Hormones and pheromones; a common ancestor?

This paper will add to the knowledge we have on the evolution of pheromones and hormones.

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Summary

Hormones and pheromones are comparable chemicals; they both cause physiological and behavioral changes by communicating information between different systems. In hormones, this communication occurs between the organs and cells of one individual. In pheromones this occurs between individuals, outside the body. Because of the different level of communication, the evolution is expected to be enormous between the two. There is an enormous diversity in pheromones, whilst a limited variation in hormones. There are millions of pheromones, each matching with a couple organisms. There are hundred hormones, each matching with millions of species. Hormones are more conserved between animals. In this study the hypothesis that hormones and pheromone evolved from the same purpose, when life was mostly unicellular, but while evolving the mechanisms of pheromone action and diversity became more complicated than that of hormones. We needed a more specific system to prevent crosstalk between sexes and species, and to avoid predators. Evolutionary pressure such as signaling honesty, stemming from the need to communicate between individuals became important and probably put vastly different evolutionary pressure on pheromones than hormones. Finally, the recent findings that cells within the same body have different competitive interests might put similar, even though less dramatic, evolutionary pressure on the evolution of hormones, will be discussed. Nowadays we use our knowledge about pheromones and hormones for medical and industrial problems, when the pheromones and hormones will evolve faster and faster we have to increase our knowledge around the evolution of hormones and pheromones.

Introduction

At the turn of the 19th century, Jockichi Takamin, worked in a small independent laboratory, where he discovered a chemical substance in the adrenal gland of sheep and cows that could cause a change in blood pressure when it is released in the bloodstream. It turned out to be a signaling molecule, produced by the adrenal gland (Bennett, 1999), secreting a chemical substance in the bloodstream resulting in a change in physiology and behavior. The discovery of this chemical substance was a medical sensation and gained enormous popularity in a short time span. The chemical substance was named adrenalin.

Nowadays we know that adrenalin is released in stressful situations by the adrenal medulla, which produces a hormonal cascade, which results in the secretion of adrenalin (Bratford, 1915). It is the key regulator of the fight-flight response (Cannon et all, 1929). It regulates, among others, blood pressure and heartbeat (Olpin, 2013). After the discovery of adrenalin, several other molecules that allow communication between organs of the same individual and which mediate change in behavior and/or physiology have been discovered. These are collectively called hormones (Neave, 2008).

Apart from the above mentioned molecules, another class of molecules was discovered, which, unlike hormones, communicate between individuals, instead of between organs. These other chemical substances do, in some respect, resemble hormones, but they also show big difference. These active chemical substances have been called pheromones, coming from the greek word ‘phero’, which means ‘to bear’ and the ‘impentus’ from hormone. Unlike hormones, pheromones are not secreted in the blood, but are stored outside the body. Like hormones, these chemical substances can cause changes in physiology and behavior.

Some pheromones cause change in physiology and are called 'primer pheromones', whilst others cause changes in behavior, called releaser pheromones. In 1959, Karlson and Lüscher first used the concept pheromones to describe the secreted chemicals that have evolved for communication between members of the same species (Karlson et all, 1959). There are different types of pheromones; namely aggregation-, alarm-, signal-, territorial-, trail- and sex pheromones. All pheromones share the same characteristic, namely they are used for communication between animals of the same species and are a stimuli for change in behavior and/or physiology. The secretion and detection of pheromones amongst species, life cycles and environmental cues are not the same for all pheromones. Therefore pheromones do not operate the same among animal species.

Hormones and pheromones are in many respects comparable, but also differ dramatically. Pheromones are inherently social, whilst hormones do not change due to evolutionary selective pressure. Hormones should be under 'normal' natural selection at a level of individual fitness, where pheromones also have to take in account inclusive fitness and signaling honesty. We might wonder why the evolution of communication between individuals, such as pheromones, is different from the evolution of intra-individual communication, such as our own hormones.

In this thesis the focus will lie on what the evolutionary base might be of the differences of pheromones among species compared with hormones.

The basics

To learn more about the evolutionary base of hormones and pheromones, we first have to figure out what the basic principles of hormones and pheromones are.

What are the basic principles of hormones?
Ernest Starling was the first who used the term hormone in one of his lectures.
He defined 'hormones' as, 'the chemical messengers which speed from cell to cell along the blood stream'. The chemical messenger, named hormone, may coordinate the activities and growth of different parts of the body' (Starling, 1905). Now, one hundred years later, the function and regulation of hormones have been described and studied in thousands of species. Hormones and their indispensable role in communication within the body, is documented in organisms varying from mammals to insects and plants.

In 1960, Carroll Williams discovered juvenile hormones in the abdomens of adult male silk moths. Juvenile hormones regulate many functions in moths; they control development including metamorphosis, reproduction and seal dimorphism. Additionally, they support reproductive functions such as deposition of yolk in eggs and production of secretions of accessory reproductive glands. The juvenile hormone can also cause behavioral changes in locomotion, feeding and silk spinning (Riddiford et al., 1996). All these changes can only occur when the corpus allatum, which produces the juvenile hormones, becomes activated. The little gland, the corpus allatum can be found behind the brain. The corpus allatum becomes activated through activation of specific areas in the brain. The Juvenile Hormone is, in some respects, not species–specific, because it can be found in a lot of animals. The synthesis of the Juvenile Hormone is not constant during your entire life.

Figure 1 shows that the synthesis of the juvenile hormone is age dependent.

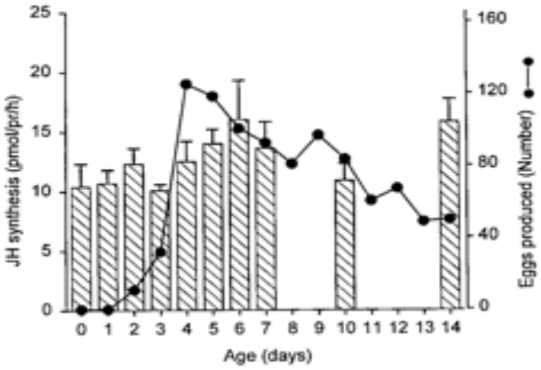

Fig. 1. Bar graph shows rates of juvenile hormone synthesis in vitro by corpora allata from adult female Lacanobia oleracea at different ages (corbitt et al., 1996).

Furthermore, it shows that the synthesis of the juvenile hormone increases with age. At day four when the moth enters adulthood, the production is at its maximum height (Audsley, 1999).

The chemical name of the juvenile hormone is methyl 10-epoxy-7- ethyl-3,11-dimethyl-2,6-tridecadienoate. In figure 2 the structure formula of the juvenile hormone can be found.

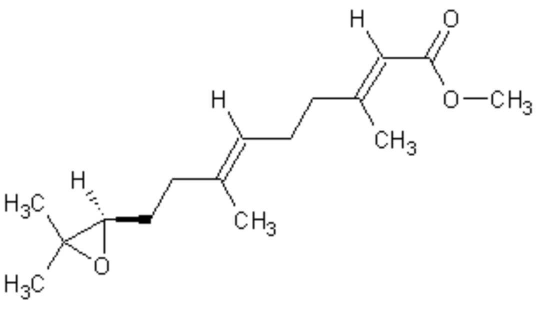

Fig. 2. The juvenile hormone (Mckenney, 2012).

Now that we possess sufficient knowledge ona specific hormone, namely the juvenile hormone, it is time to scrutinize a pheromone. To make a proper comparison between hormones and pheromones, a pheromone which shared the same basic characteristics as the juvenile hormone; 1.the pheromone is present in the moth;2. the pheromone is active in the same life cycle, has been chosen to elaborate on. The pheromone, which fits this description the best is a sex pheromone.

What are the basic principles of pheromones?

In 1939, Butenandt received the Nobel price for being the first person who isolated and characterized the mammalian sex hormones oestrone, androsterone and progesterone. Immediately after receiving this price he started a new challenge, namely the isolation of an insect sex pheromone. He investigated these sex pheromones derived from the moth (Butenandt 1961).

A sex pheromone is a chemical substance used to attract mates from the opposite sex. In other words, an individual tries to encourage another individual of the opposite sex to mate with him/her, or perform some other function closely related with sexual reproduction.

After twenty years of research, Butenandt succeeded in isolating and characterizing the sex pheromone of a silk moth. He named the sex pheromone ‘Bombykol’. Bombykol is a chemical substance secreted by a pheromone gland. The pheromone gland is located between the eighth and ninth abdominal segment of a female moth. When the pheromone gland is activated a female releases Bombykol, which can be detected by the antennae of a male moth. After detecting the Bombykol, the male begins to flutter its wings and starts a flutter dance, which is a mating ritual.

The production of the pheromone is age-dependent. The pheromone gland is activated during the photophase, starting from the day of adult occlusion (Ando et al., 1988) (Fónagy et al., 2001).

The chemical name for Bombykol is (E,Z)-10,12-hexadecadienol. In figure 3 the structure formula of Bombykol is displayed.

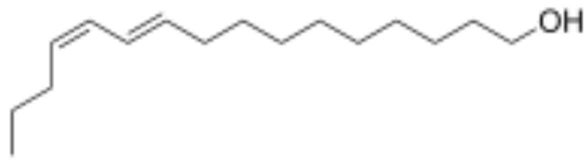

Fig. 3. Bombykol (Xu et al., 2012)

The connection between hormones and pheromones.

Noteworthy is the connection between the two systems. Research has shown us that overlap between hormones and pheromones are present, however they can also influence each other.

An example of this is Drosophila Melanogaster. In Drosophila Melanogaster a pheromone can be found called a sex peptide (Chen et al., 1988). This is the best-characterized male peptide sex pheromone influencing female reproductive behavior in insects (Kubli, 1996). The sex peptide is capable of influencing the corpus allatum and therewithal the synthesis of the juvenile hormone (Moshitzky et al., 1996).
From this example, there can be derived that pheromones are capable of influencing hormone production.

Alternatively, hormones are capable of influencing the pheromone production. For example hormones regulate the development of an individual. When hormones changes cause a diapause the individual won't develop and will not produce pheromones, because they didn't enter the right life cycle yet.

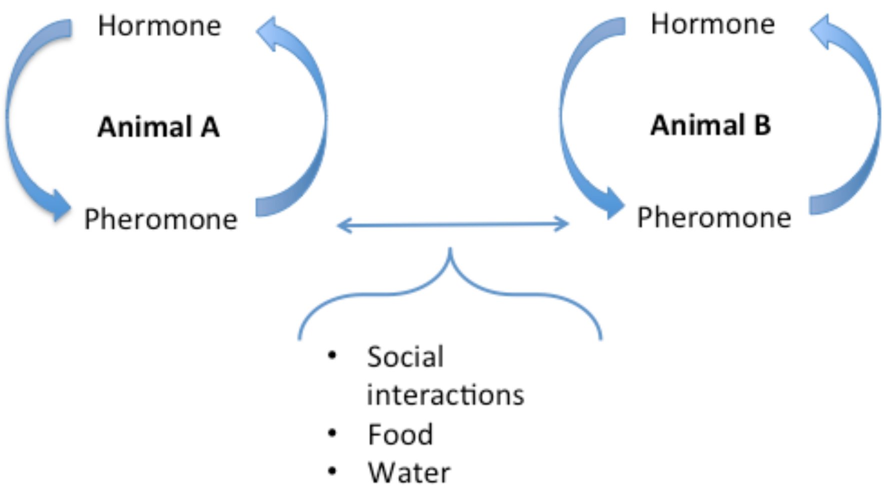

Fig. 4. The circles show the interaction between; system 1. Hormones and system 2. Pheromones.

Figure 4 shows the connection between those two systems. Pheromones can influence other individuals. Pheromones are influenced by environmental cues like food and water. These two communication systems are connected and dependent to each other in many different ways.

Perception of odors and pheromones.

Now we know more about the basic principles of the ligands of hormones and pheromones, but what are the differences in the perception of these ligands?

How works the mechanism around the perception of odors?

When I walk in the park I smell the odor of trees, dogs and the smell of sweaty joggers passing me. When I walk in the lunchroom I smell coffee, sausages and the most delicious cookies. Along with me, millions of species are able to sense and discriminate a remarkable number of odors (Hildebrand and Shepherd, 1997).

In the insect world, the regulation of olfactory information is received and encoded by olfactory receptor neurons (ORN). ORNs distinguish the quality and intensity of odors by sending action potentials to the brain. Drosophila melanogaster have 120 to 1200 ORNs, which vary in sensitivity and specificity. They are located at the antenna (Stocker 1994, Shanbhag et al. 1999). The ORNs in Drosophila can be divided into sixteen functional classes, each class can response to approximately 47 odors. (De Bruyne et al., 2001). Figure 5 shows the enormous diversity of combinations which can be made between receptors and odors. Even with only eight odors there are a lot of combinations possible to create a smell by activating different receptors.

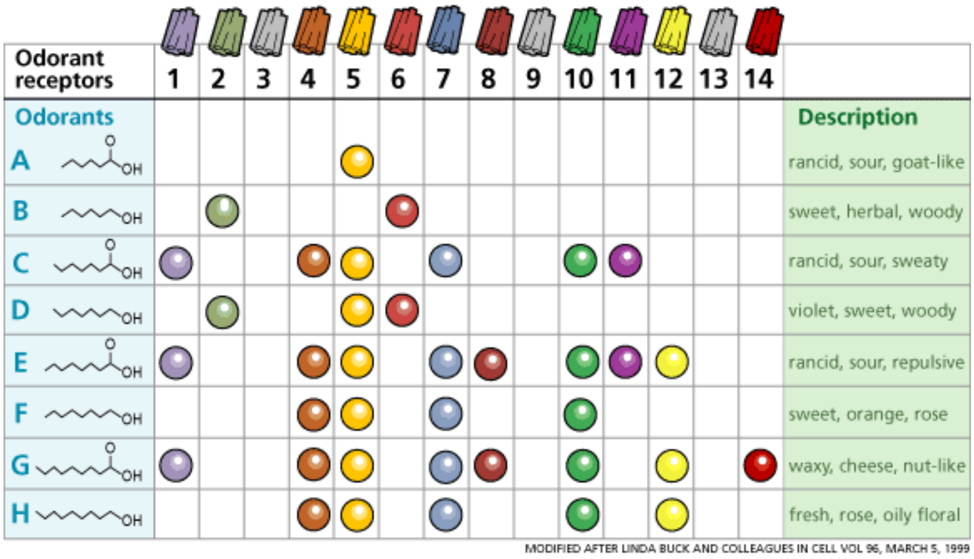

Fig. 5. Different odorants are detected by different combinations of receptors and thus have different receptor codes. These codes are translated by the brain into diverse odor perceptions (Sandoz, 2007).

Is the perception of a pheromone different then the perception of a regular odor?

The method described above can be applied to normal odors. Pheromones are covered by another system named labeled line (see figure 6).

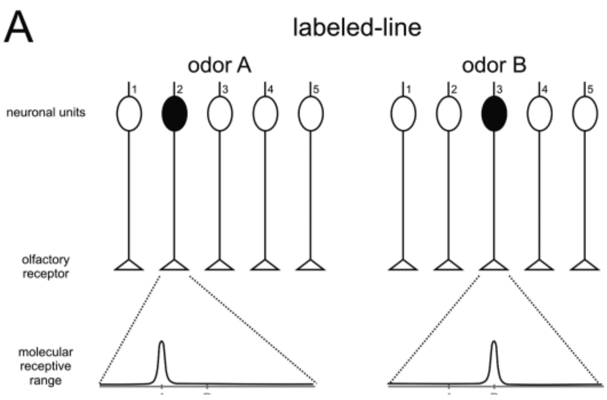

Fig. 6. The principle of labeled line. Both odor A and odor B respond to one specific molecule. (Jean-Christophe Sandoz, 2007)

Figure 6 shows that when you offer odor A and odor B to five receptors, their will only be one receptor that responds and activates one neuronal unit. Therefore only five odors can be coded in figure 6.
In comparison with the perception of 'normal' odors (figure 7), also called across-fiber pattern, you see that the specificity of the receptor is quite low.

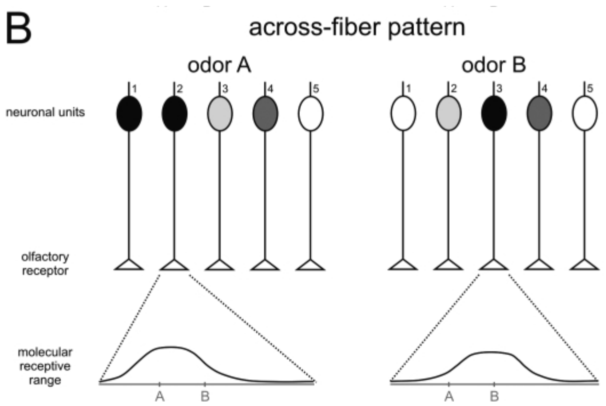

Fig. 7. The principle of across-fiber pattern. Each receptor has a large molecular receptive range and can thus be activated by many different odors. (Jean-Christophe Sandoz, 2007)

In this case the five receptors have different receptive ranges. When we compare these ranges with the one from the labeled line we see that in across-fiber patterns the ranges of the receptors are big. More receptors will react to one odor, however the intensity of the reaction depends on the receptors. The combination of different intensities with the different receptors will lead to a huge amount of odors that can be detected. This system allows the fine coding of many odors.

The evolution

Now that we know that the perception of pheromones is very specific. The next step is to find out to what extent the pheromones and hormones evolved.

How did pheromones evolve?

'The evolution of a pheromone should be under strong stabilizing selection against small changes in the signal, because slight deviations from the signal would be less attractive and, hence, strongly selected against' (Paterson 1985).
Nevertheless, there are some animals, which changed the composition of their pheromone. For example, in Yponomeuta moths, closely related species exhibit considerable qualitative differences in sex pheromone composition (Löfstedt et all 1991). This suggests an evolution of the pheromone.
However, even when the pheromones of closely related species differ considerably in exact chemical composition, the compounds they use often have close structural similarities (Tillman et. al,1999). Figure 8 shows the overlap in compound between species in pheromones.

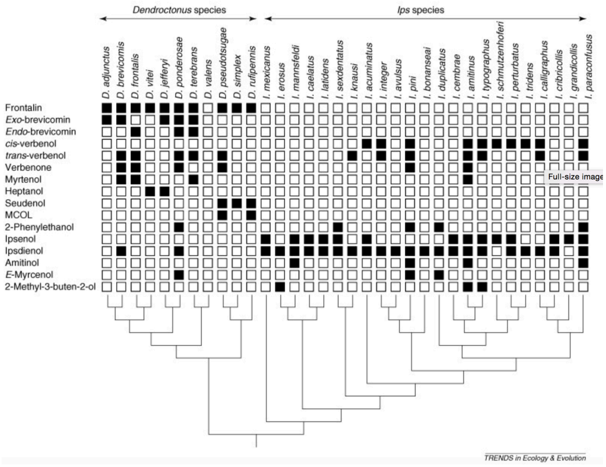

Fig. 8. Comparison of different compounds in different species (Seymonds, 2008).

The composition of pheromone blends can be under control of one or a small number of genes (C. Löfstedt 1990). For moths, these genes encode enzymes, such as desaturases, oxidases and reductases, which are responsible for converting fatty acid precursors into pheromone components (Roelofs et. al, 2003).

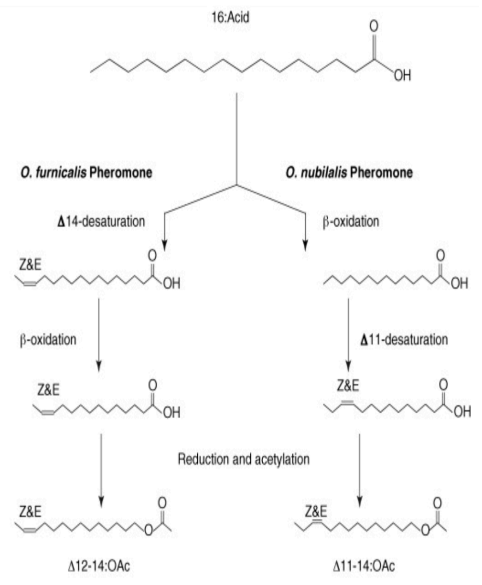

Fig. 9. Pheromone biosynthetic pathways for Asian corn moth. (Seymonds, 2008).

Figure 9 shows an example of the pheromone structures of moths. This example shows how one compound can be converted into another pheromone, because the two types of moths use different biosynthetic pathways. They make another type of pheromone, while they started with the same molecule.

This shows that not only the begin structure is important but also the pathway from fatty acid to pheromone is relevant.

How did hormones evolve?

A lot is known about hormones in mammals. This knowledge extends to use of hormones for medical purposes. Nowadays, the pancreas of animals is used to collect insulin, which can then be used for humans. It turns out that the amino acid sequence of insulin is almost exactly the same in different animal species. The structure of insulin can be described as two peptide chains with three disulfide bridges. It seems that this is conserved in all the nearly 100 different species investigated so far. Some people get an allergic reaction to the insulin, this can be explained by the by-products which arise at the synthesis. The fact that we can use hormones from other species suggests that the evolution of hormones is minimal.

Results and Discussion

Basic principles

In this review, the juvenile hormone was compared to the sex pheromone Bombykol. When making this comparison, an overlap between hormones and pheromones has been detected. Evidence for this overlap is summed up in the following:1. they both cause physiological and behavioral changes; 2. both hormones and pheromones are age dependent and thus are only present or active in specific life cycles; 3.both consist of one specific molecule that can be activated by different pathways in the body. However, apart from this overlap, differences are present. Firstly, hormones are active between cells in the same body (intracellular), whilst pheromones are active between animals of the same species. Secondly, the structure of the hormone and the pheromone are not similar.

To compare a hormone to a pheromone, Bombykol and the juvenile hormone were chosen. However, unfortunately, Bombykol is a special pheromone and is an exception to the rule because it only consists of one component. Most of the pheromones consist of more then one component. This makes it hard to present firm evidence for the conclusion. Perhaps if a different pheromone, consisting of more components, was used to make the comparison, even less similarities might be found. Throughout it seems that the basics of the chosen hormone and pheromone are similar to teach other. Nevertheless in this paper we compared one specific hormone with one specific pheromone. We can doubt of this really describes the basics for all hormones and pheromones.

The connection between hormones and pheromones

Evidence of the former suggests that there is a connection between the system of a hormone and a pheromone. We talked about the fact that hormones and pheromones can influence each other. For example a hormone can influence age specific physiologic developments and the stage in life is dependent for the pheromone production. When this connection is discussed, one barrier becomes evident, which is the interaction between two organisms. The pheromone system is necessary to survive, because they need each other to communicate about reproduction (finding a mate), predators and food etc. Individuals have their own benefits, so the honesty of the signal can be doubted in the pheromone system. Is it the signal from a predator or is it the true signal from a delicious cookie around the corner? So when discussing pheromones, it is important to keep in mind the concept of honesty.

The signal has to be species specific because only then the signal is noticed by the intended organism and not by predators. (Smith, 1995) published a paper about different types of signals. A remarkable thing Maynard noticed are the different types of costs a signal can have. It is all about the rate between costs of the receiver and the signaler. If the intensity of the signal is high, it's correlated with some quality of interest to the receiver. A predator should not use high costs for a potential prey but he should use high costs to warn his offspring to flight. Why should we use different pheromones when we can play with intensities and costs of a signal?

Can we conclude that the hormones are dependent of the signals the pheromones detect? Or are the hormones taking care of the signals the pheromones detect? Nevertheless, whatever which system initiates the other; we can conclude that the two systems are needed to survive and therefore species anticipate and find a way to combine the two systems and make it their own.

Perception

There are two systems, which can detect odors. The labeled line principle and the cross-fiber pattern principle. Pheromones are detected by the labeled line principle. This means that the receptors for those odor are very specific. The normal odors work with the fiber pattern, which has a broad range of odor which can be detected. We can conclude that the receptors for pheromones are more specific and less sensitive.
That would also mean that a small change in your pheromone composition could mean a change or loss in signals. If the addition or loss of even one chemical component can fundamentally change a signal then the potential for diversity is

large. However, because the receptor is so specific, the change would work against you. This is because the changed component won't be recognized by the receptor. The increase in amount of species leads to an increase in the amount of pheromones. When the amount of different pheromones keeps growing, it is necessary to have a great specificity in the detection of pheromone components (Leal et. al, 2005). This is in line wit the labeled line theory.

Evolution of pheromones

As mentioned before, when there is a small change in components, such as the loss or gain of single components, or a change in relative proportions of components over evolutionary time, then a new chemical substance will evolve (Roelofs et al, 1982). Research has shown that there is an enormous diversity in pheromones, even among closely related species. Furthermore, there is evidence that a great overlap in the compounds of the different pheromones is present. Still results show that there is also a huge variety in pheromones. We also noticed that change pheromones by changing a compound will select against you. We also noticed that sometimes the change of compounds is due to enzymes and pathways. When the climate or the nutrition of those animals changes it could cause a changed pathway, resulting in a different pheromone. Maybe when the climate and other environmental cues change the organism will develop to a new species with different receptors and different pheromones and then it won't select against you.

Evolution of hormones

Nowadays, hormones from different animals are used in humans and also work in human. They use insulin from pigs in humans and, with help of hormones, a person is able to transform to the opposite sex. We can conclude that hormones are not species-specific or sex-specific. Furthermore, the conclusion that the hormones didn't evolve much over time and over different species, can be drawn.

Evolution hormones compared with pheromones

To conclude, pheromones evolved a lot through time, whereas hormones did not. When we are searching for an explanation we have to go back to where it al started, Imagine we live in a world were only one-cell organisms live. To survive one-cell organisms have to communicate with each other to for example aggregate. The one-cell organisms carry all the same genetics so we can say they were all (when we look at genetics) the same person. This means that the signals to each other are honest and the benefits are the same for each cell. They developed a system for extracellular communication, pheromones. Thousands of years later the organisms evolved to more complexity. The organisms became so complex that they needed another kind of communication system, which would have to exist within their bodies. At this point they needed hormones to communicate between organs. Logically, the more complex the organism, the more diverse the organisms become.
All those species that were developed needed to communicate with each other in the same way. The pheromones needed to evolve and become species-specific to prevent organisms to connect with the wrong species, also called crosstalk.

The connection between the receiver and the transmitter is completely honest in a hormone. The connection between a receiver and a transmitter in pheromones is not always clear, especially when taking into account the context of pheromones. The honesty of the transmitter could delude you. For example the signal could also be from a predator, who tries to trick you by imitating your way of communicating. As you see, the environment of pheromones is so different and is influence by a lot of things.

This could explain why hormones did not evolve much and pheromones did. However, there are some articles on the competition between cells in the same body (McLean, 1997). These articles speak of a potential evolvement of hormones, as within the body, honesty could become a real issue. Another example of competition within your own body is cancer and diseases like rheumatism.

However, for this research, insects were the focus and any conclusions are directed at the industry of insects. Nowadays, many farms are often victim of a large array of insects. To tackle this problem, more knowledge is necessary on the communication between the insects, so that, in the future, the communication between these insects can be disturbed or retained.

To complete this review, a few concluding notes shall be made. First of all, all the conclusion are based on one hormone and one pheromone. The pheromones and hormones which were compared, were specific to insects. Mammals were left completely out of the equation. There are thousands of other animals and thousands of other hormones and pheromones, perhaps in these species or these hormones and pheromones a different reason for evolution can be found.

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