Investigating division of labor and elite foraging in bumblebee colonies using automated tracking

James D Crall[1,‡], Nick Gravish[2], Andrew M Mountcastle[1], Albert B. Kao[1,3], Stacey A Combes[1]

[1]Organismic and Evolutionary Biology, [2]School of Engineering and Applied Science, [3]Center for Brain Science, Harvard University ‡james.crall@gmail.com

Aims and Methodology

Here, we use a novel, automated tracking system to investigate division of labor in bumblebee colonies, a social insect with relatively small, simple colonies compared to ants and honeybees. Our system tracks the in-nest behavior, foraging activity, and flight performance of individually-identified bees over extended time periods (several weeks). This system uses BEEtags methodology (Crall et al 2015), which allow for unique identification of individual-visual markers. Here, we present the results from tracking five bumblebee colonies between July and October, 2014.

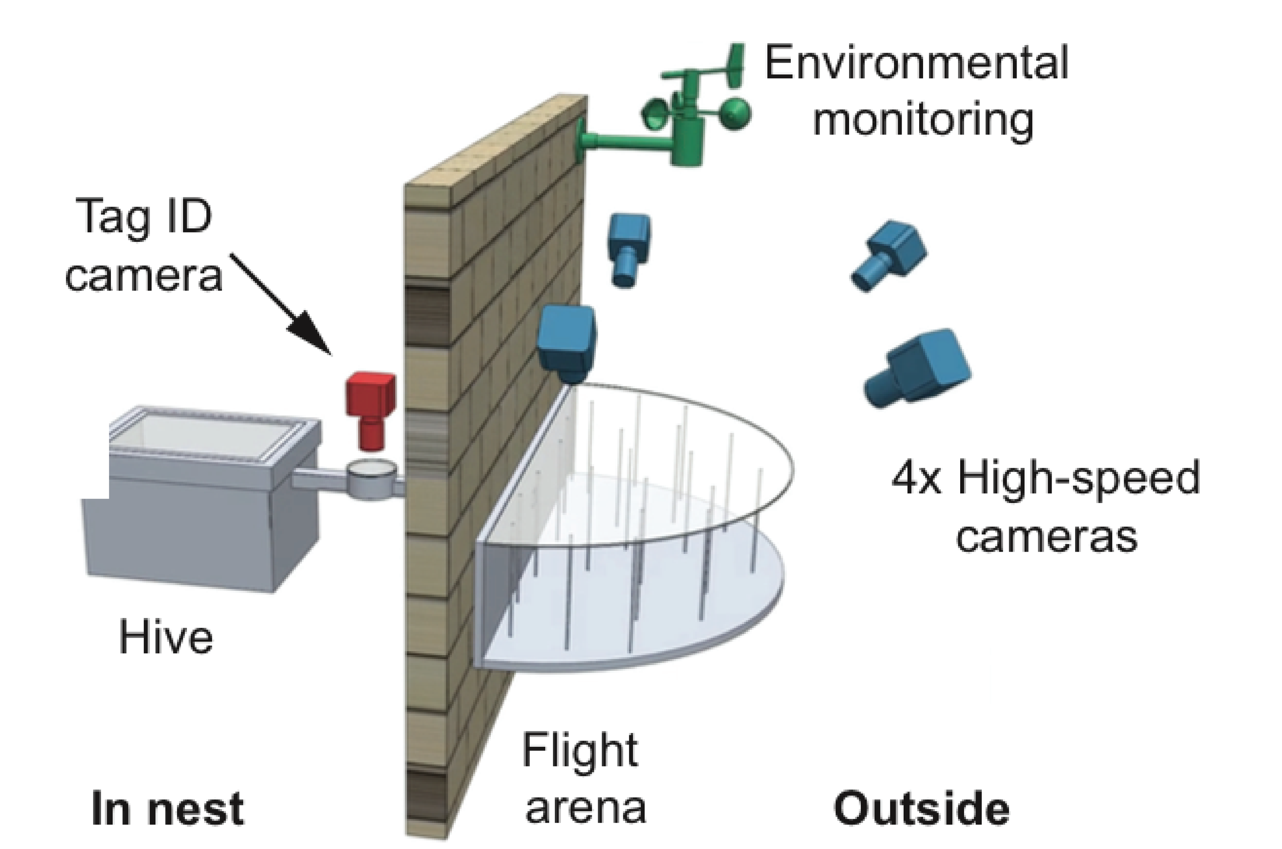


Figure 1. Schematic diagram of colony setup and flight arena for tracking individual behavior, foraging activity, and flight performance. Inside, a single bumblebee colony with a visually clear top is monitored by a video camera, and is connected to the outside environment by a foraging tunnel monitored by a motion-capture camera. Once outside, bees fly through a flight arena with automatically-triggered motion capture and path reconstruction.

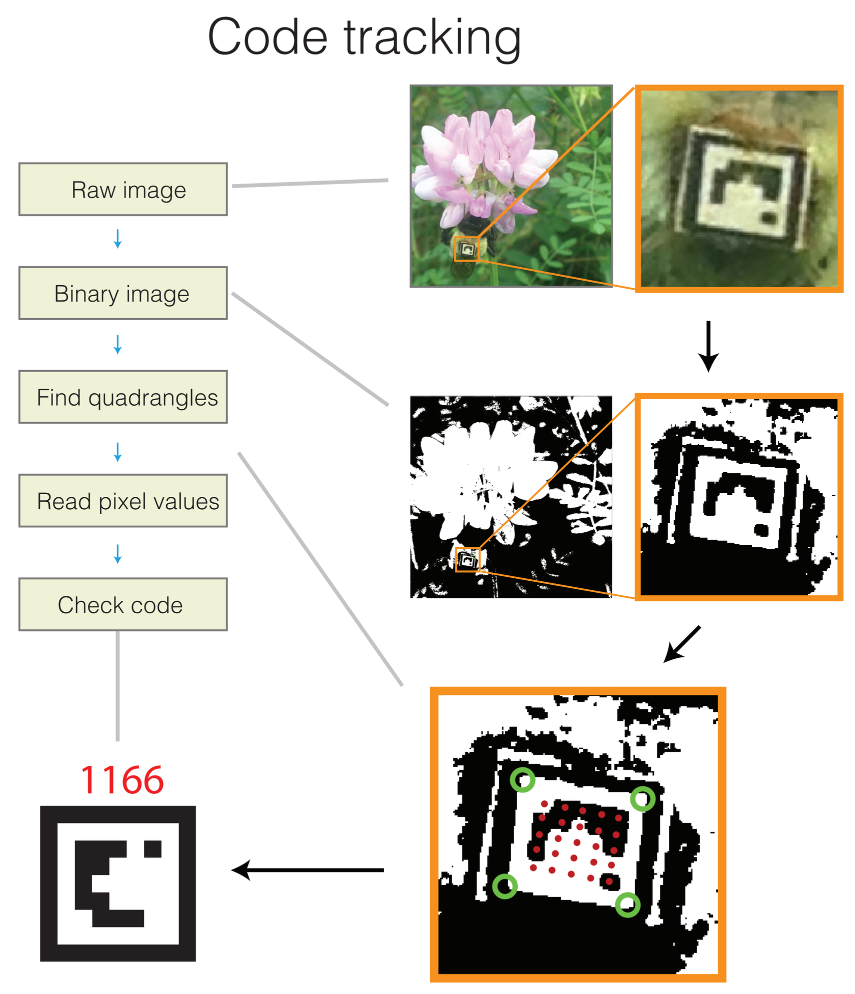


Figure 2. Example tracking of BEEtags. Images are converted to binary, then analyzed for potentially valid tags using a series of error-checks that minimize false positive identification.This photo was taken with an iPhone 5 camera, and is identifying a BEEtag measuring approximately 2.4 mm across. Over 7,000 individuals can be uniquely tagged and tracked with this system. (Crall et al 2015).

Automated tracking reveals individual variation

Bumblebees show behavioral variation within the nest

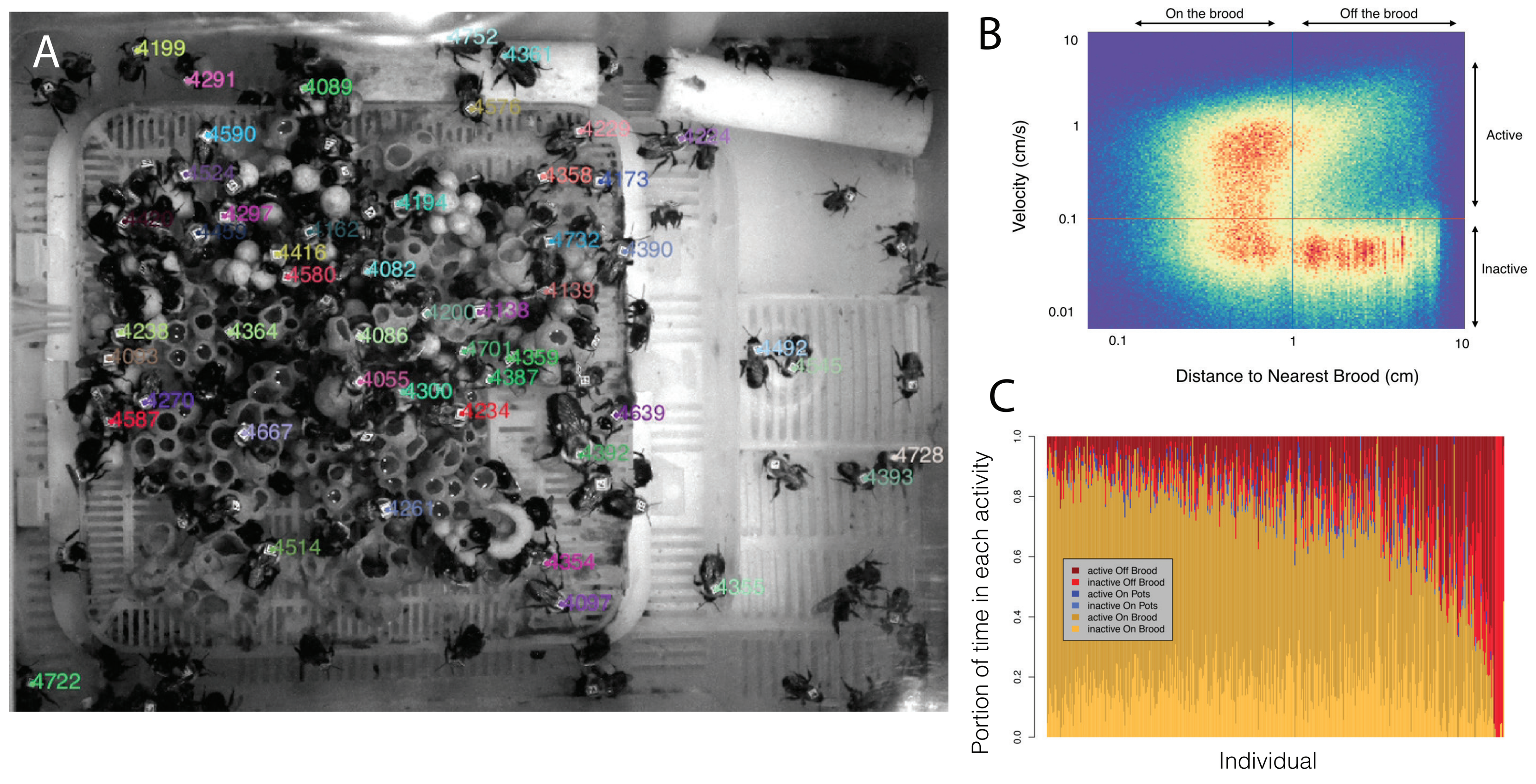
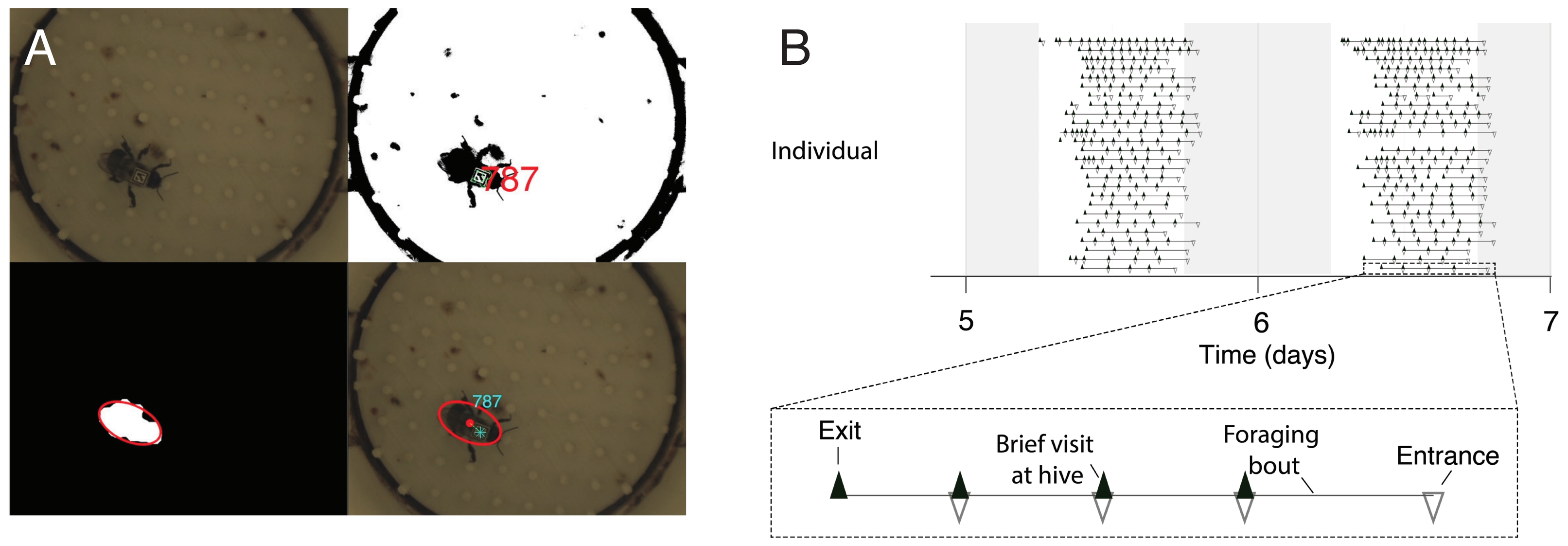


Figure 3. Tracking individuals within a bumblebee colony reveals significant inter-individual variation. (A) Sample frame from a 0.5 Hz video tracking the position of individual bumblebees over time. (B) A heat map of over a million data points mapping velocity vs distance from closest brood. Color indicates relative frequency of data points occupying that region of the graph, ranging from blue (lowest frequency) to red (highest frequency). Position and activity level (i.e. velocity) can be used to categorize behaviors, and the portion of time each individual spends in different acitivites is shown in (C).

A small number of bumblebees do the majority of foraging work



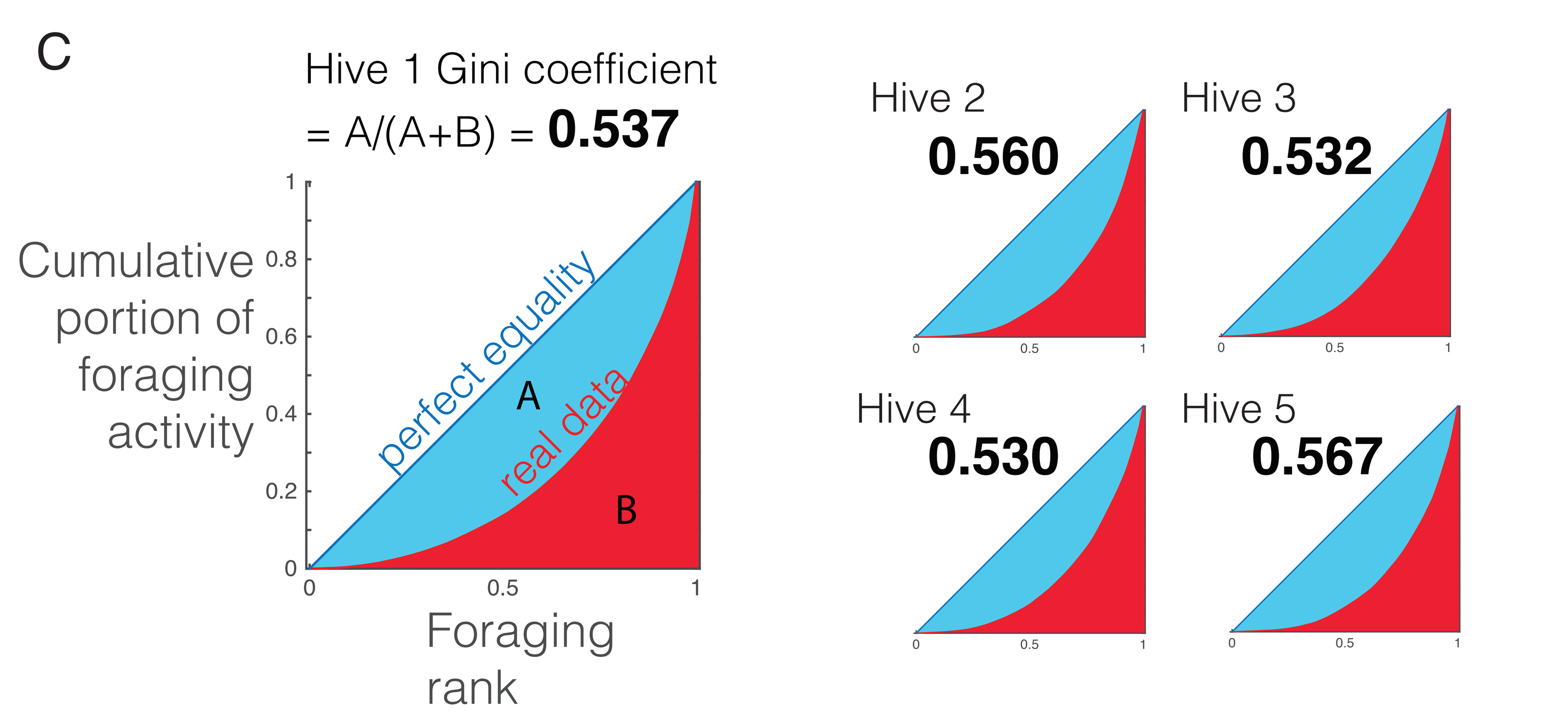


Figure 4. Individual variation in foraging behavior. (A) Image analysis is used to track the movement and orientation of identified bees entering or exiting the hive. (B) Tracking entrances and exits allows for the reconstruction of individual foraging patterns. (C) Gini coefficients provide a statistical estimate of inequality in foraging work among individuals within a hive. Individuals are ranked by the total number of foraging bouts taken on the x-axis, and the y-axis represents the cumulative foraging work. Blue line represents hypothetical perfect equality of labor (Gini coefficient = 1), and red regions show real data from five separate colonies.

Modeling division of labor in bumblebee colonies

Skewed division of labor among foraging bumblebees can potentially be explained by a simple extension of the response-threshold model. In this model, individuals switch tasks depending on the level of a particular stimulus, such as the amount of food in the nest. Division of labor results from individuals within a colony having different response thresholds. Here, we implement a probabilistic extension of the response-threshold where individual bees switch from in-hive work to foraging with probability determined by the following equation:

$$P_{f,i} = 1 - \frac{1}{1 + e^{-0.05(\Upsilon_i - \lambda)}} \quad (1)$$

where P_f is the probability of foraging, Υ is the amount of food in the hive, and λ represents individual sensitivities to the food stimulus. λ is normally distributed among individuals from a colony. Simulations show that this simple model can recreate substantial individual variation in foraging work, which is affected by the variation between individuals in response-thresholds as well food intake rates.

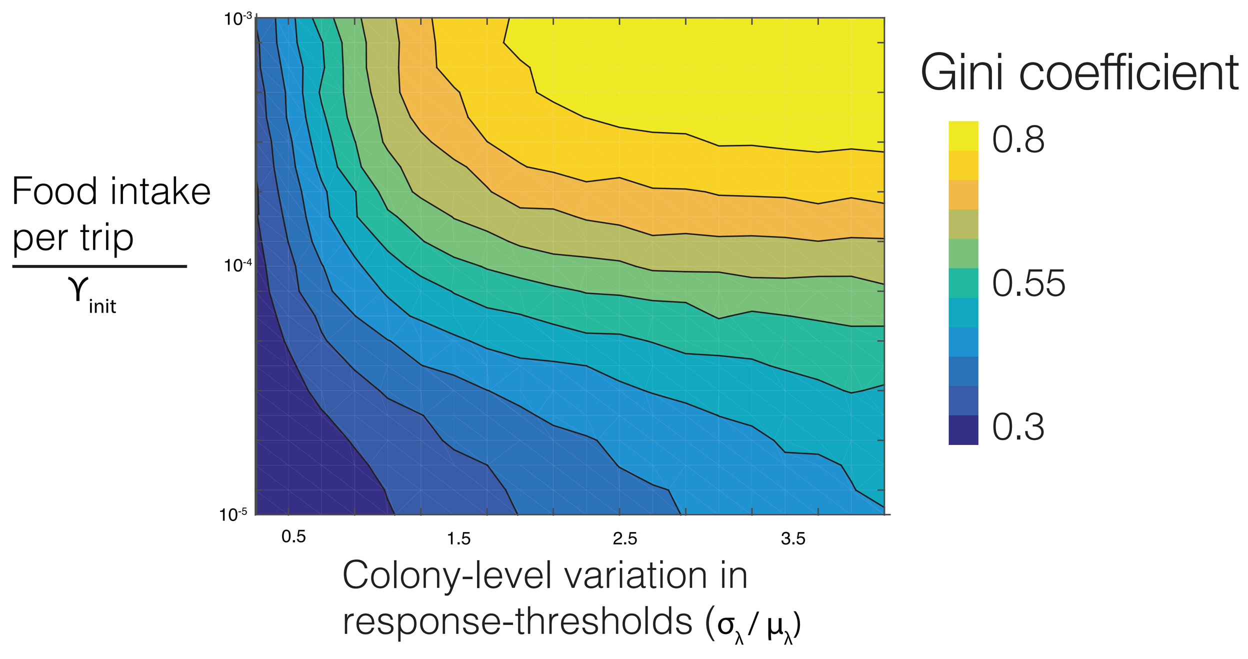


Figure 5. Effects of food brought back per foraging trip [relative to initial food availability (Υ_{init})] and standard deviation of response-thresholds (σ_λ) [normalized to the population-average (μ_λ)] on colony Gini coefficient for foraging trips. Contour map is generated by averaging 10 runs of 2000 time steps for each combination of parameters.

Conclusions and future directions

Overall, this work reveals substantial inequality of work within bumblebee colonies. In ongoing and future work, we are using our experimental platform to test predictions of the model developed above, such as the effects of forager removal or manipulation of in-hive food availability on foraging behavior.

Acknowledgements

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Work Cited

Crall JD, Gravish N, Mountcastle AM, Combes SA. (2015). BEEtag: a low-cost, image-based tracking system for the study of animal behavior and locomotion. In press, PLOS One