Incorporating Sleep Biology into AI: Enhancing Learning in Artificial Neural Networks

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Introduction

This project explores the integration of sleep biology insights into the development of advanced deep-learning systems, specifically targeting Artificial Neural Networks (ANNs). The research leverages the architectural similarities between ANNs and the honeybee brain to improve AI capabilities in continual learning, knowledge generalization, and task transfer. By characterizing multi-phasic sleep patterns in honeybees, both in vivo and through biophysical models, the project aims to uncover fundamental principles of sleep's role in memory consolidation, which are then applied to enhance AI algorithms.

Goals and Objectives

Characterize Bee Antennal Movements: Analyze and classify the antennal movements of bees, focusing on attributes related to sleep, pre-sleep behavior, and post-sleep behavior.

Develop Classification System: Create a robust system to categorize all observed antennal movements into specific behavioral characteristics, aiding in the precise study of bee sleep patterns.

Assess Memory Retention: Evaluate the memory retention of bees under conditions of undisturbed sleep versus induced sleep disturbances to understand the impact of sleep quality on learning and memory.

Challenges

Behavior Consistency: Ensuring behaviors observed in the lab reflect natural conditions.

Software Selection: Choosing between DeepLabCut and SLEAP for tracking antennal movements.

Odor Delivery: Implementing an automatic system for consistent sleep disturbance experiments.

Methodology

Our research focuses on understanding the mechanisms of sequential learning and memory recall in bees, specifically examining the role of sleep in olfactory memory. In our experiments, bees are trained to associate certain scents with rewards. Their memory recall is tested under two conditions: after a full night's undisturbed sleep and following intermittent sleep disruption.

To monitor and analyze sleep patterns and other behaviors, we use SLEAP, a machine learning tool that captures real-time video frames to analyze antennal movements. This tool classifies different types of movements and pulls in keypoint data, comparing it to trained data to determine whether the bee is awake or asleep. When a bee is detected as sleeping, the system, powered by a Nvidia Jetson Nano, can induce sleep disturbances based on the experimental requirements. This approach allows us to gather insights into the cognitive processes involved in scent learning and memory in bees.

Results

I. Quantification of sleep phases in honey bees by monitoring antenna movements

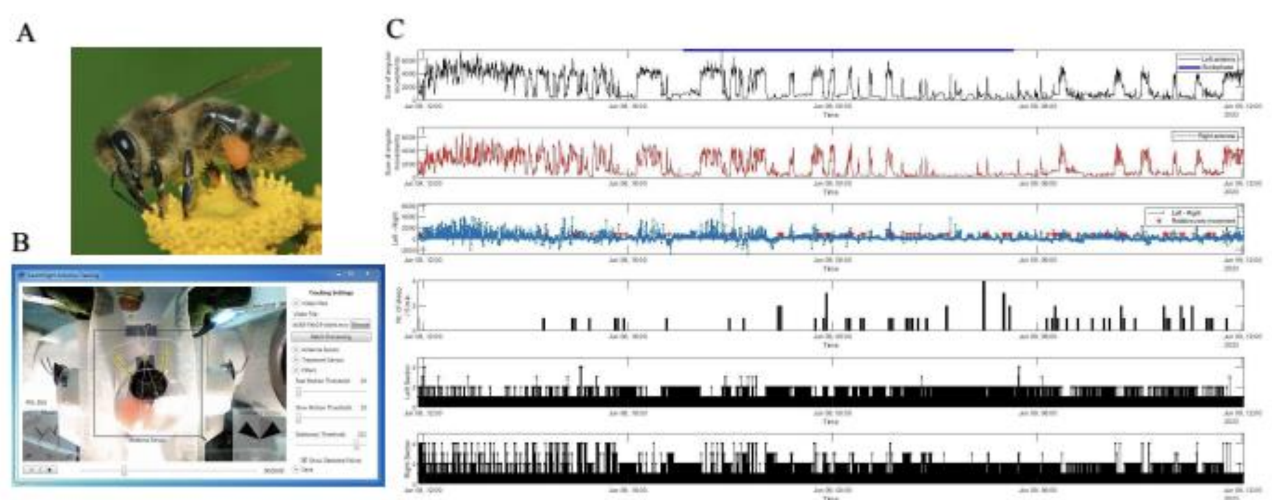


Fig.1 Identification of sleep phases. A. The honey bee, *Apis mellifera*. B. Software for quantifying antennal movements (SwarmSight.org). Bee antennae are automatically tracked (yellow pixels). Their positioning and moving speed are calculated based on pixel dimensions. C. Continuous recording over 24 hrs showing low or no-movement periods of various durations on left and right antenna (top two panels). The blue line indicates scotophase (sunset to sunrise). Middle two panels show identified sleep events (asterisks). Bottom two panels show left and right antenna positions during 24 hrs.

II. Ethograms derived from antenna movement data

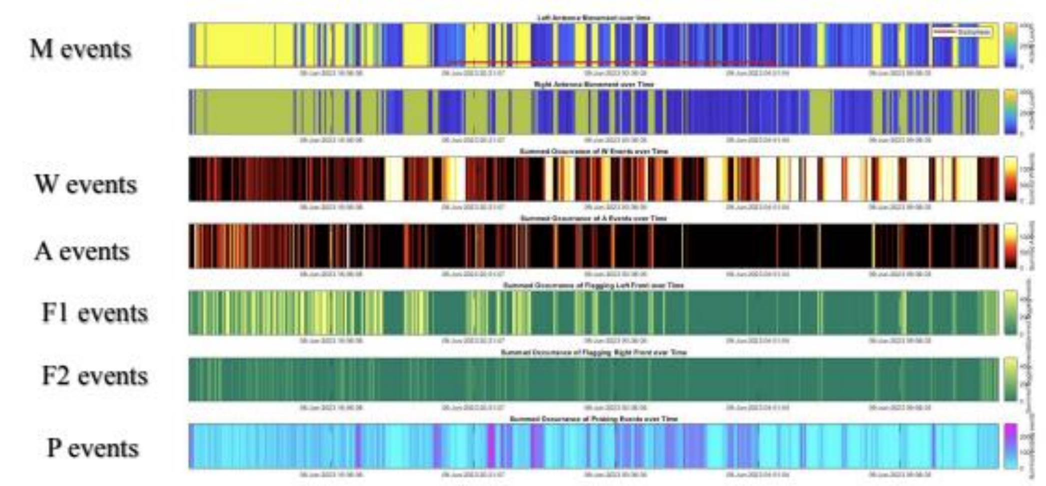
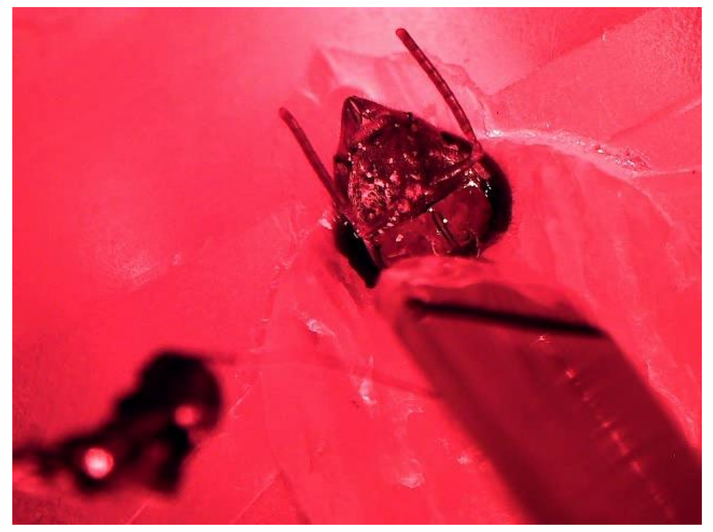
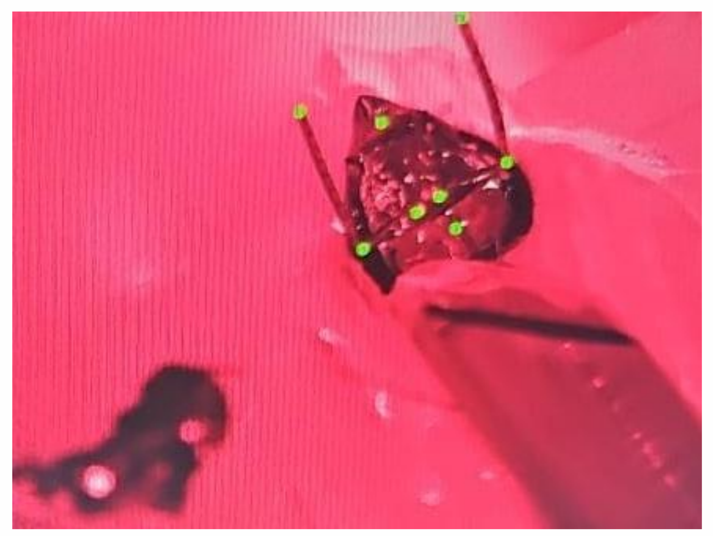


Fig. 2 Sleep associated events on left and right antenna. M: antenna moving speed (left and right); W: antennae shaping as W; A: antennae shaping as letter A; F1: antennae shaping as flagging with left antenna at front; F2: antennae shaping as flagging with right antenna at front; P: random movements;



A



B

Fig A: Pre-SLEAP Analysis.
Fig B: Post-SLEAP Analysis.

Future Direction

Automated Multi-Bee Feeder: Develop a system to feed multiple bees simultaneously, ensuring consistent and controlled nutrition during experiments.

Closed-Loop System: Implement a complete closed-loop system for real-time data analysis, enabling prediction of the bees' activity phases.

Correlation Analysis: Correlate antennal movements with neural spikes to establish connections between physical behavior and neural activity.

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