CV – Dr. Anna Verbe

Personal Information:
E-mails: anna.verbe@cnrs.fr, anna.verbe@outlook.com,
Website: http://anna.verbe.free.fr/
Social media: Google Scholar, LinkedIn, ResearchGate, Github and ORCiD: 0000-0003-3121-0214

Current position:
Postdoctoral Fellow, Claire Eschbach team on Recurrent Circuits, Learning and Memory.
Institut NeuroPSI - UMR9197
CNRS Université Paris-Saclay
Campus CEA Saclay
Saclay, FRANCE

Research interests:
Insects, Sensory systems, Mechanosensors, Neuroethology, Locomotion, Biomimicry.

Knowledge:
- Theoretical skills: Behaviour, Mechanosensors, Locomotion, Insects, Control theory, Neurosciences, Optogenetics, Connectomics, Fruit flies' genetics.
- Technical skills: Setup building, Fast camera, Calcium imaging, 2-photon, Optogenetics, In-vivo and Ex-vivo recording, Dissection, Small electronics, 3D printing and laser cutting.
- Coding: Python, Matlab, R, C++, HTML, CSS,
- Computer skills: Deeplabcut, ImageJ, Tracker, Adobe Illustrator, Photoshop and Premiere Pro, Blender, 3D Autodesk Fusion 360,

Professional experience:
01/06/2024 to present: Postdoctoral Scholar, Advisor: Dr. Claire Eschbach. Team Recurrent Circuits, Learning and Memory. NeuroPSI. Paris Saclay University. France. Project title: 'Developing 2-photon imaging with in vivo optogenetic stimulation of the larval brain of *Drosophila melanogaster*.'
01/05/2022 – 30/04/2024: Postdoctoral Scholar, Advisor: Dr. Bradley Dickerson. Dickerson's lab, Princeton Neuroscience Institute; Princeton University, Princeton, NJ, USA. Project title: 'Functional Stratification of Sensory Encoding in a Biological Gyroscope.'
01/10/2017- 12/03/2021: Ph.D student , Advisor: Dr. Stéphane Viollet and Prof. Jean-Louis Vercher. Bio-inspired Systems (SBI) team, Institute of Movement Sciences, Marseille, France. Project title: 'Aerial righting reflex of hoverflies.'
01/01/2017 - 30/06/2017: master's internship second year. Advisors: Prof. Jérôme Casas and Mcf. Miguel Piñeirua Menendez. IRBI – Tours (6 months). Project title: 'The effects of the pressure exerted by the legs on the locomotion performance of an insect on sandy slopes.'
01/02/2016 – 30/04/2016: master's internship first year. Advisor: Prof. Claudio Lazzari. IRBI – Tours (3 months). Project title: 'Response of male Aedes aegypti to signals associated with vertebrate hosts and females.'

Education:
01/10/2017- 12/03/2021: PhD in movement science, supervised by Dr. Stéphane Viollet and Prof. Jean-Louis Vercher. Bio-inspired Systems (SBI) team, Institute of Movement Sciences, Marseille, France.
01/09/2015 – 30/06/2017: master's degree in Behavioural Ecology, Evolution and Biodiversity. François Rabelais University, Tours, France
01/09/2012 – 30/06/2015: bachelor's degree in sciences - Integrative and Evolutionary Biology. François Rabelais University, Tours, France.

Overview of publications:
5 peer-reviewed journal publications, 3 in first author, and 1 additional first-author paper in preparation.

Peer-reviewed journal publications:
2024 - Verbe A., Lea K., Fox J., and Dickerson B. Flies tune the activity of their multifunctional gyroscope. *Current Biology.* (Cited 1 time).
Summary: Members of the order Diptera, the true flies, are among the most manoeuvrable flying animals. These aerial capabilities are partially attributed to flies' possession of halteres, tiny club-shaped structures that evolved from the hindwings and play a crucial role in flight control. Halteres are renowned for acting as biological gyroscopes that rapidly detect rotational perturbations and help flies maintain a stable flight posture. Additionally, halteres provide rhythmic input to the wing steering system that can be indirectly modulated by the visual system. The multifunctional capacity of the haltere is thought to depend on arrays of embedded mechanosensors called campaniform sensilla that are arranged in distinct groups on the haltere's dorsal and ventral surfaces. Although longstanding hypotheses suggest that each array provides different information relevant to the flight control circuitry, we know little about how the haltere campaniforms are functionally organized. Here, we use in vivo calcium imaging during tethered flight to obtain population-level recordings of the haltere sensory afferents in specific fields of sensilla. We find that haltere feedback from both dorsal fields is continuously active, modulated under closed-loop flight conditions, and recruited during saccades to help flies actively manoeuvre. We also find that the haltere's multifaceted role may arise from the steering muscles of the haltere itself, regulating haltere stroke amplitude to modulate campaniform activity. Our results underscore the crucial role of efferent control in regulating sensor activity and provide insight into how flies' sensory and motor systems coevolved. *Contribution*: I did the conceptualization, methodology, software, validation, formal analysis, investigation, resources, data curation, writing and visualization.

Dispatch on the paper from Current biology by Michael Dickinson: Animal flight: Fly gyros get a new spin. DOI: 10.1016/j.cub.2024.07.035

2023 – Piñeirua M., Verbe A. and Casas J., Substrate-mediated leg interactions play a key role in insect stability on granular slopes. *Physical Review E.*

Summary: Locomotion on granular inclines is a subject of high relevance in ecological physics as well as in biomimetics and robotics. Enhancing stability on granular materials represents a huge challenge due to the fluidization transition when inclination approaches the avalanche angle. Our motivating example is the predator-prey system made of the antlion, its pit, and its prey. Recent studies have demonstrated that stability on granular inclines strongly depends on the pressure exerted on the substrate. In this work, we show that for multilegged locomotion, along with pressure, the distance between the leg contacts on the substrate also plays a major role in the determination of the stability threshold. Through a set of model experiments using artificial sliders, we determine a critical distance below which stability is importantly affected by the interactions between the perturbed regions generated by each contact point. A simple model based on the Coulomb method of wedges allows us to estimate a stability criterion based on pressure, inter-leg distance, and substrate characteristics. Our work suggests that mass-to-leg-length allometric relationships, such as the ones observed in ants, may be an important key in determining the locomotion success of multilegged locomotion on granular inclines. *Contribution*: I conducted preliminary experiments and helped draft the manuscript.

2023 – Verbe A., Martinez D. and Viollet S. Sensory fusion in the hoverfly righting reflex. *Scientific reports.*
Summary: We study how falling hoverflies use sensory cues to trigger appropriate roll-righting behaviour. Before being released in a free fall, flies were placed upside-down with their legs contacting the substrate. The prior leg proprioceptive information about their initial orientation sufficed for the flies to right themselves properly. However, flies also use visual and antennal cues to recover faster and disambiguate sensory conflicts. Surprisingly, in one of the experimental conditions tested, hoverflies flew upside-down while still actively flapping their wings. In all the other conditions, flies were able to right themselves using two roll dynamics: fast (~50ms) and slow (~110ms) in the presence of consistent and conflicting cues, respectively. These findings suggest that a nonlinear sensory integration of the three types of sensory cues occurred. A ring attractor model was developed and discussed to account for this cue integration process. *Contribution:* I did the methodology, software, validation, formal analysis, investigation, resources, data curation, writing and visualization.

2020 – Verbe A., Varennes L., Vercher J-L, and Viollet S., How do hoverflies use their righting reflex? *Journal of Experimental Biology.* (Cited 12 times).
Summary: When taking off from a sloping surface, flies must reorient themselves dorsoventrally and stabilize their body by actively controlling their flapping wings. We have observed that righting is achieved solely by performing a rolling manoeuvre. How flies manage to do this has not yet been elucidated. It was observed here for the first time that hoverfly reorientation is entirely achieved within 6 wingbeats (48.8ms) at angular roll velocities of up to 10 000°/s and that the onset of their head rotation consistently follows that of their body rotation after a time lag of 16ms. The insects' body roll was found to be triggered by the asymmetric wing stroke amplitude, as expected. The righting process starts immediately with the first wingbeat and seems unlikely to depend on visual feedback. A dynamic model for the fly's righting reflex is presented, which accounts for the head/body movements and the time lag recorded in these experiments. This model consists of a closed-loop control of the body

roll, combined with a feedforward control of the head/body angle. During the righting manoeuvre, a strong coupling seems to exist between the activation of the halteres (which measure the body's angular speed) and the gaze stabilization reflex. These findings again confirm the fundamental role played by the halteres in both body and head stabilization processes. *Contribution*: I did the methodology, software, validation, formal analysis, investigation, resources, data curation, writing and visualization.

2018 – Goulard R., Verbe A., Vercher J-L, and Viollet S., Role of the light source position in freely falling hoverflies' stabilization performances. *Biology Letters*. (Cited 6 times).
Summary: The stabilization of plummeting hoverflies was filmed and analysed in terms of their wingbeat initiation times as well as the crash and stabilization rates. The flies experienced near-weightlessness for a period that depended on their ability to counteract the free fall by triggering their wingbeats. In this paradigm, hoverflies' flight stabilization strategies were investigated here for the first time under two different positions of the light source (overhead and bottom lighting). The crash rates were higher in bottom lighting conditions than with top lighting. In addition, adding a texture to the walls reduced the crash rates only in the overhead lighting condition. The position of the lighting also significantly affected both the stabilization rates and the time taken by the flies to stabilize, which decreased and increased under bottom lighting conditions, respectively, whereas textured walls increased the stabilization rates under both lighting conditions. These results support the idea that flies may mainly base their flight control strategy on visual cues and particularly that the light distribution in the visual field may provide reliable, efficient cues for estimating their orientation concerning an allocentric reference frame. In addition, the finding that the hoverflies' optic flow-based motion detection ability is affected by the position of the light source in their visual field suggests the occurrence of interactions between movement perception and this visual vertical perception process. *Contribution*: I conducted experiments and helped draft the manuscript.

Paper in preparation:
Verbe A., Engels T., Viollet S. (in prep) Passive stabilization in freely falling hoverflies. their legs contacting the substrate. The prior leg proprioceptive information about their initial orientation sufficed for the flies to right themselves properly. However, flies also use visual and antennal cues to recover faster and disambiguate sensory conflicts. Surprisingly, in one of the experimental conditions tested, hoverflies few upside-down while still actively flapping their wings. In all the other conditions, flies were able to right themselves using two roll dynamics: fast (∼50ms) and slow (∼110ms) in the presence of consistent and conflicting cues, respectively. These findings suggest that a nonlinear sensory integration of the three types of sensory cues occurred. A ring attractor model was developed and discussed to account for this cue integration process. *Contribution*: I drew up the research project, performed the experiments, analyzed the data; performed the simulations and wrote the paper.

Funding:
08/2024 - Travel fellowship from BISCIT. ($2000)

01/2024 - Travel fellowship from The Society for Integrative & Comparative Biology (SICB). ($600)
01/10/2017 – 31/12/2020 Graduate fellowship from Aix-Marseille University (46000euros)

Awards: Two best posters prizes from the international student course in behavioural biology (IFE), Paris, France, 2019 and from the Institute of Movement Science Doctoral Day (JED), Marseille, France, 2019

Conference and workshop title:
2024 – BioInspired Sensing Computing and Control with International Teams - BISCITs workshop, London, UK. **Invited Keynote Talk.** Title: Flies tune the activity of their multifunctional gyroscope.
2024 – The Society for Integrative & Comparative Biology (SICB), Seattle, USA. **Keynote Talk.** Title: "Functionally stratified encoding on Drosophila halteres".
2023 – GRC, Gordon Research Conference. Neuroethology: Behavior, Evolution and Neurobiology. USA, **Poster**. Title: "Functionally stratified encoding on Drosophila halteres".
2023 – GRS, Gordon Research Seminar. Neuroethology: Behavior, Evolution and Neurobiology. USA, **Poster**. Title: "Functionally stratified encoding on Drosophila halteres".
2023 – SOAR/BISCIT workshop, Washington DC, USA. **Lighting Talk**. Title: "Sensory Encoding of Drosophila's halteres".
2022 – Conference on the Structure and Function of the Insect Central Complex, Janelia, USA. **Keynote Talk**. Title: "Nonlinear sensory fusion in the hoverfly righting reflex: a ring-attractor-based model".
2021 – Conference from the Société Francaise pour l'Etude du Comportement Animal (SFECA), Online. **Virtual Presentation.** Title: "A study of aerial righting reflex in hoverflies *Episyrphus balteatus*".
2020 – Animal Behaviour Live, online. **Virtual Poster**. Title: "A study of aerial righting reflex in hoverflies *Episyrphus balteatus*".
2019 – Interdisciplinary Day, Marseille, France. **Invited Keynote Talk and Poster**. Title: "A study of aerial righting reflex in hoverflies *Episyrphus balteatus*".
2019 – International student course in behavioural biology (IFE), Paris, France. **Poster**. Title: "A study of aerial righting reflex in hoverflies *Episyrphus balteatus*".
2019 – Institute of Movement Science Doctoral Day (JED), Marseille, France. **Poster**. Title: "A study of aerial righting reflex in hoverflies *Episyrphus balteatus*".

Teaching:
Total of 4 hours to undergraduates as a Postdoctoral scholar at Princeton Neuroscience Institute (2023)
Total of 171 hours to undergraduates as a Teaching Assistant during my PhD.
2017-2018:

- Behaviour and evolution, 15h, Undergraduate course.
- Building a personal project, 48h, Undergraduate course.

2018-2019:

- Neuroscience course, 32h, Undergraduate course.
- Career guidance,20h, Undergraduate course.

2019-2020:

- Neuroscience course, 16h, Undergraduate course.
- Career guidance, 20h, Undergraduate course.
- Statistics, 20h, Undergraduate course

Mentoring:

2024 – now: Advising of three undergraduate students (2 master students and 1 Licence student)

2022-2024: Advising of two undergraduate students and four graduate students at Princeton University. Reference of one graduate student: Serene Dhawan, sd9695@princeton.edu

2018: Co-advising of one master's student at Aix-Marseille University.

Volunteering activities:

- Co-organisation of the Invertebrate Neuroscience Journal Club (2022 to 2024) – Princeton Neuroscience Institute.
- Co-organization of the Institute of Movement Science Doctoral Day (JED) of 2019.
- Vice-president of the Ph.D. Student Association - 3 years (2017 to 2019).
- Vulgarisation at the Science Day of Marseille in 2017

Major accomplishments:

My research has consistently expanded our knowledge in the understanding of insect neural circuits, from the stepping pattern of insects walking in granular materials, the throughout study of hoverflies' righting reflex and the related sensors implicated, the functional stratification of sensory encoding in a biological gyroscope, to the fine study of dopamine neurons activity in decision making and flexible memory.

<u>During my Ph.D</u>. I worked on the righting of winged insects (Hoverflies) from an upside-down to a right-side-up position. Hoverflies feature stunning aerial capabilities allowing them to orient themselves in various positions and orientations. Flies can land on surfaces no matter how tilted they may be, they can even settle upside down on the ceiling. When taking off from the tilted surface, flies must reorient dorsoventrally and stabilize body roll via active control of their flapping wings. Righting reflex has been shown to exist in mammalian and wingless insects but was never studied in winged insects at that time.

After being released upside-down and dropped in free fall, I observed for the first time that hoverflies systematically rotate their body in roll once the wingbeats are triggered. I showed that the aerial righting reflex is achieved by *Episyrphus balteatus* in 45.8ms (median value) within 6 wingbeats and by *Eristalis tenax* in 69.19ms. As expected, a wing asymmetric stroke amplitude is at the origin of the body righting. I showed for *Episyrphus balteatus* that the body rotates first at maximum roll speed as fast as 10 000°/s and then that head rotates after a time lag of 16ms (median value) at a similar angular speed. We developed a dynamic model of the righting reflex that accounts for head-body response by implementing a closed-loop control of both head and body combined with a feedforward control of the head-body angle.

The feedforward control of the head orientation from the body angular speed, provided by the halteres, introduced a time lag between the head and body, which was coherent with the fly's response. Our model suggests that a closed-loop control of both body angle and body speed merged with a fast head stabilization reflex, is at work at an early stage during the righting process. The model also suggests that halteres are involved both in body and head roll rate and roll angle control. These results highlight the strong coupling existing between the activation of the halteres and gaze (head) stabilization reflex. Further tests tend to confirm it (e.g., experiments with halteres loaded with a drop of glue). **(Verbe et al., 2020)**

I then studied how falling hoverflies use sensory cues to trigger appropriate roll-righting behaviour. Before being released in a free fall, flies were placed upside-down with their legs in contact with the substrate. The prior leg proprioceptive information about their initial orientation sufficed for the flies to right themselves properly. However, flies also use visual and antennal cues to recover faster and disambiguate sensory conflicts. Surprisingly, in one of the experimental conditions tested, hoverflies flew upside-down while still actively flapping their wings. In all the other conditions (e.g., in the dark or with only the light coming from below), flies were able to right themselves using two roll dynamics: fast (~50ms) and slow (~110ms) in the presence of consistent and conflicting cues, respectively. These findings suggest that a nonlinear sensory integration of the three types of sensory cues occurred. A ring attractor model was then developed and discussed to account for this cue integration process. **(Verbe et al., 2023)**

As a postdoc in Bradley Dickerson's lab at Princeton Neuroscience Institute, I worked on the neurobiology of a specific Dipteran species linked to a strong genetic toolkit, the fruit fly *Drosophila melanogaster*. Flies have developed elegant solutions to navigate their environment. One of the reasons for Dipterans' flight abilities comes from the halteres, a specialized mechanosensory organ known to be the only biological gyroscope. Recent work shows that the haltere also provides crucial timing information to the flight circuit on a stroke-by-stroke basis via modulation of a set of tiny muscles that are inserted at the base of the haltere. This sensory input helps structure the timing of the steering muscles, which ultimately control wing motion and aerodynamic force production. Halteres are covered in arrays of strain-sensitive mechanosensors known as campaniform sensilla, that are arranged in distinct groups on the dorsal and ventral aspects of the haltere and may exhibit different directional sensitivities. However, due to the difficulty of studying the haltere–a tiny moving structure–during flight, this longstanding hypothesis remains untested. Using a genetically encoded calcium indicator expressed in the haltere afferents of Drosophila, my goal was to uncover how sensory information is encoded by these arrays during visually mediated flight manoeuvres.

I developed an experimental setup to record the activity changes in the dorsal haltere campaniforms during tethered flight while presenting flies with an array of visual motion stimuli. To do this, I imaged through the cuticle of the haltere with a standard epifluorescent microscope, all while leaving the animal intact. I found that during wide-field visual motion, haltere campaniform sensilla activity is modulated throughout the flight. Additionally, during spontaneous turning events termed saccades, each dorsal field is recruited prior to the turning event. This result suggests that, in addition to their previously known role in terminating active turns, halteres are implicated in triggering saccades. Finally, saccade amplitude appears to be correlated with the level of campaniform field recruitment. Specifically, this relationship appears to be nonlinear as larger changes in ipsilateral wingstroke amplitude are correlated with increases in campaniform field fluorescence. In conclusion, these results support the hypothesis that the haltere steering muscles of Drosophila receive descending visual input, suggesting that flies, through the halteres, may tune the strength of haltere mechanosensory feedback to achieve flight turns. My results demonstrate the crucial role of biomechanics in determining the dynamic range of sensors so that they can mediate manoeuvres for both stabilization and active manoeuvres. **(Verbe et al. 2024)**

In the meantime, I worked on the ascending connectivity between the haltere and neck. It has been postulated that gaze stabilization, essential to stable flight, is facilitated by ascending mechanosensory information from the haltere We however lack evidence for such a circuit. To bridge this gap in our understanding, I used electron microscopy connectomics to map the synaptic connectivity between the haltere sensory afferents and those motor neurons responsible for head steering movements. In parallel, I developed custom machine vision software to quantify 3-dimensional head movements in tethered flies and will implement it in my previous rig to correlate haltere activity with gaze.

As a Postdoc in Dr. Claire Eschbach's team in NeuroPSI Paris-Saclay, I am now studying the formation of flexible memory as a key ability to track the value of a choice outcome for adaptive decisions in dynamic environments. I am looking at how brain circuits compute such values in the larval brain of *Drosophila melanogaster*. Drosophila larvae uniquely allow a combination of sophisticated, multi-scale, approaches. With online tracking, specific genetic targeting of neurons (to e.g. activate, silence, or image neuronal activity), computational modelling of networks, and the use of a detailed connectome as a road map, we can study the way recurrent networks implement reinforcement learning to an unprecedented level of precision. Using these advanced neurogenetics approaches I am recording specific dopamine neuron activity, both Calcium and dopamine release (a red fluorescent GPCR-activation–based dopamine sensors, GRABDA), using 2-photon microscopy either with the larva brain in-vivo (agar technique) or ex-vivo. First, I am looking at surprisingly inerrant activity fluctuations depending on the dopamine neuron. Associated with optogenetics and pharmacological stimulation I want to identify the identity of each neuron and how those inerrant fluctuations impact behaviour. Secondly, I am quantifying the dopamine realise when a neuron receives different levels of optogenetic activation. This will help us better understand larva behaviour when experiencing optogenetic activation and will be a base for further studies. On the other hand, I am helping in the making of a decision-making Y maze, with odour release, to quantify decisions while optogenetically activating specific neurons.

Membership in professional societies:

- Society for Integrative and Comparative Biology (SICB), member.
- Société Française pour l'Etude du Comportement Animal (SFECA), member.
- BioInspired Sensing Computing and Control with International Teams (BISCCITs), member.

- International Society for Neuroethology (ISN), member.

References:

Dr. Bradley Dickerson, Assistant Professor, Princeton Neuroscience Institute, Princeton University, Princeton, NJ, USA bdicker@princeton.edu. + 1 609-258-3510. ORCID: 0000-0002-1185-3223
Dr. Stéphane Viollet, CNRS Research Director - Head of the Bio-inspired Systems (SBI), Institute of Movement Sciences, Marseille, France. stephane.viollet@univ-amu.fr. (+33)4.91.26.61.25. ORCID: 0000-0003-1585-9822
Dr. Claire Eschbach, head of Circuits récurrents, apprentissage et mémoire team at NeuroPSI Paris Saclay. claire.eschbach@universite-paris-saclay.fr. +33(0)1 69 82 34 48. ORCID : 0000-0002-8092-3440
Pr. Claudio Lazzari, CNRS, IRBI, PEC team, Tours, France claudio.lazzari@univ-amu.fr. +33(0)247367389. ORCID: 0000-0003-3703-0302