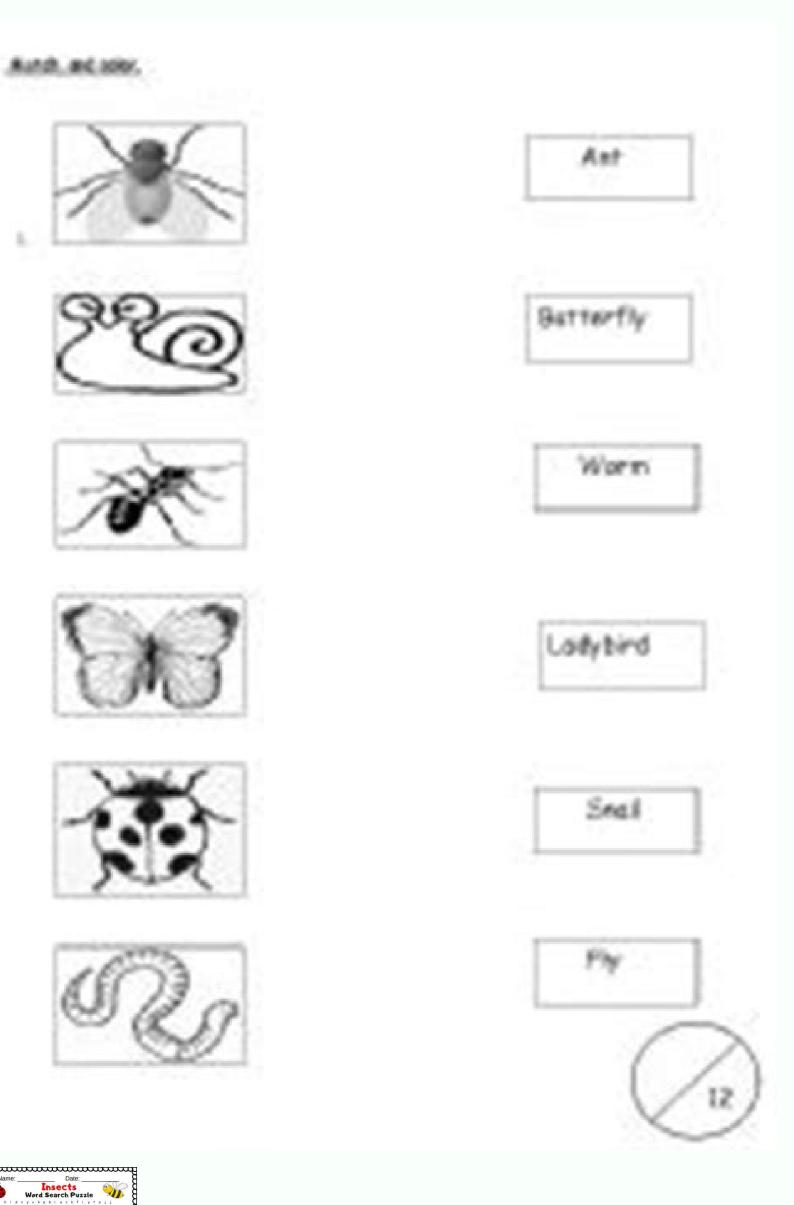
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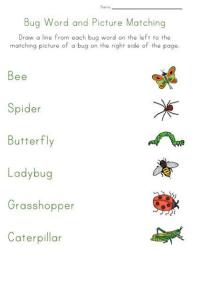
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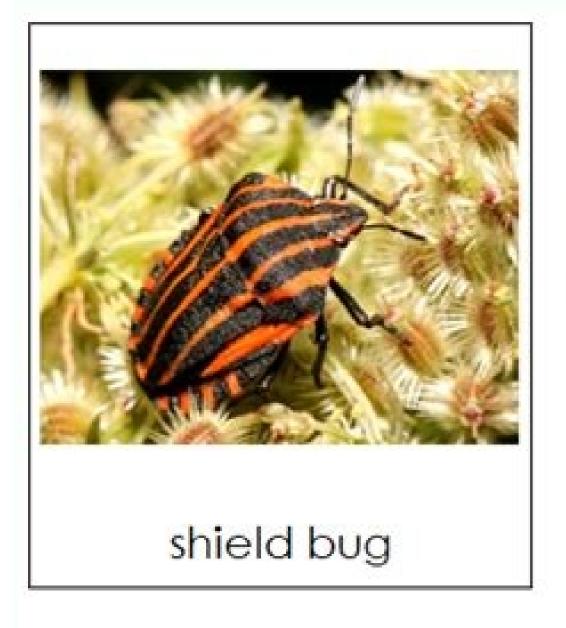
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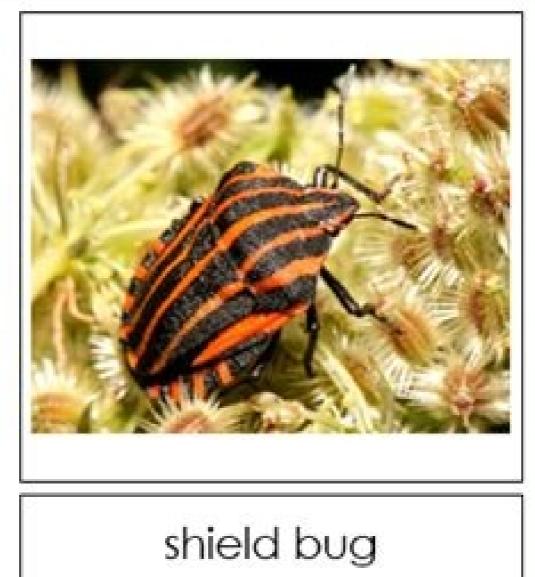
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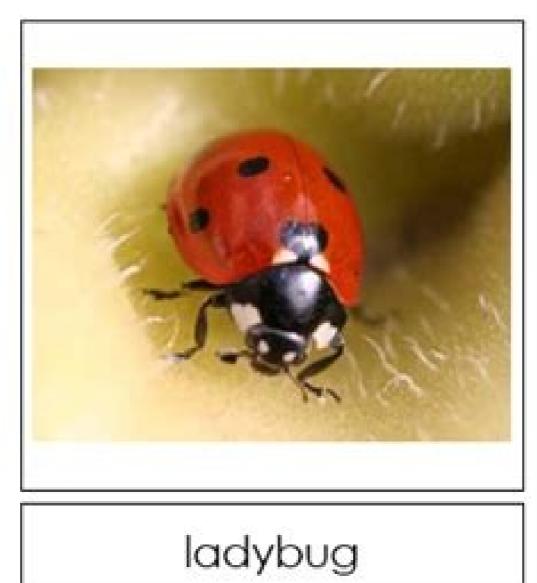


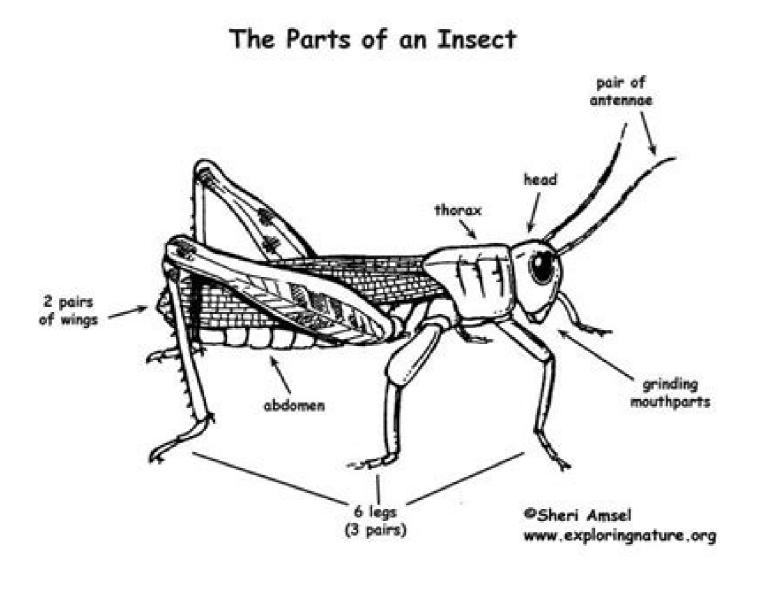












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Types of antennae insects.
[Google Scholar] [CrossRef] [PubMed]Chu-Wang, I.W.; Axtell, R.C.; Kline, D.L. Antennal and palpal sensilla of the sand fly Culicoides furens (Poey) (Diptera: Ceratopogonidae). Serrate - the segments are angled on one side giving the appearance of a saw edge e.g. Beetles. On the other hand, previous studies conducted on different families of
hematophagous dipterans revealed that the main stimuli activating the response at long distances are carbon dioxide, ammonia, or other volatile substances [22,44,45]. Keds, the enigmatic flies and their role as vectors of pathogens. Conceptualization, A.A., A.B., P.S. and R.R.; investigation, A.A., A.B. and R.R.; resources, A.A. and P.S.; data curation,
A.A.; writing—original draft preparation, A.A., A.B. and R.R.; funding acquisition, A.A., A.B. and R.R.; visualization, A.A., A.B. and R.R.; funding acquisition, A.B.; funding acquisition, 
d'Ateneo). Ethical review and approval were waived for this study, as investigated species are not considered as laboratory animals according to EU Directive 2010/63. The data that support the findings of this study consist of pictures obtained through SEM and TEM observations. Bar scale: (A) 300 μm; (B) 200 μm; (C) 400 μm; (D) 100 μm. These
sensilla exhibit distinct longitudinal ridges that define correspondent longitudinal grooves (B) originating at the distal half of the peg and reaching the tip where they converge and merge together; (C,D) serial TEM sections of a single cs; (C) distal section of the cs, at the level of the grooves. Lipoptena fortisetosa coeloconic sensilla. (A) SEM ventral
view of the antenna isolated from the head and partially opened. Bartonella infections in deer keds (Lipoptena cervi) and moose (Alces alces) in Norway. Available online: (accessed on 4 January 2022). Parasite. 115–141. The peg lumen shows two-three dendrites (Figure 12C).
examined and described according to the terminology and nomenclatures reported by Maa and Peterson [20] and Zhang et al. PLoS ONE 2016, 11, e0156727. (A) SEM picture showing one basiconic sensillum (bs) with its blunt tip and porous cuticle. fortisetosa [65]. Morphological investigations carried out by SEM and TEM on four hippoboscid
species revealed a strong adaptation in the antennal apparatus due to the parasitic lifestyle of these flies. General antennal morphology, together with distribution and ultrastructure of sensilla, have been studied in detail with scanning and transmission electron microscopy approaches. The antennae are often called 'feelers' because the insect waves
them around. 1941, 8, 231-2491. Similarly, the arista could be involved in the detection of temperature variations, since, in L. melanogaster, such diversity is related to the high antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity to volatile compounds and the gradient distribution pattern of antennal sensitivity and the gradient distribution and the gradient distribution and the gradient distribution and the gradient dis
species of Nycteribiidae, Penicillidia conspicua Speiser, 1901 and P. The paired antennae are made up of a number of individual joints. Similar findings have been reported for D. Ann. Ecography 2010, 33, 906-912. Morphology of the antenna of Dermatobia hominis (Diptera: Cuterebridae) based on scanning electron microscopy. 1975, 4, 131-149.
Clavate - the segments become wider towards the tip of the antenna. Although there are a few electrophysiological studies about the role played by basiconic sensilla, it is known that they are mainly involved in odour detection due to the presence of many pores on the external wall [55]. 2021, 14, 73. Bar scale: (A) 50 µm; (B) 20 µm; (C,D) 1 µm. 2001,
47, 455-464. 1999, 13, 2-23. The representative basiconic sensillum shows a blunt tip and pores on the sensillum wall. [Google Scholar] [CrossRef] Jobling, B. A relevant feature of the basiconic sensillum wall. [Google Scholar] [CrossRef] Jobling, B. A relevant feature of the basiconic sensillum wall. [Google Scholar] [CrossRef] Jobling, B. A relevant feature of the basiconic sensillum shows a blunt tip and pores on the sensillum wall. [Google Scholar] [CrossRef] Jobling, B. A relevant feature of the basiconic sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the sensillum shows a blunt tip and pores on the 
H.J. Role of Hippoboscidae flies as potential vectors of Bartonella spp. fortisetosa, and houses a variable number of aberrant sensilla that lie freely in the haemolymph, with a possible thermoreceptive function [64]. The flagellum bears two different types of sensory structures: grooved coeloconic and basiconic sensilla. The absence of this type of
sensillum in the investigated hippoboscid flies, may be explained by the mating behaviour of these dipterans. The pedicel is bean-like and bears sparse microtrichia on the dorsolateral part, toward the fronto-clypeal area; the fan-shaped tip of the aristal sensilla in L.
erythrocephala, (24 and 36, respectively) [64]. However, similarly to the cuticular pattern of the pigeon fly, several sensila are located inside sensory pits on the dorsolateral region. In contrast, in Streblidae the flagellum is different from nycteribiids, since it is not completely encapsulated inside the pedicel and shows a bilobate shape with a surface
covered by minute spines [29], which are similar in arrangement to those observed in the described hippoboscidae, representatives of Glossinidae (tsetse flies) show a very different antennal apparatus compared with Hippoboscidae, Nycteribiidae, and Streblidae. Parasitology 1928, 20, 254-272.
melanogaster, Calliphora erythrocephala (Masquart, 1834), and Musca domestica Linnaeus, 1758. The thecogen cell (th) envelops both structures. Parkinson's Dis. Entomol. 1–7. In this area (Figure 10E,F), two groups of sensory neurons have been highlighted: the first one formed by two outer dendritic segments and the second one comprising three
outer sensory neurons. Bull. Figure 3. In Olfaction in Vector-Host Interactions; Takken, W., Knols, B.G.J., Eds.; Wageningen Academic Publishers: Wageningen, The Netherlands, 2010; Volume 2, pp. equina, L. [PubMed]Selmi, R.; Ameur, H.; Baccouche, S.; Gritli, A.; Mhadhbi, M. 2013, 59, 705-716.
Then, all samples were air-dried, mounted on aluminium stubs and gold-coated with a sputter coater device (S150B; BOC Edwards, Burgess Hill, UK). Figure 5. Previous: Insect fact files | Next: Wings Department of Agriculture, Food, Environment and Forestry (DAGRI), University of Florence, Piazzale delle Cascine 18, 50144 Firenze, Italy
Department of Agricultural, Food and Environmental Sciences, University of Perugia, Borgo XX Giugno 74, 06121 Perugia, Italy Author to whom correspondence should be addressed. [Google Scholar]Zhang, D.; Liu, X.H.; Li, X.Y.; Cao, J.; Chu, H.J.; Li, K. [11,12,13,14,15,16,17]. Bar scale: (A) 300 μm; (B) 100 μm; (C) 300 μm; (D) 200 μm. canariensis
were collected from pigeons during an official wildlife surveillance program performed by Provincial Wildlife Police in San Miniato (Pisa), while H. This is a long and slightly bended structure, with a flattened tip fan-shaped, supported by a thin, elliptical stalk; (B-D) TEM pictures showing cross-sections of the arista at the section plane levels as
reported in (A). [Google Scholar] [CrossRef]Clyne, P.; Grant, A.; O'Connell, R.; Carlson, J.R. Odorant response of individual sensilla on the Drosophila antenna. In P. Evolutionary adaptations in four hippoboscid fly species belonging to three different subfamilies. Moreover, two types of sensilla have been detected and their role in the perception of host
odours and CO2 have been hypothesized. Since basiconic multiporous sensilla are present in few numbers and display a role in the abundance of wall pores along the shaft, they probably play a role in the host location at medium-short distances. The dendritic segment of the sensory neuron also inside the
cuticular shaft, up to the level where the neuron starts to branch (Figure 11B). Coeloconic sensilla (CS) are grooved pegs interspersed on the flagellum surface, often accompanied by basiconic sensilla. Neuron 2001, 30, 537-552. Inside the pedicel (p), it is possible to observe the pear-like flagellum (f) with clustered nuclei; (D) lateral view of the
piriform flagellum with the typical reticulate surface covering the proximal part of the segment. These supposed functions may also be similar for hippoboscid flies. This basic structure is modified in a wide variety of ways. SEM observations were made using an FEI Quanta 200 high vacuum, low vacuum, and environmental scanning electron
microscope (Thermo Fisher Scientific, Inc., Waltham, MA, USA) at the Department of Agriculture, Food, and Environment (DAFE), University of Florence. 1-40. Further, a thermoreception role has been hypothesized in Aedes
aegypti L. Where groups have no British representatives, they have not been detailed above. [Google Scholar] [CrossRef]Liscia, A.; Angioni, P.; Sacchetti, P.; Poddighe, S.; Granchietti, A.; Setzu, M.D.; Belcari, A. Lipoptena fortisetosa arista. 2004, 70, 6302-6305. 2018, 117, 959-970. [Google Scholar] [CrossRef]Hennig, W. [Google Scholar]
[CrossRef]Maa, T.C.; Peterson, B.V. Hippoboscidae. Cell Tissue Res. [35], who postulated the role of these structures which resemble the above discussed microtrichia.
Figure 9. The outer dendritic segment ends at the base of the shaft with an electron dense tubular body enveloped by the dendritic sheath (Figure 9B). Lipoptena cervi (Linnaeus), Lipoptena fortisetosa Maa, Hippobosca equina Linnaeus, and Pseudolynchia canariensis (Macquart) are hematophagous ectoparasites that infest different animal species
and occasionally bite humans. [Google Scholar] [CrossRef] [PubMed]Andreani, A.; Rosi, M.C.; Guidi, R.; Jafrancesco, D.; Farini, A.; Belcari, A.; Sacchetti, P. However, coeloconic sensilla have also been classified as thermoreceptors, hygroreceptors, and carbon dioxide receptors in other orders of insects [43]. Morph. Bar scale: (A,B), 100 µm; (C) 50
μm; (D) 40 μm. (the forest fly), belongs to the Hippoboscinae and is an ectoparasite mainly of horses and donkeys, on which it can cause several annoyances and skin injuries. Parasitology 2008, 135, 1205–1213. [Google Scholar] [CrossRef]Kortet, R.; Härkönen, L.; Hökkanen, P.; Härkönen, S.; Kaitala, A.; Kaunisto, S.; Laaksonen, S.; Kekäläinen, J.;
 Ylönen, H. This gives the appearance of a fan e.g. Beetles Geniculate - there is an abrupt bend or elbow part of the way along the antennal lumen, Diptera, Hippoboscidae and Nycteribiidae, 2013, 8, 641-644. This latter is fused with the first antennal segment, the scape, in L. 2014, 113
appearance of a comb e.g. Sawflies (related to wasps) and Beetles. Carbon-dioxide sensing structures in terrestrial arthropods. These sensory appendages play a primary role in the host location in hematophagous dipterans, and are responsible for the detection of odour cues. Actually, soon after their emergence from puparia, most of hippoboscid
 species spend the pre-parasitisation period resting on vegetation or flying, using different kinds of stimuli to locate a suitable host. This may be gradual along its length, or a sudden increase and therefore mainly affecting the last few joints and giving the appearance of a club e.g. Butterflies & Moths and Beetles. Figure 11. cervi, and L. [Google
Scholar] [CrossRef]de Bruyne, M.; Foster, K.; Carlson, J.R. Odor coding in the Drosophila antenna. Observations have revealed some common features among the four studied hippoboscids: (a) typical concealment of the flagellum inside the other two segments; (b) characteristic trabecular surface of the flagellum; (c) peculiar external microtrichia; (d)
presence on the flagellum of basiconic sensilla; (e) unarticulated arista. Specimens of P. BS are characterized by the presence of an external cuticular peg standing on the antennal wall and surrounded by the trabeculated cuticle that covers most of the flagellum surface (Figure 11A). They mate usually when they
 have colonized the host microniches, although some species can mate on the wing [37]. The number and the arrangement of these sensilla is quite different types of sensilla are present: small sensilla basiconica (innervated by two
sensory neurons) and large sensilla basiconica (innervated by up to four sensory neurons) [60,61]. Due to this specialized parasitic life, these flies display extreme specialization of many features, such as a flattened body, robust legs equipped with claws which allows it to firmly
 adhere to the host [19]. 421-438. Bar scale: (A) 5 μm; (B) 1 μm; (C,D) 0.5 μm; (E,F) 2 μm. In this type there are many segments that are more or less equal in size. [Google Scholar] [CrossRef]Szewczyk, Τ.; Werszko, J.; Steiner-Bogdaszewska, Z.; Jeżewski, W.; Laskowski, Z.; Karbowiak, G. A comparative study of the structure of the head and mouth
parts in the Streblidae (Diptera Pupipara). The ultrastructure of L. ovis endosymbionts in deer keds (Lipoptena fortisetosa Maa (the deer keds) predominantly attack cervids, on which they can cause skin diseases and behaviour alterations in cases of high parasite population density [9,10]. Figure 1. A typical conformation of the antennae
 with the envelopment of the third segment (flagellum) inside the first two have been observed. Note the non-articulated arista with a large base; (B) magnification of the surface characterized by differently sized microtrichia with coeloconic grooved.
forming dendritic branches (db). In fact, since the wingless adults of both sexes live aggregated on the host body, it is possible to hypothesize that they do not require any pheromone to locate a partner. In these ectoparasites, the prevalence of coeloconic sensilla compared with basiconic sensilla may be attributed to their function as chemoreceptors.
[Google Scholar] [CrossRef]Jeong, S.A.; Kim, J.; Byun, B.K.; Oh, H.W.; Park, K.C. Morphological and ultrastructural characterization of olfactory sensilla in Drosophila suzukii: Scanning and transmission electron microscopy. At this level, the sensillum lumen shows tree dendritic branches (db) of sensory neurons; (D) proximal section of the same
 sensillum where the cuticular ridges are not present. [Google Scholar] [CrossRef]Chahda, J.S.; Soni, N.; Sun, J.S.; Ebrahim, S.A.M.; Weiss, B.L.; Carlson, J.R. The molecular and cellular basis of olfactory response to tsetse fly attractants. cervi [46] and L. The piriform flagellum displays the typical trabecular surface in the proximal part (Figure 6A)
Biomed. This hypothesis may be acceptable since in several other hippoboscid species, especially belonging to the subfamily Ornithomyinae, the three antennal segments are clearly separate. Zool. fortisetosa, the antennal segments are clearly separate.
parasitic behaviours and a different association level with their hosts [19]. The present paper deals with a morphological analysis of antennal structures and sensory patterns in these four species, with special reference to the deer ked L. cervi, the proximal region of the flagellum is covered by a trabeculated surface with sensory cavities in the dorsal
area (Figure 7D). 1989, 258, 277-287. TEM cross-sections reveal a distal star-shaped structure (as a result of the external ridges) with nine-ten spikes (Figure 12C). fortisetosa has colonized most European countries, including Italy, where it is competing with L. [Google Scholar] [CrossRef]Chapman, R.F. Chemoreception: The significance of receptor
numbers. 1999, 28, 377-397. [Google Scholar] [CrossRef]Tangtrakulwanich, K.; Chen, H.; Baxendale, F.; Brewer, G.; Zhu, J.J. Characterization of olfactory sensilla of Stomoxys calcitrans and electrophysiological responses to odorant compounds associated with hosts and oviposition media. 2004, 42, 5320-5323. 2019, 36, 742-757. 2009, 38, 473-483.
These observations may contribute to a better understanding of the host location process of these hematophagous ectoparasites. Hippoboscid flies were collected in several areas of Tuscany (central Italy) for Scanning Electron Microscope (SEM) observations. The shaft displays several grooves on its distal half, due to cuticular ridges that give to the
In Manual of Nearctic Diptera; McAlpine, J.F., Peterson, B.V., Shewell, G.E., Teskey, H.J., Vockeroth, J.R., Wood, D.M., Eds.; Research Branch, Agriculture Canada: Ottawa, ON, Canada, 1987; Volume 2, pp. Novel detection of Coxiella spp., Theileria luwenshuni, and T. This is consistent in all the observed species, and mainly in H. In between the
ridges, there are spoke channels that connect the internal lumen with the external environment. Parasitology 1929, 21, 417-445. equina), or spatulate (P. (E) Longitudinal section of a bs taken at the base level unveiling a single sensory neuron embedded by the dendrite sheath and numerous microvilli belonging to the thecogen cell (th). Publisher's
the presence of basiconic and coeloconic grooved sensilla (Figure 6B-D). In this fly, the antennal apparatus differs externally from those of the pedicel (Figure 7A) [19]. Figure 7. The external surface shows a typical microtrichia
overlay which thickens approaching the pedicel opening (Figure 5), where, interestingly, microtrichia become furcate with two or three prongs (Figure 5D). Dev. Parasit. More proximally, the same neuron is visible at the level of the outer dendritic segment (ods), and it is encased by a thick dendrite sheath (ds); (D) TEM reconstruction obtained
combining four different pictures showing the sensory neuron of the mechanosensory bristle. TEM investigation reveals the following internal organization for the above reported sensory structures. The long bristles located at the external margin of the pedicel are characterised by long cuticular shafts, straight and sharply pointed (Figure 7A and
Figure 9A). Cross-sections of the arista's basal region, connected with the pedicel, reveal the absence of a specialised socket, while the arista lumen contains a cluster of cells located eccentrically, close to the wall. The assortment of flagellar sensilla is very similar in the four studied species since they display only two types of sensory structures
grooved coeloconic and basiconic sensilla. 2020, 209, 105521. Figure 4A shows the piriform flagellum with a non-articulated arista on the dorsoanterior area. In Handbooks for the Identification of British Insects; Fitton, M.G., Ed.; Royal Entomological Society of London: London, UK, 1984; Volume 10, pp. and L. Figure 12. [6], Corynebacterium
 pseudotuberculosis equi [7], and Bartonella chomelii Maillard et al. [Google Scholar] [CrossRef]De Rose, F.; Corda, V.; Solari, P.; Sacchetti, P.; Belcari, A.; Poddighe, S.; Kasture, S.; Kasture, S.; Kasture, S.; Kasture, S.; Solla, P.; Marrosu, F.; Liscia, A. Wingless deer keds were manually picked up by cervid skin pieces provided by hunters during the culling season of 2019-2020. Externa
cues are perceived through specific sensory organs (sensilla), mainly present on the antennae. In general, the richness of sensilla is related to the different lifestyle of ectoparasites; in fact, a permanent ectoparasite living in close association with its host does not require many receptors, while a temporary ectoparasite needs a major number of
 sensilla to frequently locate a new host [36,37]. Isolation of Bartonella schoenbuchensis from Lipoptena cervi, a blood-sucking arthropod causing deer ked dermatitis. [Google Scholar] [CrossRef]Stange, G.; Stowe, S. Coeloconic grooved sensilla, almost always sunken in sensory pits, are mainly spread in the proximal part of the flagellum, while
multiporous basiconic sensilla occur around the arista (Figure 4A,C,D). The external edge of L. (B) Antennal section carried out at the distal part of the pedicel, housing the flagellum with its elaborate and trabeculate cuticle; (C) flagellum, sectioned subapically (c line
in A), showing some invaginations occupied by sensilla, as well as basiconic sensilla (bs), along with the typical cuticle; (D) detail of one of the cuticular cavities (sensory pit) occurring dorsally on the flagellum, accommodating several basiconic sensilla; (E) close-up view of the innermost part of a sensory pit: two basiconic sensilla are clearly visible
(B) 50 µm; (C) 100 µm; (D) 10 µm. Host location in hippoboscid flies needs to be further investigated, especially in those species in which newly emerged adults occur in areas with no availability of hosts, leading to an active host searching mediated by external stimuli, which are especially detected by antennal sensilla. Basiconic sensilla occur in
declare no conflict of interest. Handling procedures for vertebrate animals followed all regional, national, and institutional guidelines. Reeves, W.K.; Lloyd, J.E. Louse flies, keds, and bat flies (Hippoboscoidea). In Glossina morsitans, flagellar sensilla show a more complex pattern compared with that of hippoboscoid flies, displaying four types of sensilla
 basiconic, coeloconic, trichoid, and intermediate sensilla [38]. [Google Scholar] [CrossRef]McAlpine, J.F.; Peterson, B.V.; Shewell, G.E.; Teskey, H.J.; Vockeroth, J.R.; Wood, D.M. Manual of Nearctic Diptera, Volume 1, Monograph 27; Research Branch, Agriculture Canada: Ottawa, ON, Canada, 1981; pp. Grids were investigated with a Philips EM 208
responses to volatile organic compounds from the host plant and bacterial filtrate. This behavioural aspect has been demonstrated in members of the suborder Brachycera, such as muscids, tabanids, and glossinids [22]. Colour Preference
of the Deer Ked Lipoptena fortisetosa (Diptera: Hippoboscidae). cervi antennae presents different types of sensilla previously described [19]. [Google Scholar] [CrossRef] [PubMed]Sukontason, K.L.; Piangjai, S.; Boonchu, N.; Chaiwong, T.; Ngern-klun, R.; Sripakdeea, D.; Vogtsbergerb, R.C.; Olson, J.K. Antennal sensilla of some
the ciliary constrictions (cc) level, where the dendrite sheath originates. [Google Scholar] [CrossRef]Härkönen, L.; Kaunisto, S.; Kortet, R.; Laaksonen, S.; Kaunisto, S.; Kortet, R.; Laaksonen, R.;
housed inside a rounded socket and exhibits sturdy external grooves running from the base to the tip. © 2022 by the authors. 2010, 100, 279-285. However, further experiments, such as electrophysiological and behavioural bioassays, are needed to confirm these hypotheses. Similar to the previously described species, L. Plumose - the segments each
have a number of fine thread-like branches. For example, in P. Experiments on the ectoparasitic deer ked that often attacks humans; preferences for body parts, colour and temperature. The structure of the head and mouth-parts in the Nycteribiidae (Diptera Pupipara). Arthropod Struct. fortisetosa were collected in a wooded area in Schignance
(Prato) at about 550 m a.s.l. (43.967432 N; 11.101761 E). equina has a higher number of sensilla compared with the other three hippoboscid species of the Palpalis group (Diptera: Glossinidae). In fact, Glossinidae are free-living parasites
 which do not establish a permanent association with the host, with antennae more similar to Muscomorpha [30]. The pedicel (pe) surrounds the flagellum (fl). Micron 2011, 42, 471-477. In these hematophagous flies, antennae are always three-segmented with a well-developed external flagellum bearing a long arista which originates from the
dorsoproximal part of the segment [31]. fortisetosa were CO2 anaesthetised and thereafter immersed in a glutaraldehyde/paraformaldehyde solution (2.5% in 0.1 M cacodylate buffer +5% sucrose, pH 7.2-7.3) for 3-4 h. In fact, the partial or total fusion between the scape and the pedicel, together with the introflexion of the flagellum, likely allowed
the flies to reduce the antennal surface and consequently to mechanically protect these appendages inside the antennal sockets or fossae. [Google Scholar] [CrossRef] [PubMed]Meijerink, J.; Braks, M.A.H.; Van Loon, J.J.A. Olfactory receptors on the antennal surface and consequently to mechanically protect these appendages inside the antennal sockets or fossae.
components. Other antennal structures seem to be involved in the detection of temperature and humidity variations. The antenna tapers gradually from the base to the tip e.g. Bristletails, Cockroaches, Mayflies, Stoneflies and Caddisflies. However, a prevalence of coeloconic sensilla has been highlighted in all the investigated hippoboscids. After the
first fixation step, samples were rinsed twice in 0.1 M cacodylate buffer (15 min each step) and kept at 4 °C overnight. The family Hippoboscidae encompasses three subfamilies—Ornithomyinae, Hippoboscidae encompasses three subfamilies—Ornithomyinae, Hippoboscidae encompasses three subfamily Hippoboscidae encompasses three 
 Peterson, B.V. Streblidae. Close to the arista, the cuticle forms shallow depressions in which microspines are present. The aim of this research was to study the antennae of four hippoboscid species, Lipoptena cervi (Linnaeus, 1758), Lipoptena fortisetosa Maa, 1965, Hippobosca equina Linnaeus, 1758, and Pseudolynchia canariensis (Macquart, 1840)
 investigating the morphology and the sensory structures present on these appendages. Additionally, a small furcate arista protrudes in the ventral region of the hollow which is wallpapered by a dense covering of microtrichia (Figure 3C,D). in Lipoptena cervi and Lipoptena fortisetosa (Diptera: Hippoboscidae) and their potential role in the
transmission of pathogens. As in L. Recently, the Asian species L. Additionally, on the arista (properly termed as stylus) of the marsh fly Sepedon fuscipennis Loew 1859, mechanosensilla arranged differently in females and males may have possible functions related to mating and foraging behaviour [63]. Ultrastructural investigations on L. Bar scale
(A) 50 μm; (B,C) 30 μm; (B,C) 30 μm; (D) 5 μm. Hippobosca equina seems to display a higher number of sensory pits compared with the other three species, with most of these depressions housing coeloconic sensilla. Bar scale: (A,B) 2 μm; (C,D) 0.5 μm; (E-G) 1 μm. For Transmission Electron Microscopy (TEM), winged adults of L. [Google Scholar]
 [CrossRef]Kynkäänniemi, S.M.; Kettu, M.; Kortet, R.; Härkönen, L.; Kaitala, A.; Paakkonen, T.; Mustonen, A.M.; Nieminen, P.; Härkönen, H.; et al. Generally, among hippoboscids the scape is not well recognizable, being partially or completely fused with the lunula [20]. Selected pictures are displayed in the article. Lipoptena fortisetosa
 basiconic sensilla. The length and number of joints varies much between them. Olfactory sensilla on the antenna and maxillary palp of the sheep head fly, Hydrotaea irritans (Fallen) (Diptera: Muscidae). This arrangement is comparable to that of Hippoboscoidea and other parasites of veterinary importance, e.g., in the muscid flies Haematobia irritan
(Linnaeus, 1758) [33] and Hydrotaea irritans (Fallén, 1823) [34]. Hippobosca equina L. 2000, 29, 211-229. (B-G) TEM images of the bs; (B) longitudinal section of a bs characterized by a thin wall with many pores (po) and dendritic branches (db) entering the sensillum lumen. Parasitol. Figure 4. In both cases, the grouped sensory neurons are
embedded by dendrite sheaths. Basiconic sensilla (BS) can be mainly found inside the deeper cavities that are spread on the flagellum with numerous sensillar pits located mostly on the dorsoproximal part. [Google Scholar] [CrossRef] Andreani
A.; Sacchetti, P.; Belcari, A. Proximally, the cuticular shaft exhibits the typical double-walled organization delimiting an innermost lumen, housing two-three dendrites, and an outermost space (Figure 12D). domestica, and C. Sci. 2016, 2016, 3508073. In particular, the main sensory area, the flagellum, is concealed inside the pedicel. New bedding site
examination-based method to analyse deer ked (Lipoptena cervi) infection in cervids. [Google Scholar] obling, B. At this level the dendrite sheath appears less compact and not so tightly associated with the outer dendritic segments (ods). Host finding by female mosquitoes: Mechanisms of orientation to host odours and other cues. fortisetosa differ
month [24], so that the host-seeking period may be extended. TEM cross-sections show shallow cavities occupied by cuticular pegs and sparse basiconic sensilla are housed in deeper invaginations of the flagellum cuticular wall (Figure 8D,E). The typical stellate structure related to the presence of
cuticular ridges (cr) is visible. In Invertebrate Receptors; Carthy, J.D., Newell, G.E., Eds.; Symposia of the Zoological Society London, Academic Press: London, UK, 1968; Volume 23, pp. [Google Scholar] [CrossRef] [PubMed] Werszko, J.; Steiner-Bogdaszewski, W.; Szewczyk, T.; Kuryło, G.; Wołkowycki, M.; Wróblewski, P.; Karbowiak, G.
convey volatile compounds towards the flagellar sensory area. This trabecular organization of the surface appears even more evident in serial cross-sections of the antenna performed at the very distal region of the flagellum, as well as more proximally (Figure 8B,C). Recently, six types of microtrichia, including branched ones, have been detected also
on the flagellum of the tabanid fly Haematopota pandazisi (Krober, 1936) by Pezzi et al. Cross-sections under the sensillum base show the sensory neuron enclosed by a well-defined dendrite sheath and the thecogen cell (Figure 11E-G). [Google Scholar] [CrossRef]Duodu, S.; Madslien, K.; Hjelm, E.; Molin, Y.; Paziewska-Harris, A.; Harris, P.D.;
Colquhoun, D.J.; Ytrehus, B. canariensis, H. [Google Scholar]Krinsky, W.L. Tsetse flies (Glossinidae). The arista appears differently shaped in the species studied and is not articulated with the flagellum, which is a unique feature in dipterans. cervi, L. Additionally, the number and the arrangement of these two types of sensilla is different among the
investigated flies. In fact, because of their highly specialized parasitic lifestyle the main sensory area during the movements of the ectoparasites within the host coat. Soc. Hippobosca equina. Filiform antennae This is the most basic form of insect antennae. This
 sensillum is innervated by a single sensory neuron that is highly branched inside the sensory peg, for which a role in CO2 perception is hypothesized [59]. Antennae were excised from the heads and dissected to extract the internal flagella. Similarly, in Anopheles gambiae these sensilla are involved in ammonia detection [42]. In the planthopper
Hyalestes obsoletus Signoret, a grooved peg sensillum coeloconicum has been observed at the level of the expanded base of the thread-like flagellum. Predicting range expansion of an ectoparasite-the effect of spring and summer temperatures on deer ked Lipoptena cervi (Diptera: Hippoboscidae) performance along a latitudinal gradient. Heat and
colour take part in the host location at medium and short distances, as reported for L. Available online: (accessed on 20 April 2021). Dick, C.W. Checklist of World Hippoboscoidae (Diptera: Hippoboscoidae); Department of Zoology, Field Museum of Natural History: Chicago, IL, USA, 2006; pp. 2009, 104, 919-925. Lipoptena fortisetosa as a vector of
hippoboscid species living on mammals. This latter shows three dendritic branches; (E) cross-section at the base of the cs, where a thick dendrite sheath (ds) embeds two sensory neurons associated with multiporous sensilla is
 reported for other species belonging to different insect orders. Our findings confirm that these hippoboscids use chemoreception for host location, giving insights into this complex process in this poorly investigated group. Then, samples were post-fixed in a 1% osmium tetroxide solution (OsO4) for about 50 min. (A) SEM ventral view of the flagellum
been hypothesized for the described antennal structures. Figure 3. canariensis). [Google Scholar] [CrossRef]Pezzi, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Furini, M.; Giannerini, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Krčmar, S.; Chicca, M.; Bonacci, T.; Whitmore, D.; Whitmore,
filling the shaft lumen for all its length (Figure 11B-D). The ciliary constriction (cc) region appears as a throttling, from which the dendrite sheath starts to be visible; (E) longitudinal section of a microtrichium showing no evidence of associated sensory neurons. 1-321. Iran. Microbiol. [Google Scholar] [CrossRef]Kaunisto, S.; Kortet, R.; Härkönen, L.;
Härkönen, S.; Ylönen, H.; Laaksonen, S. PLoS Genet. Ultrastructural characterization of sensilla and microtrichia on the antenna of female Haematopota pandazisi (Diptera: Tabanidae). Glob. [21] speculated that these modifications may have caused the lack of the primary sensory function (olfaction), defining these flies as "inactive ectoparasites"
 1982, 16, 247-356. [Google Scholar] [CrossRef] [PubMed]Dehghani Samani, A.; Pirali Kheirabadi, K.; Dehghani Samani, A. The internal double-walled organization of the cuticle appears clear at this level, defining an outermost (ol) and an innermost lumen. The antenna is housed inside a deep antennal fossa which encloses almost all the segmen
surface (Figure 7C). Figure 6. [Google Scholar] [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [Google Scholar] [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [Google Scholar] [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed]White, S.L.; Bay, D.E. Antennal olfactory sensilla of the horn fly, Haematobia irritans (L.) (Diptera: Muscidae). [CrossRef] [PubMed] [PubMed] [PubMed] [PubMed] [
pedicel edge; (B) lateral view of the opened pedicel with microtrichia (mt) showing the introflexed flagellum with the characteristic trabecular surface; (C) ventrolateral view of the dissected pedicel displaying the arista with
furcate microtrichia (mt). The anterior part of the flagellum bears the arista (ar) that protrudes externally from the pedicel; (B,C) TEM cross-section of the whole antenna taken according to the two dotted lines depicted in (A). [Google Scholar] [CrossRef]Cardé, R.T.; Gibson, G. Die Verwandtschaftsbeziehungen der Pupiparen und die Morphologie der
Sternalregion des Thorax der Dipteren. Figure 10. 2020, 34, 344-363. cervi), fan-shaped (L. Comparative morphology of the deer ked Lipoptena fortisetosa first recorded from Italy. [Google Scholar] [PubMed]Hu, F.; Zhang, G.N.; Jia, F.X.; Dou, W.; Wang, J.J. Morphological characterization and distribution of antennal sensilla of six fruit
flies (Diptera: Tephritidae). equina, where the distribution of these sensilla has been mapped, highlighting the higher abundance of coeloconic compared with basiconic sensilla [21]. Internally, a single sensory neuron innervates each sensillum. [Google Scholar] [CrossRef]Hutson, A.M. Keds, flat-flies and bat-flies. Drosophila mutant model of
Parkinson's disease revealed an unexpected olfactory performance: Morphofunctional evidences. [Google Scholar] [CrossRef]Yao, C.A.; Ignell, R.; Carlson, J.R. Chemosensory coding by neurons in the coeloconic sensilla of the Drosophila antenna. All the examples quoted are from insect groups with British representatives. Ultrathin sections (60-90)
nm) were collected using formvar coated, 50 mesh copper grids, and then stained with uranyl acetate (20 min at room temperature). Figure 11. Invertebr. Illustration of filiform antennae. Lipoptena cervi. Peculiar sensory neurons characterize the unarticulated arista which could be able to detect
temperature variations. Insect Morphol. Figure 8. In Medical and Veterinary Entomology, 3rd ed.; Mullen, G.R., Durden, L.A., Eds.; Elsevier: London, UK, 2019; pp. Types, external organization, innervation and distribution of olfactory sensilla. Three mechanosensory bristles are present on the distal part of the segment [19]. Serial cross and
longitudinal sections reveal the presence of a single sensory neuron with a large cell body containing a prominent nucleus and a relatively short inner dendritic segment (Figure 9D). melanogaster, coeloconic grooved sensilla are involved in the detection of ammonia, ketones, and amines [41]; moreover, these kinds of sensilla are able to perceive
humidity variations, but not temperature changes [41]. (A) Lateral view of flagellum with cuticular pits housing mainly grooved coeloconic sensilla and rare basiconic sensilla and rare basiconic sensilla. For this reason, microtrichia do not play a primary role in the sensory perception but, being furcated in two or three branches and forming a kind of dense carpet of hairs, could
be involved in directing odours, conveying them towards the internal sensory area on the flagellum. 2019, 15, e1008005. equina adults were picked up from horses in a stable in Marradi (Firenze). J. [Google Scholar] [CrossRef]Romani, R.; Stacconi, M.V.R.; Riolo, P.; Isidoro, N. Kans. Acta Trop. G Vet. fortisetosa revealed that microtrichia and the
flagellar reticulated cuticle are not innervated. The dendrite sheath (ds) enters the sensillum and embeds the sensory neuron until it starts branching fortisetosa and H. The large filiform antennae of a solitary bee. (A-B) SEM pictures showing two coeloconic sensilla (cs) inserted on the flagellar wall. Lipoptena fortisetosa. Trop. The apical part of a
single sensory neuron (tubular body, tb) that innervates the associated mechanosensory bristle is depicted, in military livestock from Tunisia. 2019, 19, 15-19. Several representatives of these three subfamilies are well known for their veterinary and medical importance, since they can be responsible for diseases harmful to humans and animals
[4]. Among members of the subfamily Ornithomyinae, Pseudolynchia canariensis Macquart (the pigeon fly) is a medium-sized specially on Columbiformes. Antennal sensory structures of hippoboscid flies have been studied in Hippoboscid flies have been studi
thermoreception, hygroreception, and carbon dioxide reception at long distances, while the poorly porous basiconic sensilla could play a role in the host odour perception at medium-short distances, while the poorly porous basiconic sensilla could play a role in the host odour perception at long distances, while the poorly porous basiconic sensilla could play a role in the host odour perception at long distances, while the poorly porous basiconic sensilla could play a role in the host odour perception at long distances.
porous chemosensilla, which are mainly present inside the sensory pits, to improve the perception of volatile stimuli. Available online: (accessed on 4 January 2022). Been, T.H.; Schomaker, C.H.; Thomas, G. canariensis antennae, depicted in Figure 1A-C, displays the arrangement of these appendages protruding externally from the socket with the
scape articulated with both the lunula and the proximal part of the pedicel, to some extent, fused with the scape (Figure 1A,B). Several long bristles constitute the external sensillar apparatus of the first two segments, which have been described in a previous paper [19]. [Google Scholar] Diehl, P.A.; Vlimant, M.; Guerenstein, P.;
Guerin, P.M. Ultrastructure and receptor cell responses of the antennae, which are the essential olfactory organs. The cross-section of the
proximal part of the arista displays a lumen filled with extracellular material (Figure 4B). The thinner and shorter microtrichia present on the dorsolateral side of the pedicel are not innervated (Figure 4B). The thinner and shorter microtrichia present on the dorsolateral side of the pedicel are not innervated (Figure 4B). The thinner and shorter microtrichia present on the dorsolateral side of the pedicel are not innervated (Figure 4B).
portion, stick-like, that is connected to the flagellum; and a distal region that is enlarged and fan-like (Figure 10A). 2002, 39, 36-43. (A) Dorsal view of the bean-like pedicel showing sparse microtrichia (mt) thickening close to the hollow from which the arista (ar)
protrudes with a spatulate tip; (C) light microscopy cross-section of the head showing the deep and large antennal fossa (af), where the pedicel is inserted. Bar scale: (A) 50 µm; (B) 2 µm. Figure 5. Clin. 2015, 52, 614-621. 1283-1291. Am. 2010, 103, 661-670. At this level, the base of the arista is connected with the flagellum
However, in nycteribids, the piriform flagellum differs from that of hippoboscids in the surface pattern and for the sensory pits, only in terms of position and number. Adv. infecting wild and domestic ruminants. 1980, 25, 27-47. These flies belong to the superfamily Hippoboscoidea together with other important families, such as Glossinidae (tsetse
flies), Nycteribiidae, and Streblidae (bat flies) [1]. The flagellum is marked by an irregular surface of dense and long microtrichia mixed with cuticular trabeculae, uniformly arranged and forming several pits located on the dorsolateral area (Figure 2). 2019, 33, 140-153. This article is an open access article distributed under the terms and conditions
of the Creative Commons Attribution (CC BY) license (. These sensilla have a typical organization with a short cuticular shaft positioned inside a shallow depression. Molecular detection of Bartonella spp. Environ. The shaft is inserted on the antennal wall without a flexible socket (Figure 11B). 1999, 47, 416-427. 1. In fact, the flagellar surface
appears reticulose and bears only four sensory pits located on the dorsodistal part [28]. Figure 12. fortisetosa revealed that no sensilla on the external surface, nor are cuticular pores present. cervi for territories and host microniches [18]. The four above-mentioned hippoboscid flies live at the expense of a few host species, wherewith they established
a strict interaction depending on the host behaviour and morphology. (A) SEM dorsolateral view of the antenna: the arista (ar), the long and sharply pointed long bristles (mb), and numerous thin microtrichia (mt) are clearly visible; (B,C) TEM cross-sections of the whole antenna taken along the dotted line depicted in (A). This means that a number of
different types may be recognised. 1-674. [Google Scholar] [CrossRef]Kurtovic, A.; Widmer, A.; Widmer, A.; Widmer, A.; Widmer, A.; Widmer, A.; Dickson, B.J. A single class of olfactory neurons mediates behavioural responses to a Drosophila sex pheromone. Med. The antennae are actually the insects 'nose' - they are used for the sense of smell. Ent. These groups show examples of a number of
different antenna types. In fact, electrophysiological studies demonstrated that neurons associated with coeloconic sensilla were activated by different kinds of external stimuli, such as CO2, temperature, and humidity, in many species of insects [57,58]. Lamellate - the segments towards the end are flattened and plate-like. Ultrastructural
investigation of antennae in three cutaneous myiasis flies: Melophagus ovinus, Hippobosca equina, and Hippobosca equina, and Hippobosca equina, and Hippobosca longipennis (Diptera: Hippobosca equina, and Hi
the studied hippoboscid flies reveals how the host location process in these ectoparasites is quite complex; in fact, the abundance of coeloconic grooved sensilla supports the long-distance activation of the newly emerged winged adults of L.
Within Diptera, sensilla basiconica are described in detail in D. Vector. It may transmit to its hosts the avian malaria parasite, Haemoproteus columbae Kruse, and, additionally, it can produce skin dermatitis in case of severe infestations [5]. Bar scale: (A) 50 µm; (B) 10 µm; (C,D,F) 2 µm; (E) 10 µm. The flattened distal region examined through TEM
shows no lumen (Figure 10B.C). The surface of the flagellum is covered by a reticulated cuticle from which short microtrichia rise up. Otherwise, it is also possible that this segment is not completely absent, but fused with the pedicel, as postulated for species of Nycteribiidae [25]. Sections carried out more proximally show dendrities still embedded
by the dendrite sheath, but this appears less thick and tight (Figure 12F). The antennal appearatus of the described hippoboscids reveals a general similar arrangement in the structure of the segments in both sexes. fortisetosa, it houses peculiar sensory neurons. Finally, we hypothesize that locating hosts at medium and long distances in winged adult
hippoboscids occurs mainly due to these sensilla; although, it is a complex process that involves visual stimuli as well. This structure shows a remarkable difference in the morphology of the distal part, being furcate (L. Given the concealment of the flagellum and the reduction in the other antennal segments, Zhang et al. fortisetosa, we hypothesize
that the great reduction in number and size of sensilla basiconica, as well as in the number of associate sensory neurons, could be linked to the reduced range of volatiles exploited during intra- and interspecific interactions. The arista was unarticulated in all the four investigated hippoboscids. Appl. This means they can be very mobile. Winged adults
were caught by sweeping, maintained in microvials containing a small piece of cotton soaked with water and sugar, and kept at low temperature (4-6 °C) for a few days, pending TEM analysis. All hippoboscid adults (at least 20 specimens each species, about 60 for L. As already mentioned, this morpho-functional organization protects the antennal
sensory function of hippoboscids in a dense and harsh environment, such as the animal coat [19]. The morphology and location of antennae in Nycteribidae (Hippoboscoidea) are quite similar to those of the four species studied in this paper. 1988, 17, 121-133. Asia-Pac. Available online: (accessed on 30 January 2020). Bezerra-Santos,
M.A.; Otranto, D. 2013, 79, 322-327. These microtrichia are shorter and display a wider base than those of P. The antennae of the Lepidoptera, Neuroptera, P.M.; Chiarini-Garcia, H. (A) Dorsal view of antenna housed in the large antennal fossa,
bearing three mechanosensory sensilla (mb). Res. Longitudinal sectioning reveals a cuticular shaft made of a thin cuticle perforated by numerous pores distributed on the distal half (Figure 11B-D). From the somata (so), a relatively short inner dendritic segment
(ods). Right below the socket, from the increase in the arista size, and this could explain the low number of sensory neurons
recorded in L. Figure 6. The antennae of some specimens were isolated from the rest of the head capsule to reduce the size of the structure; (B) ventral view of the antennae with the pedicel partially covered by a
dense layer of microtrichia (mt) present also on the wall of the antennal fossa; (C,D) lateral and dorsal view of the antenna showing microtrichia (mt) present also on the typical branched arista (ar). These processes have been observed for their ultrastructure on L. [Google Scholar] [CrossRef]Lee, S.H.; Kim, K.T.; Kwon, O.D.; Ock, Y.; Kim, T.; Choi, D.; Kwak, D.
Can. Nature 2007, 446, 542-546. After that, the samples were rinsed again in distilled water to remove KOH residues. [Google Scholar] [CrossRef]Gibson, G.; Torr, S.J. Visual and olfactory responses of haematophagous Diptera to host stimuli. Parasitology 2020, 147, 1629-1635. Moreover, the pedicel surface adjacent to the fronto-clypeus is partially
covered by microtrichia. The arista appears flattened and without a perceptible internal lumen in (B,C), while in (D) the cuticle is thicker, and the small lumen is occupied by extracellular material; (E) TEM reconstruction obtained combining nine different pictures showing a cross-section of the region as reported in (A). Int. The lack of external
sensory structures differs from that observed on the arista of the human bot fly, Dermatobia hominis (Linnaeus Jr. in Pallas, 1781), which showed different kinds of receptors, such as Dragonflies, Grasshoppers and Crickets, Book Lice,
Biting Lice, Scorpion Flies and Beetles. Vet. 2011, 25, 327-336. Understanding how ectoparasites belonging to the Hippoboscidae locate their hosts is crucial, since these flies infest animals and can attack humans, with veterinary and medical implications. Tech. Available online: (accessed on 4 January 2022). Moniliform - The round segments make
the antenna look like a string of beads e.g. Beetles. This is a wrong name because they are not only used for touch. Their arrangement on the flagellum, while basiconic sensilla are fewer and are mainly distributed in the anterior
part of the segment, around the base of the arista. longipennis Fabricius, and Melophagous ovinus L., where the external surface of the flagella have different kinds of sensilla [21]. Two groups of neurons can be differentiated, one with three (ne3) and another with two neurons (ne2), in both cases enclosed by a dendrite sheath (ds). Similarly,
basiconic sensilla are more represented in some saprophagous species [49,50,51,52], as well as in phytophagous dipterans like fruit flies [53,54]. These structures are generally involved in volatile detection, such as CO2, ammonia, and other odours, but they can also play a role in perceiving changes in humidity and temperature. 1293-1301. cervi
winged adults usually landed on the hotter part, demonstrating that they were attracted to and perceived temperature at short distance [46]. The basic form of antenna is filiform. TEM data were obtained at the "Centro Universitario di Microscopia Elettronica e Fluorescenza (CUMEF; Università degli Studi di Perugia, Italy)". The four studied species
show a similar arrangement of the antennal pattern with antennae inserted inside peculiar head cavities, named fossae or antennal sockets. Pseudolynchia canariensis. Figure 7. Some pores are visible (arrowheads); (D) cross-section showing two bs sectioned at their distal region: clusters of dendritic branches filling the lumen are visible, as well as
several cuticular pores. Academic Editor: Jiří Skuhrovec Insects 2022, 13(3), 236; Received: 21 February 2022 / Revised: 21 February 2022 / Revised: 21 February 2022 / Revised: 22 February 2022 / Revised: 23 February 2022 / Revised: 24 February 2022 / Revised: 25 February 2022 / Revised: 26 February 2022 / Revised: 27 February 2022 / Revised: 27 February 2022 / Revised: 28 February 2022 / Revised: 28 February 2022 / Revised: 29 February 2022 / Revised: 29 February 2022 / Revised: 20 February 2
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[CrossRef]Boo, K.S.; McIver, S.B. Fine structure of sunken thick-walled pegs (sensilla ampullacea and coeloconica) on the antennae of mosquitoes. fortisetosa and are not innervated. 2004 [8]. [Google Scholar] [CrossRef]Foelix, R.F.; Steinbrecht, R.A. Fine structure of a sensory organ in the arista of Drosophila melanogaster and some other dipterans. (A) Dorsolateral view of the flagellum showing a typical trabecular surface and the non-articulated arista (ar) with the branched tip. Additionally, we can speculate that, once the principal odour stimulus is detected, other factors may guide the adult towards the host, canariensis, the scape is distinguishable and partially articulated with the fronto-clypeal region and the lunula, as also seen in the Nearctic louse flies Olfersia fumipennis (Sahlberg, 1849), Ornithoctona erythrocephala Leach, 1817, and Icosta americana (Leach, 1817) [20], 1997, 3, 127-135. The limited number of pores on the basiconic walls could be due to the perception of the host at short-medium distances. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. However, full heads were also processed. [Google Scholar] [CrossRef] [PubMed] Figure 1. 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The bs is surrounded by the elaborated cuticular sculpture of the flagellar wall. For instance, H. Subsequently, adults were dehydrated in a series of graded ethanol concentration). Additionally, in hippoboscid species, the lack of the external flagellum may have led during the evolution process to the development of these sockets which could act as a funnel, directing external volatile compounds towards the sensilla located on the introflexed flagellum. Noteworthy are the microtrichia which densely cover the antennal hollow of the four hippoboscid flies. Microsc. [Google Scholar] [CrossRef]Lourenço, S.I.; Palmeirim, J.M. How do ectoparasitic nycteribiids locate their bat hosts? Vectors 2017, 10, 487. Except for P. [Google Scholar] [CrossRef]Shanbhag, S.R.; Müller, B.; Steinbrecht, R.A. Atlas of olfactory organs of Drosophila melanogaster. Hippoboscids are obligate hematophagous ectoparasites of vertebrates. 2013, 145, 265-272. fortisetosa) were anaesthetized at -20 °C for 20 min and then maintained in 70% ethanol pending preparation procedures. 2020, 23, 1165-1180. fortisetosa (five) compared with the amount found in D. [Google Scholar] [CrossRef]Schneider, D.; Steinbrecht, R.A. Checklist of insect olfactory sensilla. Each sample was finally infiltrated with an Epon-Araldite resin and incubated at 65 °C for 48 h. 2015, 114, 1887-1896. Taxon. This gives the appearance of a feather e.g. Flies. Figure 2. Bar scale: (A) 20 µm; (B) 2 µm; (C,D), 1 µm. Micron 2004, 35, 671-679. Thus, the arrangement of the antennae in tsetse flies is similar to those of higher dipterans, but these appendages are housed in a deeper antennal socket [32], which presumably protect the flagella during the trophic activity. Molecular detection of selected pathogens with zoonotic potential in deer keds (Lipoptena fortisetosa). [Google Scholar] [CrossRef] [PubMed] [Zacharuk, R.Y. Ultrastructure and function of insect chemosensilla. Digital photographs (1376 × 1032 pixels, 8 bit, uncompressed greyscale TIFF files) were obtained using a high-resolution digital camera MegaView III (SIS, Muenster, Germany) connected to the TEM. The lumen of the arista displays a region (dotted square in (E) where (F) groups of neurons are visible. (A) Frontal view of the head with antennae (a), which are partially fused with the lunula (l) and the fronto-clypeus (fc); (B) dorsal view of the antenna with the visible articulation between the scape (s) and the protruding arista; (D) flagellum with the non-articulated, shovel-shaped arista (ar). Pathogens 2021, 10, 324. (A) Ventral view of the antenna with arista protruding from the hollow densely covered by microtrichia. This species can also act as a vector of pathogens dangerous both to animals and humans, such as Anaplasma spp. canariensis, the scape and pedicel are fused and house the third segment, the flagellum. The outer part of P. [Google Scholar] [CrossRef] Lehane, M.J. The Biology of Blood-Sucking in Insects, 2nd ed.; Cambridge University Press: Cambridge, UK, 2005; pp. Figure 10. 369–382. [Google Scholar] [CrossRef] Setzu, M.D.; Poddighe, S.; Angioy, A.M. Sensilla on the antennal funiculus of the blow fly, Protophormia terraenovae (Diptera: Calliphoridae). A non-articulated branched arista protrudes from the pedicel hollow, named antennal sockets or fossae. canariensis. Insects 2021, 12, 845. The multiporous basiconic sensilla occurring on L. Specimens were removed from ethanol, rinsed with distilled water several times, and then sonicated for 15 min in a 10% potassium hydroxide (KOH) distilled water solution to remove impurities and secretions from their bodies. Subsequently, specimens were exposed to pure propylene-oxide, then to a 50/50 blend of propylene oxide and Epon-Araldite resin to improve resin infiltration. Molecular detection of Trypanosoma spp. [PubMed]Arafa, M.I.; Hamouda, S.M.; Rateb, H.Z.; Abdel-Hafeez, M.M.; Aamer, A.A. Oedematous Skin Disease (OSD) transmission among buffaloes. Although the arista tips are so diverse, our investigations performed on L. dufourii (Westwood, 1835), were found to be more active moving more often towards the heat source; although they responded more strongly to the combination of carbon dioxide and heat stimuli [47]. Regarding basiconic sensilla. It is noteworthy that externally the arista does not show any specialized cuticular structures that could be related to a sensory function. Note the cuticular depressions housing sensilla; (B) magnification of the dorsodistal part of the flagellum showing trabeculae and sensory pits; (D) magnification of a multiporous basiconic (bs) sensillum and a grooved coeloconic sensillum (cs). Figure 2. [Google Scholar] [CrossRef]Isaac, C.; Ravaiano, S.V.; Vicari Pascini, T.; Ferreira Martins, G. As a matter of fact, a previous work conducted in field using people with two heated bags to one shoulder and two cold bags to the other shoulder, showed that L. All microscopy data are available from the authors upon request. The authors would like to thank Laura Chiarantini (Centro di Servizi di Microscopia Elettronica e Microanalisi, Università di Firenze, MEMA) for invaluable technical assistance in SEM investigations; Riccardo Antonelli (Department of Agriculture, Food and Environment, University of Pisa) is truly acknowledged for his helpful contribution to SEM investigations. 1980, 53, 641-652. After rinsing with the same buffer, specimens were then dehydrated in a graded series of ethanol (from 50 to 90% with 10% increasing concentration each, then 95% and 99%), with each step lasting 15 min. Bar scale: (A) 50 µm; (B), 1 µm; (C-E) 2 µm. fortisetosa), branched (H. Figure 4. Embedded samples were sectioned using a diamond knife (Drukker) using a Bromma ultramicrotome (LKB, Stockholm, Sweden). An unbranched arista, with a shovel-shaped (Figure 2A). 1975, 53, 262-266. Insect Physiol. Rev. Prevalence and rate of parasitemia of Haemoproteus columbae in Columba livia domestica in Southwest of Iran. Annu. equina the microtrichia are present also on the internal surface of the antennal fossa, lending support to this hypothesized role. to the base of the arista, with an apparent lack of connection with the external cuticle. These insects require remarkable energy expenses to detect external signals, mainly odour cues. The cuticular shaft is made of thick cuticle with a small lumen located in the centre, where no dendritic branches are found. Within these hollows, different kinds of receptors, mainly coeleconic grooved and a few basiconic sensilla, are interspersed. In this species, the antennal socket with only the dorsal surface externally exposed and entirely covered by microtrichia except for a small area on the top (Figure 3A,B). Berl. In fact, Nycteribiidae and Streblidae species display the reduction or absence of the first antennal segment, the scape, and the complete or partial introflexion of the flagellum inside the previous segment.

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