Final Report Summary - VSIB2009 (Visual Search and Attention in Bumblebees)

1. Introduction

Visual search is an integral part of our lives. We search for specific products in supermarkets or for cars in parking lots. The ease and speed with which we perform the search depend on the specific sensory mechanisms and faculties -including attention- that help us perform this complex task. The study of visual search is therefore unsurprisingly a major field of enquiry in human psychophysics. We, however, know comparatively little about similar faculties in non-human animals despite the fact that several animals have to perform similar visual search tasks. Studying these processes in other animals not only informs us about how they make decisions but also sheds light about what the minimum neuronal hardware needed to solve similar problems might be.

To address these questions, our project undertook to investigate the mechanisms of visual search and attention-like processes in a model system for analysing how simple nervous systems solve complex tasks: the bumblebee. The project investigated four specific aspects of visual search behaviour and attention-like processes in bees. We first investigated the speed at which bees are capable of making visual decisions about briefly presented images with different features. We then investigated whether they can search for multiple learned target types and how this is constrained by their working memory. Further studies investigated the relative influence of colour contrast and reward value on which targets were chosen by bees. Finally, we investigated how search tasks in different modalities (olfaction and vision) interact with each other and if attention constrains search performance regardless of modality.

Results

Can bees see at glance?

Humans and other primates can make rapid visual decisions even when presented scenes for as little as 12 ms. Our project asked the question of whether bumblebees can make similar visual decisions about different targets when presented flashing on a virtual display for very brief durations (<100 ms). We found that they could distinguish between certain elemental target features like edge orientation or colour even when the targets were presented for only 25 ms. They were not, however able to perform a more complex colour discrimination task as rapidly and failed to perform a discrimination task that required whole image analysis even when the targets were presented at 100 ms. The latter task is significant because the bees failed on the task despite it involving an ecologically relevant stimulus - the shape of a cryptic yellow spider, a natural predator on bees.

Multiple visual targets

Bees were trained in separate tasks to recognize two target colours as rewarding. They were then tested with both targets in the presence of distracting colours. The aim was to see if bees could flexibly switch between rewarding targets or if they could only deal with one search template at a time. We found that bees switch flexibly and rapidly between learned target types, thus demonstrating that they are capable of switching between multiple learnt search templates.
Saliency and Reward
Given that bees could switch between multiple targets, we then asked what influences which targets a bee attends to and chooses. We specifically investigated the role of saliency (defined here as colour contrast) and reward value (the concentration of the sucrose reward associated with a target). In separate experiments we found that both saliency and reward influence which of two rewarding targets a bee chooses. We then crucially traded one off the other such that less salient targets were more rewarding and vice versa. Interestingly we found that both factors still influence the choices made by the bee. Thus both saliency and reward influence visual search.

Modality-Specific Attention
Building on our previous results showing that bees can search for multiple target types, we designed a study comparing multiple search tasks (searching for a higher rewarding target while simultaneously avoiding predators) in either the same modality (visual) or in different modalities (visual and olfactory). If search or attention were constrained by a centralized pool of neural processing power, we would expect search to be similar in both conditions. If, however, attentional processing were independent in each modality, bees would be expected to perform better when the tasks were in different modalities. We found that bees indeed performed both search tasks when one was an olfactory task and the other was visual but failed to perform both tasks when both tasks were visual.

Conclusions and Impact
Our results demonstrate that bees have several adaptations to perform visual search tasks flexibly and efficiently. We have thus revealed it as an ideal model system for further investigations into the mechanisms of attention in invertebrates and the differences and similarities they might have to analogues in vertebrates. The crucial advantage of an insect system is that this would open up vital avenues for neurophysiological and genetic studies into the basis of attention. In addition, given the relatively simpler nervous systems of bees, this also paves the way for the development of bio-inspired algorithms of attention that can be harnessed in computers or robots. Finally, our results also have agricultural implications – indicating that one should consider both the saliency and reward of potential plants for pollination and that potentially having strong odour cues could enable bees to avoid predators visually.

The work has resulted in one publication in the Journal of Experimental Biology and another has been submitted. At least two more publications are expected. The work has also been presented in several national and international conferences (including the International Congress of Neuroethology at Maryland, USA 2012 and the Animal Behaviour conference in Newcastle, UK, 2013). The results have thus been well disseminated and will have a significant and lasting impact in the field.