ECR Spotlight – Frederik Püffel

ECR Spotlight is a series of interviews with early-career authors from a selection of papers published in Journal of Experimental Biology and aims to promote not only the diversity of early-career researchers (ECRs) working in experimental biology during our centenary year but also the huge variety of animals and physiological systems that are essential for the ‘comparative’ approach. Frederik Püffel is an author on ‘Strong positive allometry of bite force in leaf-cutter ants increases the range of cuttable plant tissues’, published in JEB. Frederik is a Postdoc in the lab of David Labonte at Imperial College London, UK, investigating biomechanical systems across animals of different sizes.

Describe your scientific journey and your current research focus
My scientific journey started during my undergraduate course in Biomimetics (in Bremen, Germany), where I was first exposed to experimental work in the context of human physiology, animal locomotion and the mechanical characterisation of biological materials. As part of the degree, I spent one semester abroad (in Cambridge, UK), where I turned my attention to the field of insect biomechanics, investigating the cutting mechanics of leaf-cutter ant mandibles. Building on that, I started a PhD on the biomechanics of the insect bite apparatus in the Evolutionary Biomechanics group at Imperial College London, in 2018, supervised by David Labonte. I passed my PhD viva in March 2023.

My current research revolves around the physical boundaries of insect herbivory – the ability of insects to produce sufficiently large bite forces, transmitted via sufficiently sharp mandibles, to feed on tough plant materials.

How would you explain the main finding of your paper to a member of the public?
Leaf-cutter ants live in colonies with up to several million workers, all in a single nest. Despite all workers being biological siblings, they look strikingly different. Some ants are very small, weighing less than a single milligram, while others are 200 times bigger. Not only does body size vary across workers, their preferences vary too. Smaller workers cut and carry softer leaves, and only large workers harvest tough plants. In this study, I determined the ability of differently sized leaf-cutter ant workers to cut leaves, so establishing a link between a common phenomenon and the underlying mechanics of plant feeding. To this end, I measured the peak bite forces leaf-cutter ant workers can generate with their muscle-driven jaws. I found that (i) leaf-cutter ants of all sizes produce exceedingly high bite forces given how small they are. Some ants bite as strongly as other animals which are 20 times heavier; they produce forces large enough to lift an entire apple (∼100 g), with a body mass of only 50 mg. (ii) Across the large range of worker sizes, the largest workers bite the strongest. This may not be a surprising result at first, but we found that large workers bite not only stronger but disproportionally stronger than small workers. The muscle–jaw complex of large workers differs from that of small workers such that it produces 250% of the expected bite force; this adaptation to generate even larger bite forces is necessary to cut the tough vegetation of the tropical rainforest these ants call their home.

What are the potential implications of this finding for your field of research, and is there anything that you learned during this study that you wish you had known sooner?
I hope that the findings of this paper will inform and promote the discussion about insect specialisation (both morphological and physiological) to cope with the biomechanical challenges of their environments. This paper may also be of practical interest to researchers who aim to design similar experimental setups to measure forces of small insects.

One thing that I wish I had known earlier is how strongly the mandibular opening angle affects bite force. Bite forces in leaf-cutter ants peak when mandibles almost overlap, but they are only a fraction of this peak at large opening angles. Because mandible opening is difficult to control experimentally, extracting peak bite forces was particularly challenging in this project. We solved this problem by incorporating a rather involved correction to rescale our measured forces, based on biomechanical modelling, morphometric analysis and force measurements across a range of opening angles.

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Which part of this research project was the most rewarding/challenging?
Perhaps surprisingly, the most challenging aspect of this project was not the experimental part. The ants bit quite eagerly (or angrily) onto the sensor, allowing me to collect experimental data with relative ease. The most challenging part was the analysis and correction I described above. On the flip side, the most rewarding element then was to see how this post-analysis ‘improved’ our data, substantially increasing the coefficient of determination of the regression model, and bringing the experimental data much closer to the predictions from morphology.

Why did you choose JEB to publish your paper?
JEB is one of the key journals in my field. As described below, multiple JEB papers informed my experimental choices and provided key findings to compare my results with. JEB was thus a natural choice, further encouraged by the fact that neither the reference list nor the methods section counts towards the overall word limit. This may appear trivial but I find it important to acknowledge all relevant work from a continuously growing body of literature, without restrictions due to journal policies. A thorough documentation of methods is essential for other researchers to replicate experimental protocols and analyses. After all, replication sits at the very core of the self-correcting ability that makes science (arguably) unique.

Are there any modern-day JEB papers that you think will be the classic papers of 2023?
I really enjoyed reading the Review by Mendoza et al. (2023) on muscle physiology (‘The importance of comparative physiology: mechanisms, diversity and adaptation in skeletal muscle physiology and mechanics’; doi:10.1242/jeb.245158). The authors not only paid due diligence to the vast amount of work that has accumulated but also highlighted the substantial gaps of knowledge that still exist in the field. I could imagine this Review to serve as a guideline for future experimental work in this area of research.

What do you think experimental biology will look like 50 years from now?
It is difficult to imagine any field of experimental research that will not be strongly affected by advances in technology in the next 50 years. In experimental biology, more specifically, I expect fundamental changes in how we collect experimental data. The development of cheap but accurate sensors may allow us to collect more data in the field, including regions that were previously inaccessible, via autonomous robots. Advances in computer technology and data processing may enable us to collect and integrate complex data in real time; such developments may fundamentally redefine our approaches to behavioural research. Some data may be collected via crowdsourcing where non-scientists can contribute with their own devices using customised applications; crowdsourcing may substantially increase otherwise strongly limited sample sizes. The community of experimental biologists is widely spread across the globe, their work is increasingly interdisciplinary, and it profits from frequent scientific exchange and international collaboration. The future of experimental biology will thus also be determined by politics and the extent to which open science will be promoted, established and maintained.

If you had unlimited funding, what question in your research field would you most like to address?
Many insects use their bite apparatus to feed on plants, including some of the most hazardous pest species. Studying the species-specific biomechanical interactions between insect pests and their host plants could yield important insights into desirable plant mechanical traits to ultimately enhance crop resistance. With sufficient funding, a thorough investigation of such interactions could be conducted involving the biomechanical characterisation of both plant materials and bite apparatus; these studies may provide answers to questions such as: how strongly can the most hazardous insect pests bite?; how much force do they need to fracture the relevant plant tissues?; what plant properties can induce mandibular wear?; and can the musculoskeletal development of the insect be altered to reduce feeding rates?

What’s next for you?
I will continue my postdoc in the Evolutionary Biomechanics group at Imperial College London for another 6–12 months. During this time, I will apply for other postdoctoral research opportunities and research fellowships in STEM.

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