Swarming Locusts can be Socially Informed by Robotic Avatars about Potential Treats

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Abstract

Social learning, a complex cognitive trait, is increasingly reported in invertebrates as well. Animal-robot hybrid interaction offers a promising emergent paradigm for studying this phenomenon. Our study focused on *Locusta migratoria*, a species well-suited for exploring social learning. We investigated whether this insect, in its gregarious phase, could learn from robotic models to enhance their predator avoidance. We employed robots with various shapes and colors—some mimicking locusts, others neutral—to observe if their movements, such as hiding actions, influenced nearby focal locusts. We found that locusts responded differently to different robotic models, with biomimetic shapes significantly reducing the time it took for locusts to react and promoting social learning. Additionally, color patterns played a role in triggering social behaviors, especially when the biomimetic model resembled the locusts' gregarious pattern. This study highlights how gregarious locusts can exploit social cues in specific environmental contexts, shedding light on the complex behavioral ecology of invertebrates. Moreover, our animal-robot interaction approach points up the potential for robots to convey social information to living organisms, paving the way for innovative investigations in socio-biology and environmental management through this emerging field of artificial life interfacing robotics, entomology, and ethology.

Introduction

Social behaviors have independently evolved across various animal groups, serving crucial roles in individual survival. Among these behaviors, social learning (e.g. learning through observation) plays a significant evolutionary role by facilitating the development of novel behaviors within and across generations (Rendell, et al. 2010). By observing others, animals, including humans, can update their environmental knowledge without the effort and risk associated with individual learning. However, theoretical models suggest that social learning can be prone to errors, potentially leading individuals to gather outdated or inadequate information, especially in unstructured environments (Feldman, et al. 1996). To mitigate these risks, animals must selectively utilize social information.

While social learning has been extensively studied in vertebrates, recent research indicates its presence in invertebrates as well (Coolen, et al. 2005), offering insights into the evolution and mechanisms of this phenomenon. Despite psychological investigations into social information acquisition, the contexts influencing social learning remain largely unexplored.

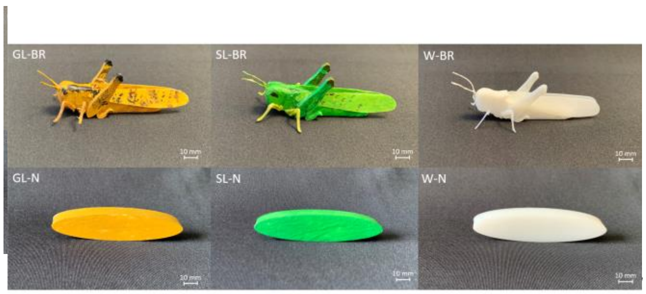
Artificial life and robotic systems have emerged as a promising tool for studying social learning in both vertebrates and invertebrates (Yang, et al. 2019; Romano, et al. 2021). By leveraging principles from zoology and ethology, robotic platforms can replicate animal behaviors and interact with them, providing new strategies for understanding animal cognition and advancing artificial agent design. Moreover, robotics enables the isolation of specific cues in social interactions, minimizes interference from non-focal conspecifics, and upholds ethical standards in animal research.

In a recent study (Romano and Stefanini, 2024), we proposed the animal-robot interaction paradigm to investigate social information transfer in the gregarious phase of *Locusta migratoria* (Linnaeus 1758) (Orthoptera: Acrididae). Due to their gregariousness, these locusts are ideal models for studying social learning. We aimed to determine whether locusts can exploit social information from conspecific-like artificial agents (biorobotic demonstrators) to optimize predator avoidance behaviors, specifically hiding responses. By manipulating the appearance of these demonstrators, including color patterns and silhouettes, we investigated how visual cues influence social behavior in locusts. This research sheds light on the adaptive significance of social learning in locusts and its implications for predator avoidance strategies.

Materials and Methods

Biorobotic demonstrators mimicking the size, morphology, and color patterns of adult *Locusta migratoria*, were designed using SolidWorks and fast prototyped in a bio-compatible resin . These demonstrators are 57 mm long and include features such as head, thorax, abdomen, legs, tegmina, and antennae. They were painted with non-toxic pigments to visually resemble the integumental color pattern of adult locusts in both their gregarious and solitary forms. A control demonstrator was colored white. Additionally, non-biomimetic elliptical-shaped neutral demonstrators were created using the same process. An experimental platform comprising a horizontally suspended carbon fiber rod held by

ABS holders was employed. The rod, activated by a servomotor, facilitated the biomimetic hiding behavior of the demonstrators. Locusts were positioned on a static rod parallel to the actuated one, ensuring visual perception without movement influence during a 10-minute acclimatization period. Different robotic demonstrators, including a gregarious-like biorobotic demonstrator (GL-BR), a solitary-like biorobotic demonstrator (SL-BR), a white biorobotic demonstrator (W-BR), a gregarious-like neutral demonstrator (GL-N), a solitary-like neutral demonstrator (SL-N), and a white neutral demonstrator (W-N), were presented to locusts (figure 1).



The locusts' responses, including latency duration and behavioral reactions, were recorded. Data analysis employed non-parametric statistics and generalized linear models to assess the impact of robotic demonstrator features on locust behavior. Overall, the study aimed at investigating social learning in *L. migratoria* and how various features of robotic demonstrators influenced this behavior. Data from 50 locusts were analyzed for each robotic demonstrator, using R software.

Results and Discussion

In this study, we explored the influence of different color patterns and shapes of biorobotic demonstrators on hiding behavior in *L. migratoria*, providing unique insights into social learning in predator avoidance contexts.

Distinct color patterns significantly affected locusts' hiding behavior ($\chi 2$ = 12.425, *d.f.* = 2, *P* = 0.0020). Gregarious-like biorobotic demonstrators (GL-BR) elicited more hiding behavior compared to solitary-like (SL-BR) and white (W-BR) variants. In contrast, neutral demonstrators (GL-N, SL-N, W-N) showed no significant impact on hiding behavior ($\chi 2$ = 1.992, *d.f.* = 2, *P* = 0.3693). Similarly, biomimetic silhouettes (GL-BR, SL-BR, W-BR) significantly promoted hiding behavior compared to their neutral counterparts (GL-N, SL-N, W-N). Locusts exhibited varied responses to different biorobotic demonstrators. Gregarious-like demonstrators (GL-BR, GL-N) prompted more hiding behavior compared to jumping escape or unresponsiveness. Conversely, solitary-like demonstrators (SL-BR, SL-N) led to a more balanced distribution of behavioral responses. Biomimetic silhouettes particularly enhanced hiding behavior compared to neutral ones. Color patterns played a significant role in shaping locust behavior. Gregarious-like color patterns, especially when paired with biomimetic silhouettes, facilitated socially informed hiding behavior. Conversely, neutral color patterns resulted in fewer hiding responses. This underscores the importance of both color pattern and shape in driving social learning and behavioral responses in locusts (figure 2).

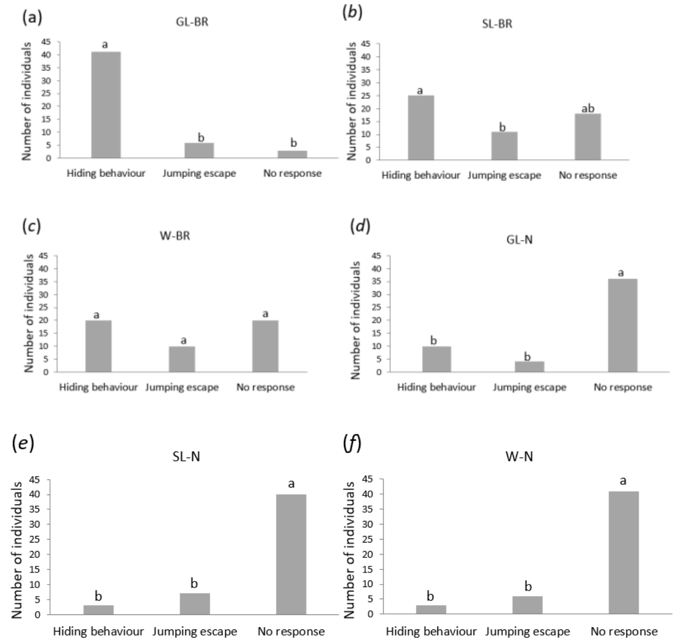


Figure 2: Number of locusts performing hiding behavior, jumping escape, or no response post exposure to different robotic stimuli (a: GL-BR; b: SL-BR; c: W-BR; d: GL-N; e: SL-N; f: W-N).

Overall, this research highlights the relevance of social information in predator avoidance behaviors in *L. migratoria*, with biomimetic silhouettes and color patterns emerging as critical factors in eliciting socially influenced hiding behavior. Moreover, the findings show the potential of robotics and artificial life systems in studying social learning processes across diverse animal species, offering insights into the complex behavioral ecology and social biology dynamics.

References

Coolen, I., Dangles, O., Casas, J. (2005). Social learning in noncolonial insects?. *Current Biology*, 15(21):1931-1935.

Feldman, M. W., Aoki, K., Kumm, J. (1996). Individual versus social learning: evolutionary analysis in a fluctuating environment. *Anthropological Science*, 104(3):209-231.

Rendell, L., Boyd, R., Cownden, D., Enquist, M., Eriksson, K., Feldman M. W., ... Laland, K. N. (2010) Why copy others? Insights from the social learning strategies tournament. *Science*, 328(5975):208-213.

Romano, D., Stefanini, C. (2024). Robot-Locust Social Information Transfer Occurs in Predator Avoidance Contexts. *International Journal of Social Robotics*, 16 :489–500.

Romano, D., Benelli, G., Stefanini, C. (2021). Opposite valence social information provided by bio-robotic demonstrators shapes selection processes in the green bottle fly. *Journal of the Royal Society Interface*, 18(176) :20210056.

Yang, Y., Clément, R. J., Ghirlanda, S., Porfiri, M. (2019). A comparison of individual learning and social learning in zebrafish through an ethorobotics approach. *Frontiers in Robotics and AI*, 6:71.