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LOVE OR WAR? - neural circuits and decisions

Morey, Marta

Departament de Genètica, Microbiologia i Estadística, Universitat de Barcelona i Institut de Biomedicina de la Universitat de Barcelona (IBUB)

Behaviors are sophisticated motor responses to complex stimulus. The study of innate robust behaviors has resulted in the identification of neural circuits behind them and has shed light on how these circuits function. Importantly, while innate behaviors determine the evolutionary success of species, they also need to adapt to the internal state of the animal and the environment. The study of *Drosophila melanogaster* behaviors, in particular male courtship and aggression, has been paramount to learn circuit function and decision making. These sexually dimorphic behaviors are genetically controlled through the expression of sex-specific gene isoforms which translate into dimorphisms between the female and male neural circuits. In addition, since according to environmental stimuli males will have to choose between mating or fighting, the neural circuits regulating these behaviors are intimately related. Multisensory integration into a cluster of neurons that work as a switch will determine whether the male courts or fights the conspecific fly it encounters. Once this switch favors one behavior or the other, the animal is committed to that particular motor pattern. However, not every time a male encounters a female it courts her, or every time it comes across another male aggression is triggered. The internal state of the animal plays an important role in decision making through neuromodulation. Neuropeptides and hormones among others can act on the circuit to enhance or dampen sensitivity at the level of sensory inputs and/or integration nodes. This way robust genetically hardwired behaviors can be flexible and coordinate with the environmental conditions and the internal state of the individuals. Importantly, the general concepts and functional strategies described in the fly are also present in other vertebrates such as mice, and thus could be conserved in others organisms.

Students were asked to write an assay on the following:
You have learned about neural circuits and decisions in the innate and mutually exclusive behaviors of courtship and aggression in *Drosophila* males. Drawing analogies from this system, hypothesize how do you think that the mutually exclusive behaviors of feeding and foraging could be working in ants.

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1. Mutually exclusive behaviours of feeding and foraging in ants

Ameku, Faith-Grace
Biomedical Sciences

Behaviour is defined as a change in motor pattern in response to a stimulus. Behaviour can be innate or acquired however, innate behaviours are robust as they are genetically hardwired. Neural circuits are triggered by stimuli, the same stimuli can result in differences in behaviour between genders due to dimorphisms in the circuit. Mutually exclusive behaviours depend on multisensorial integration in circuit nodes and neuromodulation to determine output.

It is necessary to understand and recognise the relation between behaviour and neural circuits as studies have shown that mutually exclusive behaviours such as courtship and aggression share an integration node that generates different behaviours. Therefore, this same principle can be applied to other mutually exclusive behaviours, for instance, feeding and foraging in ants. Findings in one organism can be used to hypothesise and predict the mechanism of mutually exclusive behaviours in others.

Using knowledge of the male drosophila's inability to show aggression and courtship simultaneously, a hypothesis can be drawn to explain behaviours of feeding and foraging in ants. Worker ants search for food for their queen and the young, they often forage at night. Both behaviours are controlled by one circuit, similar to drosophila, therefore there must be one sensory input which triggers both behaviours. As the worker ants search for food at night, it is likely that pheromones are the stimuli that trigger feeding and foraging. The olfactory receptors of the ant sense the chemicals released from prey or food. The stimuli activate a neural circuit that has a common node with differential integration centres and a ventral nerve cord where motor neurons carry out the locomotor output. Within the circuit, there is likely to be a multisensory integration switch that acts as an interrogation mark and can detect the frequency of the stimuli. It switches on the relevant actions so that either feeding or foraging can take place. In addition to this, the internal state and environment of the ant play a role in the outcome of behaviour. If an ant is in danger but senses a stimulus to feed or forage it is unlikely to stop and carry out the behaviour as, in this state survival instincts are in place and the priority of the ant is to live. Similarly, if an ant is hungry and senses the stimuli, it is unlikely to begin foraging instead of feeding. Finally, neuromodulation is a factor that must also be considered, young ants do not forage however, this does not mean they do not sense the stimuli. It is possible that certain neuropeptides make the sensory neuron more sensitive after a particular level of maturity in order for foraging to take place and be effective.

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2. Estímulos, integración de la señal y toma de decisión en Sistema Nervioso

Buscallà Morata, Laura
Biomedical Sciences

Este seminario trata de cómo se efectúa la toma de decisiones que dan lugar a un comportamiento determinado desde el punto de vista de la genética y la conectómica, basándose en el modelo de la mosca *Drosophila* en su decisión de aparearse o atacar. Para ello se detalla el mecanismo que actúa desde la recepción de la señal o input sensorial, pasando por la integración de ésta y la efectuación de una acción como respuesta. La experimentación llevada a cabo para describir el proceso permitió demostrar por primera vez la relación entre gen y comportamiento y más recientemente la conectómica implicada.

La importancia de la creación de analogías entre el comportamiento en *Drosophila* relacionado con la agresión o apareamiento y otros comportamientos en insectos como la acción de comer o almacenar en la hormiga es el darnos cuenta de que disponemos de un modelo a partir del cual podemos crear hipótesis de similitud respecto a la acción llevada a cabo en distintas situaciones por otras especies de una manera precisa y sencilla. Faltaría el diseño de los experimentos que permitieran corroborar o descartar estas hipótesis.

Igual que sucede con las feromonas en *Drosophila*, la hormiga recibe un estímulo sensorial, señales químicas, (sistema sensorial gustativo, olfatorio y táctil) a través de los receptores de las antenas y de la boca, indicando que hay comida. Este estímulo viaja a través de los nervios sensoriales hasta el cerebro. La información es recibida por el interruptor de integración multisensorial, que va a decidir qué hacer con esta comida. Si la hormiga está hambrienta recibirá un input interno que le indicará que coma, en caso contrario, si este input interno no existe, la hormiga almacenará la comida. Podemos hacer la hipótesis de que este nodo común (interruptor) está siempre en modo almacenar y que sólo pasa al modo comer cuando hay un neuromodulador de señal de hambre que inhibe el comportamiento de almacenar, tomando la vía motora de comer.

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3. Neuromodulating hard-wired circuits into complex innate behaviours

Carrera, Gerard; Flores, Montse; Santos, Eloy
Biomedical Sciences

Understanding the mechanisms driving decision-making in living organisms is key to unmask the basis of complex neural circuitries. As a matter of fact, the study of inheritable innate behaviours shows dimorphic organizations in key places of the connectome controlling robust responses critical for survival. What is more, node differential integrations, neuromodulators and the internal state appear to be clue in the organism's adaptability to the external environment.

Throughout the animal kingdom, there is a rich repertoire of antagonistic innate behaviours such as feeding and foraging, which need to be smoothly switched on or off. Knowledge in how the switch takes place may elucidate how the nervous system is capable of recognising its surroundings and modulate the triggering of a given response to stimuli. Hence, this kind of studies may be invaluable to decipher the interaction between genome, connectome and environmental cues in complex species.

Here, we hypothesize how the mutually exclusive behaviours of feeding and foraging could be working in ants. Both might be running through a core neural circuit based on two different types of sensory receptor neurons. During foraging, ants rely on their sense of smell to locate potential food sources using olfactory receptor neurons (ORNs). Pollen could play an important role as a neuromodulator, increasing the sensitivity of these receptors for food during springtime, when resources are not scarce. Thus, ants may be capable of stocking up on food for the winter. During the consummatory stage, ants detect available food sources using gustatory receptor neurons (GRNs). When winter comes, the progressively lowering levels of pollen in the environment may reduce the sensitivity of the foraging pathway while potentiating the feeding one. Other molecules related with starvation and the ant's physiological state might positively neuromodulate GRNs sensitivity to activate the feeding response. Consequently, neuromodulators play key roles in giving flexibility to genetically hardwired neural circuits underlying different innate behaviours crucial for the ants' survival.

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4. Dels comportaments innats a les decisions: la neuromodulació i els circuits neurals

Gordun, Alicia; Pou, Neus; Ibarzo, Ramiro; Olivares, David;
Ciències Biomèdiques

El que planteja el dilema guerra o amor és una pressa de decisions que controlaran un comportament que, al seu temps, generarà una resposta. Els comportaments poden ser innats i venir definits pels gens, però les respostes que es generen poden esser modificades en funció de l'ambient, tant intern com extern del organisme. Aquest comportament a més, en els circuits neuronals, pot venir caracteritzat pel desenvolupament i les connexions entre neurones.

Tot això ens porta al dilema inicial, el que veiem en l'estudi de la *Drosophila melanogaster* és que un mateix estímul provoca en mascle i femella comportaments contraris i que, a més, per molt fixats que estiguin aquest comportament en l'individu hi ha un cert marge d'actuació. Diferents sistemes de neuromodulació actuen en diferents punts del circuit principal i determinen si en la situació en que es troba l'organisme es pot donar un comportament o un altra.

Ara bé, que passaria si canviem aquest dilema inicial que s'ha vist en la mosca per altres casos? Plantejarem aleshores que passaria en una formiga amb el comportaments innats contraris de buscar aliment o alimentar-se. La formiga acumula aliment de manera que no menjarà sempre que disposi d'aquest. El mateix estímul, l'aliment, podrà provoca la ingesta o l'emmagatzematge d'aquest producte. Quina serà la decisió dependrà d'altres sistemes modulant el circuit principal, com podria ser el cas de l'estat nutricional del animal. Si la formiga està sentint gana el sistema seria modulat de manera que s'estimularia l'acte d'alimentar-se per sobre del de guardar el menjar per posteriors ocasions. D'altra banda, si la formiga està ben nodrida el sistema no estimularia alimentar-se, no ho necessita en aquell instant, així que guardaria l'aliment per a posteriori.