to observe cognitive performance altered by cues with negative emotional value due to cognitive avoidance in processing negative stimuli (Blanchette et al., 2017). Also, as great apes can feel and expressing a wide range of complex emotions (such as empathy), we would expect the effects of emotions on cognition to differ between great apes' species and others. Finally, we expect that, in nature, individuals in a negative emotional state will also perform less well in tasks requiring complex cognitive abilities such as social relationships and foraging.

5) Project originality and interdisciplinarity

This original study offers a unique opportunity to analyze the complex interactions that exist between cognition and emotion, to put in a new light the evolution of these relationships in primates, as no studies to date has investigated this subject. Such a new approach will allow us to understand how cognition has evolved, to highlight the origins of these interactions (i.e., effects of emotions on cognition), to point out our possible human specificities and to put forward potential common mechanisms with other primates. Moreover, the development of an algorithmic tool capable of detecting even the most discrete emotions will be a major breakthrough in all animal studies. For the first time, we will obtain data on several species of primates, lemurs, great apes, humans and not only data in controlled captive environments but also in natural environments. This project is an excellent opportunity to throw a completely new light on the fascinating subject of animal emotions.

This project is resolutely interdisciplinary with neuroscience and behavioral sciences (emotion, cognition, ethology, psychology), biology (evolutionary biology, facial morphology) and informatics (AI, algorithmic tools, mathematics). All these disciplines are well known to the supervisors and collaborators involved. Moreover, the interdisciplinary aspect of this project is twofold since it is also reflected in its applications: fundamental (evolution & convergence) and applied. Indeed, understanding in detail the interaction between emotion and cognition in animals will have strong implications for scientific ethics (which judges ethical bias according to the potential ill-being of the animal during experiments) and animal welfare. This will demonstrate the need to maintain experimental animals in optimal conditions and in a positive emotional state to have more convincing results but also to improve the well-being of the animals. Moreover, the development of an AI capable of discriminating emotions directly in the natural environment would be a great advance in

the digital sciences but also in conservation and welfare. This also could be used, for example, to detect disorders in captive animals and thus take appropriate measures. For humans, considering negative emotions such as stress, but also the personality of young students, could allow us to understand the variations in cognitive performance between individuals and thus to improve and personalize education.

6) Suitability to the initiative/institute

This project is original, innovative, ambitious and allows us to move towards a better understanding and knowledge of a current, societal, and popular issues among the public. To do so, we will use an interdisciplinary approach, bringing together several disciplines and researchers from different backgrounds and expertise. This project is in accordance with the Biodiversity, Evolution, Ecology, Society Initiatives (IBEES). Indeed, it will bring new knowledge on the evolution of primates' cognition, a better understanding of animal emotions and the development of an algorithmic tool with multiple implications for example in conservation or in educational science. Moreover, this project has major societal issues: animal welfare, educational science, conservation of endangered species…

This project is also in line with the interest of the Sorbonne Central for Artificial Intelligence (SCAI) since it is an interdisciplinary project which involves complex data analysis and the use of Artificial Intelligence and algorithmic analysis to solve a major issue in primates' behavior.

7) Respective roles of the supervisors

This interdisciplinary project requires a set of skills in cognition, neuroscience, ethology, evolutionary biology, bioinformatics... It will be co-supervised by two supervisors from different backgrounds, and each will bring his expertise in the key subjects of the project. This will ensure a complementary and high-quality supervision and thus the feasibility of the project. Fabien Pifferi (BIOADAPT lab UMR 7179, MNHN) is an expert in cognitive neuroscience and Dalila Bovet (LECD UR3456) is an ethologist with an expertise in primates' behavior and social cognition. This project will also involve different collaborators such as Emmanuelle Pouydebat expert in animal behavior and evolution; Raphaël Cornette who will bring his expertise in bioinformatics or Sabrina Krief, lead expert of chimpanzee in Uganda.

Conclusion

This ambitious interdisciplinary project, at the frontier between evolutionary biology, neuroscience and mathematics, will involve three laboratories with perfect complementarities for the success of this project whose perspectives will be very broad, on the fundamental, applied and methodological levels.

Publications of the supervisors in line with the project

Bazin, ..., **Bovet**, 2018. Plos One.
Brunon, **Bovet**, Bourgeois, Pouydebat, 2014. Behavioural Processes.
Aimé, ..., **Bovet** et al., 2015. Animal Cognition.
Maak, ..., **Bovet** et al., 2017. Behavioural Processes.
Bovet & Vauclair., 2001. Psychonomic Bulletin & Review.
Hozer & **Pifferi**., 2021. Chronobiol Int.
Chaudron, **Pifferi** et al., 2021. Am J Primatol.
Tia & **Pifferi**., 2021. Front Syst Neurosci.
Nourizonoz…, **Pifferi** et al., 2020. Nat Methods.

Profile of the desired candidate

The successful candidate should have a strong motivation for interdisciplinarity, as well as a good team spirit and be autonomous. He/She should also have a great capacitý to analyze complex datasets and ideally experience with algorithms or AI. Finally, the candidate must have great knowledge of primates, their cognition, their behaviors... Experience with primates is also a great advantage.

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