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PERCEPTION OF ENVIRONMENT IN FARM ANIMALS – A REVIEW*

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Abstract

Perception of the environment by farm animals is fundamental for expression of behaviour and of their adaptation to different environmental conditions. From a breeding-environmental perspective, perception becomes increasingly important when a production system negatively impacts on animals such that their normal expression of behaviour is compromised. Therefore, research on the perceptual abilities of farm animals is of crucial importance to understand the animal-environment relationship. This review is focused on research related to sensory perception of farm animals. It should be stressed that the world of animal senses is very difficult to explore, we have limited knowledge of the complexity of the animal's ability to perceive and process environmental stimuli.

Key words: farm animals, perception, senses, environment

Perception of the environment by farm animals has an important effect on their general behaviour and cognitive/learning ability (Jezierski, 2004; Broom, 2010; Mery, 2013). It is recognized that domestic animals generally have smaller brains and are less sensitive to environmental stimuli compared to their ancestors (Price, 1999; Diamond, 2002). Recent decades have seen a rapid change in the husbandry systems of the main species of farm animals – cattle, pigs and poultry (Diamond,

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2002; Robinson et al., 2011). As a consequence the animal-environment relationships, in which senses play a key role, have changed (Holloway, 2007; Hemsworth and Coleman, 2011; Eadie, 2012). This mainly affects animals maintained under intensive production conditions, such as domestic fowl, pigs, and high-yielding dairy cows, especially when environmental factors (i.e. limited visibility, poor ventilation) are negatively affected, thereby impacting on animal welfare (Halverson, 2001; Thornton, 2010; Butterworth, 2013).

Basic and applied research of the senses, which are crucial for perception of the environment by animals, has been conducted for many years in different livestock species. Generally, relevant environmental stimuli, affecting important life processes, are complicated and in evolutionary adaptation may involve more than one of the senses. For example the sense of sight with wide field of vision is one of the most important adaptation responses of herbivore ungulates, providing them with the ability to protect against attacks by predators. However, defense or escape is such an important part of animal life that with every sense of distance, perception is engaged in searching and identifying predators (Lima and Dill, 1990). Cooperation of far-sighted wide vision, sensitive hearing and smell, enables an animal to use its space optimally and at the same time ward off predator attacks (Kie, 1999; Laundré et al., 2001). Most farm animals are relatively safe from predators, however, free ranging domestic animals like sheep and goats sometimes must confront predation pressure, and research has shown that such species portray anti-predator behaviour (Shrader et al., 2008). The second important part of life is the acquisition of food. The sense of sight cooperating with smell allow distance recognition of plants according to aroma, shape, brightness, colours, and even patterns on a leaf (Favreau-Peigné et al., 2013). The sense of smell can cooperate with taste and touch in food selection in direct contact allowing firstly acceptance of smell, then physical characteristic of food and finally taste giving global stimulation of oro-pharyngeal area and enabling avoiding of toxic plants (Favreau-Peigné et al., 2013). The senses of sight, smell, hearing and touch cooperate in establishing and maintaining relationships among animals and thus influence reproduction through male and female effect (Delgadillo et al., 2009). In seasonal species the sense of sight allows detection of day length influencing physiology and endocrinology, however, the sense of smell and taste cooperate with sight allowing recognition of seasonal changes in food quantity and/or quality (Dohi et al., 1996; Duarte et al., 2010). Biological and evolutionary significance of the senses and perception is crucial for every life process as well as the adaptation ability of animals to their environment. Consequently, research in this area is important with regard to assessing and ensuring optimum conditions that meet the minimum requirements for animal welfare protection (Jensen, 2009; Broom, 2011).

The aim of the present review was to analyze and summarize current knowledge regarding sensory perception in farm animals with regard to species specificity.

Senses in farm animals

Cattle

Cattle are diurnal animals that show preference for places with diffuse lighting and avoid areas with excessive sun exposure. The optimal photoperiod for adult dairy cows is 16–18 hours (Dahl and Petitclerc, 2003). Accordingly, vision is the dominant sense in cattle, as they obtain almost 50% of their information visually. Bovines have been shown to identify a wide spectrum of colours, but perceive warm colours (yellow, red, orange) more easily than cold colours (purple, blue, green). Moreover bovines can distinguish between geometric figures (triangles, circles, straight lines) (Gilbert and Arave, 1986; Phillips, 2002; Blackshaw, 1986/2003). Due to the shape of the head and the location of the eyes, cattle have a large binocular field of vision (about 330°) and a small binocular field (25–50°). Compared to humans, the visual accommodation of cattle is poor. Animals pay greater attention to moving objects than to static ones, but their perception of motion is less fluid than in humans. Therefore, sudden movements by humans may cause anxiety and even panic reactions in animals (Phillips, 2002; Blackshaw, 1986/2003; Heffner and Heffner, 2010; Grandin, 2014).

Research shows that cattle have a hearing range of 20 Hz to 35 kHz. Bovines are more sensitive to high-pitched sounds than humans, for whom the hearing threshold is 10–18 kHz depending on age and noise level. However, the poor sound localization abilities of cattle may make them more fearful (Ahmed et al., 2001; Phillips, 2002).

The sense of taste is very well developed in cattle (Roura et al., 2008). Animals of this species can distinguish the four primary tastes (sweet, salty, bitter and sour), with the strength of taste perception depending largely on the animal's current food requirement. Cattle are unwilling to consume feeds that are bitter in taste (potential presence of harmful substances) and show a marked preference for sweet (energy value of the feed) and salty feeds (proper electrolyte balance of body fluids). In turn, their sensitivity to sour taste helps them to maintain optimal ruminal pH (Phillips, 2002; Ginane et al., 2011).

Olfaction is the least understood of the senses in cattle. This sense has not been conclusively shown to play a major role in the selection of feed. Yet, cattle are considered macrosmatic animals, i.e. those with a keen sense of smell as they possess the vomeronasal organ/Jacobson organ (VO). Olfactory substances reach it during the behaviour known as flehmen. In general, animals use their smell to "expand" the information gathered by other senses, although in the case of social and reproductive behaviours it is a key source of information (Lyons and Machen, 2000; Phillips, 2002).

Tactile sensations in cattle are detected mainly by mechano- and thermoreceptors as well as nociceptors (pain receptors) located on the skin and muzzle, which are used most frequently when animals explore their environment (Blackshaw, 1986/2003; Phillips, 2002; Herskin et al., 2004).

It is perceived that cattle feel physical pain in a similar way to humans. However, since they are a natural part of the food chain they do not show obvious signs of pain. This stems from the fact that under natural conditions the signs of pain shown by animals may provoke an attack from predators (Bomzon, 2011). Moreover, the fact that the cerebral cortex of animals is less developed than in humans does not necessarily mean that cattle have a much lower capacity to feel mental pain, but may indicate that these animals suffer less psychologically from the long-term consequences of pain (fear, depression) (Iggo, 1984; Phillips, 2002).

Sheep

The sense that is particularly sensitive to information processing in sheep is vision. The structure and position of the eyes in this species is evidence that they have adapted to the environment as potential victims of predatory animals. Eyes are positioned to give a wide field of vision, about 290°, with small movements of the head. The extensive visual field allows a sheep to maintain eye contact and spatial relationships with animals not only in front of it, but also behind it and on both sides. A large eyeball with a well developed reflective membrane increases sensitivity of the retina by the reflected light, which allows the sheep to see well in low light. Like other ungulates sheep show dichromatic vision, unlike humans who are trichromats (Jacobs et al., 1998). Two-colour vision can probably provide more accurate motion detection, thus avoiding danger. Dichromatic vision limits the vision of all the colours so that the sheep cannot see the colour red. For red/orange objects sheep sense it as gray or light yellow, depending on the intensity of the colour. In addition, sheep sense green colour as yellowish, which is why there is no visual difference between grass in the pasture and hay (Kendrick, 2008). Thus allowing the sheep flock to stay together enables quick communication among them (Piggins and Philips, 1996). Sheep are also able to visually identify pasture sward (e.g. grass and clover), which enables them to follow their own feeding preferences on the pasture (Bazely, 1988; Kendrick, 1992). Tests to identify geometric shapes revealed that sheep can learn to distinguish basic geometric shapes (Baldwin, 1981). Visual cues are very important for the social relations between members of the flock and are essential for the bonding of the mother to her offspring. Research shows that ewes learn to identify their lambs by their faces. White lambs that had their faces dyed dark were not identified by their dams from a large distance (Shillito-Walser, 1977). A subsequent study demonstrated that sheep can discriminate between human faces, those of other sheep, and faces within their breed according to sex and earlier acquaintance (Kendrick et al., 1995).

A survey showed that sheep have a similar hearing sensitivity to humans (about 10 dB). Sheep hear low frequency better (125 Hz) than humans (20–40 Hz).

High frequencies are heard by sheep in the field of ultrasound (42 kHz), it is a much higher range than in humans (20 kHz) and slightly lower in dogs (50 kHz) (Kendrick, 2008). It is therefore necessary to bear in mind the potential effects of exposure of sheep to stressful impact of ultrasound, which man is not able to hear (for example, the sounds made by machines). In social animals, the manifestation of emotions is an important means of communication. Different emotions are expressed by body posture and changes in facial features. In sheep, this is limited to presenting negative feelings such as stress or anxiety (protruding eyes, narrow pupils, flared nostrils and flattened ears), while the absence of these emotions plays an important role during social communication (Tate et al., 2006). Observations of sheep show that they are very sensitive to sounds and quickly identify their sources (Kendrick, 2008). Research demonstrates that ewes learn to recognize their lambs also by auditory cues and a sheep can recognize the voice of her lambs soon after birth (Shillito, 1975). It is well recognized that ewes can recognize individual flock members and humans based on their voices. Experiments using a Y-maze showed that sheep can discriminate between sheep and human vocalizations (Kendrick et al., 1995). When a sheep wants to express different emotional states, they use different pitched sounds, but these differences are not always recognizable by humans.

Taste is based on the integrated olfactory, tactile and thermal sensations. Taste receptors distributed around the mouth are the beginning of the taste trail. In seasonal animals which include sheep, stimulating taste receptors plays an important role in the activities of food intake, and therefore metabolic hormone secretion (ghrelin, leptin, orexin) (Henry and Clarke, 2008; Abizaid, 2009). Taste impulses reaching the limbic system (mainly the hypothalamus and amygdala) are relevant for the assessment of food.

Olfactory signals from the environment are received by two anatomically and physiologically independent sensory systems, the olfactory epithelium and VO. The olfactory epithelium is primarily used to collect distributed odour molecules in the air while the VO to detect more volatile molecules, such as pheromones, which belong to the semiochemical substances for the transfer of information between individuals of the same species (Swaney and Keverne, 2009). The sense of olfaction plays a significant role in forming the ewe-lamb relationship. Ewes learn to recognize their lambs by olfaction within 1–2 h of giving birth. The characteristic odour, by which the ewe learns to identify her lambs, comes mainly from the lamb's wool, skin and genital area (Kendrick et al., 2001). Odour cues are also important for recognizing other members of the same flock. When animals from several different flocks were mixed together, they had no problem in recognizing their flock mates. The characteristic odour of a flock will comprise the odours of different individuals and environmental odour cues (soil, vegetation) (Arnold, 1985). Like in other domesticated mammals, environmental olfactory cues are received by two anatomically and physiologically independent sensory systems: the olfactory epithelium and the VO. The olfactory epithelium serves to capture odorant molecules from the air, while the VO is used to detect pheromones (Galez and Fabre-Nys, 2007).

The sensory receptors located in different layers of the skin react to mechanical stimuli from the external environment. In sheep, not only external feeling is important but also deep internal feeling regarding motor functions (for example arrangement of limbs) (Bell et al., 1994).

Sensation of pain and adverse temperature changes in sheep are associated with animal stress. Sheep demonstrated the occurrence of stress-induced (fleece) hyperthermia (SIH). After the surcease of the stress factor, cortisol levels and body temperature returned to normal. Sheep are resistant to low temperatures, and less tolerant of cold blasts of air (draft) (Doyle et al., 2011).

Goats

As social browser animals, goats are well adapted to the environment not only from nutritional and reproductive point of view, but also due to the development of the sensory organs (Langbein et al., 2008).

Caprine field of vision is similar to other ruminants 320–340° of monocular field, with similar eye anatomy including specific, rectangle shape of retina (Chiao et al., 2000; Blackshaw, 1986/2003). Different breeds of goats have similar but not identical field of vision which is mainly related to housing conditions and environment, causing differences in ocular morphometry (Olopade et al., 2005). A disadvantage of such large peripheral vision is binocular field of vision reduced to 20–60° and thus small ability of stereoscopic vision. Additionally, goats are farsighted, and poorly perceive space in front of them and image depth (Blackshaw, 1986/2003). The inability to assess the distance accurately is compensated by possibility for quick and effective detection of move in long distance, which is much more important to avoid predator attack (Shrader et al., 2008). The caprine eye is characterized by large size of retina and presence of well developed *tapetum lucidium*, which allows good night vision helping to avoid night predators attack (Ollivier et al., 2004). Caprine colour perception is different than in humans, because goats are dichromats having two types of cones, sensitive to short wavelength which enable them to see bright purple, or long wavelength which enable them to see yellow-green colour. The eye of the goat can receive only two ranges of colours (purple and yelowish-green). However, the brain is able to "mix" the signals from the eye thereby enabling goats to distinguish between colours (orange, yellow, green, blue, violet) (Buchenauer and Fritsch, 1980; Chiao et al., 2000).

A very important sense of goats which enables orientation in space, identification of own flock members and recognition of dangers, is hearing. The range of auditory perception in goats is broad, between 60 Hz and 40 kHz, however, maximum sensitivity is attained at 2 kHz. Precision in sound localization is about 18°, which is a much worse result in comparison to humans or predators (Hefner and Hefner, 1992). Caprine sense of hearing is selective, which enables precise identification of individuals (animals and humans). They also have very good sound memory. Research has shown that mother doe never forgets the voice of her offspring (Briefer and MacElligott, 2011, 2012; Briefer et al., 2012).

Senses of taste, smell and also touch cooperate during food recognition, its selection and during food intake. However, smell seems to be more important as it plays a role both in early food recognition, cooperating with sight, and also in final selection when all above mentioned senses work together during global stimulation of oropharyngeal area (Favreau-Peigné et al., 2013). Goats, similar to other ruminants are able to recognize five basic tastes, with strong preference for sweet and the strongest sensitivity to bitter which is not preferred (Goatcher and Church, 1970; Ginane et al., 2011). The sensitivity of caprine sense of taste to sweet is lower than in cattle, but higher than in ewes; however, as browser animals goats are the least sensitive to bitter taste compared to grazing ruminants (Glendinning, 1994).

Olfaction is an important and also versatile sense of goats participating in food selection, recognition of dangers, but also in inter-individual relations in flock as well as in reproductive processes. Mutual sniffing is very important for recognition of own flock members as well as strange animals that try to introduce into the group (Rutter, 2002). The main glands responsible for synthesis of odour enabling recognition are pedal scent glands and a gland under the tail. The main system of detection consists of two types of sensors. The olfactory epithelium is responsible for volatile odorant detection while the main olfactory bulb captures chemical signals – pheromones (Wakabayashi et al., 2002). Pheromones by transferring the sense of olfaction directly stimulate the central nervous and endocrine system through interindividual contact among conspecifics. This interaction leads to changes in reproductive physiology, behaviour and performance (Delgadillo et al., 2009).

Main function of sense of touch is establishing and maintaining relationships inside the flock, however, its importance in goats is less clear than in sheep mainly because of the individual composition of the flock. Goats show positive reaction to physical contact with humans, especially to stroke, and can be tamed more easily than cattle or sheep (Kaminski et al., 2005). Mechanisms for sensing pain in goats are probably similar to that in cattle, and humans, however, compared to cattle or sheep, goats have lower pain threshold and show earlier responses to pain (Huozha et al., 2011).

Horses

Detailed studies on equine vision showed that horses possess vision acuity and colour discrimination lower than humans, however they are able to see better in light-limited conditions, and they have almost panoramic vision and binocular transfer of optical cues (reviewed by Murphy et al., 2009). Horses' eyes, like in most farm animals, are situated on both sides of the head, with the narrow blind zone to the rear. However, the horse is able to kick with its hindlegs with high precision as it can only slightly turn the head to eliminate the effect of blind zone. It has also been found that horses possess depth perception, better at a distance of more than few meters, as they evolved in open areas (McGreevy, 2004).

Equine hearing range is 55 Hz to 33.5 kHz, but they are the most sensitive to sounds in the range from 1 to 15 kHz (McGreevy, 2004). Thanks to tremendous mobility of ears a horse has an ability to focus on the stimulus without turning the head to hear it with both ears.

The senses of smell and taste have raised much lower scientific interest, probably because of their lower significance to equitation. However, the sense of smell plays an important role in learning about olfactory features of other individuals and is crucial for social behaviour, reproduction, and mother-young recognition (reviewed by Saslow, 2002). It is suggested that horses, having a large nose, have also a large area of olfactory mucosa (McGreevy, 2004). Like almost all mammals, the horses have a VO. It seems that flehmen, a behaviour that in horses involves the eversion of the upper lip, eye rolling back and some flicking of the tongue is the most prominent in horses among all farm animals.

It is reported that horses are able to distinguish between salt, sour, sweet and bitter taste in the feed (McGreevy, 2004). The sense of taste is involved in food recognition and preference and probably in avoiding particular area of the pasture, the behaviour particularly characteristic of horses. This sense is very important in conspecifics' recognition in horses engaged in mutual grooming.

Interestingly, the horses' sense of touch has received little attention as a subject of in-depth scientific studies despite its main function. The sense of touch is involved in gaining information about aversiveness of certain environmental elements (e.g. electric fences) and of positive ones (e.g. mutual grooming). The horses can be sensitive to the touch of the pressure of only 0.008 g (Lansade et al., 2008) but tolerate pushing by other horses or humans, without visible discomfort. Apart from tactile receptors, similarly to other animals, the skin of the horse is an organ responsible for the detection and the reaction to changes of the ambient temperature and the sensation of pain thanks to thermo- and noci-receptors. The lips and the whiskers are an important organ of equine touch. As outlined by McGreevy (2004), the vibrissae (whiskers) have an important role in grazing and in detecting small, inedible objects in the feed, but also in general perception of space restrictions.

Pigs

It is recognized that pigs do not have a particularly well developed sense of sight (Hutson et al., 1993, 2000; Lomas et al., 1998). Tanaka et al. (1998) and Zonderland et al. (2008) report that this species has poor visual acuity and performs poorly in discriminating objects based on colour alone (Tanida et al., 1991). This suggests that pigs do not rely solely on visual cues when evaluating and adapting to the environment (Lomas et al., 1998). Pigs use vision only to collect information on what is immediately in front of them (Koba and Tanida, 2001), despite the fact that the visual angle of adult pigs was estimated to be 310° (Prince, 1977). This allows them to observe their surroundings all the time but may reduce their ability to determine the distance from objects (Grandin, 1980). In another study, Tanida et al. (1996) estimated the visual angle of pigs to be 250°. Impaired vision in pigs can be questioned by the anatomical structure of the porcine eye and some research findings which indicate that pigs may be able to discriminate colours (Tanida et al., 1991; Eguchi et al., 1997; Klocek et al., 2010). The presence of cones and rods suggests that pigs are able to discriminate between different light wavelengths and thus are capable of discriminating colours. Zonderland et al. (2008) concluded that light intensity is less important for pigs than the size of objects being identified. Tanida et al. (1991) suggest that pigs may have difficulty discriminating red from green, but can discriminate blue from green.

The pigs' ear perceives frequencies ranging from 42 to 40500 Hz, while a human's range of hearing is between 31 and 17600 Hz (Heffner and Heffner, 1992; Heffner, 1998), which carries a risk that pigs are exposed to jarring sounds (including ultrasound) inaudible to humans. Like all farm animals, pigs use hearing not only to detect environmental sounds, but also to communicate with one another. Fourteen different sounds were distinguished by Kiley (1972). Each of them is connected with different situations. For example, short, single grunts are typical during exploration, contact and greeting long grunts are typical for movement and squeals are associated with distress (Marchant et al., 2001).

The taste receptors of pigs are sensitive to a wide range of tastes, including those described by humans as bitter, salty, sweet and sour (Jones et al., 2000 a).

There is no question that olfaction (Perry, 1992; Kristensen et al., 2001; Jensen, 2002; Nowicki and Klocek, 2012) and taste (Cairns et al., 2002; Studnitz et al., 2007) are the senses that help the pig to adapt to their way of life. Pigs need these senses when foraging and they are of crucial importance to social contacts (Mendl et al., 2002), including information about hostility (McGlone, 1990). Pheromones are essential for mutual recognition of animals and thus for establishing a stable hierarchy

(Mendl et al., 2002). It has also been found that pigs emit alarm pheromones. According to Croney et al. (2003), both olfactory and visual stimuli are equally important to pigs during learning and memorization processes.

The tactile stimulation plays a very important role in the pig world. Neurotransmitters and mechano-receptors render it possible for the pig to interact with their environment (Simmons and Young, 1999). The snout of the pig is the area with very high concentration of touch receptors (Kruska, 1988) and it is the reason why pigs are better at rooting and biting. Such activities enable pigs to search for food but under intensive conditions pigs experience a lack of environmental stimuli whereby they cannot investigate their environment by using rooting, sniffing, biting and chewing (Studnitz et al., 2007). Touch is also responsible for feeling of pain. The function of pain is to protect tissues which become damaged. Thus, the presence of nociceptors and pain detecting receptors as well as chemical receptors which are activated under painful conditions ameliorate the painful stimuli (Livingston et al., 1992).

Poultry

Domestic fowl have a well-developed sense of vision with high visual acuity, perception and colour sensitivity. Eyes are relatively large compared to head size, with lateral eye sockets. This ensures a visual field of more than 300°, with only 26° of binocular vision. Poultry surpass other farm animals in colour discrimination, with spectral sensitivity of the eye ranging from 326 nm to 694 nm (Prescott and Wathes, 1999). Birds are classified as having tetrachromatic vision and can potentially distinguish twice as many colours as humans (Osorio et al., 1999). As regards the anatomic structure of the eye, they have 4 classes of single cone as well as double cones (Bowmaker et al., 1997). They perceive colours in the ultraviolet range (Prescott and Wathes, 1999).

Poultry are most sensitive to sounds in the range 3000–5000 Hz with hearing range between 250 and 8000 Hz. In general, birds have ears on both sides of head with external opening surrounded by specialized feathers which protect the opening but not obstruct sound transmission. In anatomy they differ from mammals as concerns the middle ear in which they have only single ossicle the columella (Mills, 1994). Columella transmit vibrations from the tympanic membrane to the oval window. The hens were found to express about 20 distinct calls depending on specific situations. Clear and harsh sounds, mainly in the range between 400 and 6000 Hz, ensure suitable response from individual birds (Tefera, 2012). It is now accepted that hearing begins in the chicken embryo on about day 12 of incubation (Rubel and Fritzsch, 2002). In the final stages of embryo development, chicks use acoustic communication to synchronize hatching (Rumpf and Tzschentke, 2010).

It is thought that avian species are less sensitive to taste compared to mammals. Domestic fowl have much fewer taste buds (60 to 350) than other farm animals, such as pigs and cattle, which possess around 20000 taste buds (Roura et al., 2008). However, in relation to the size of oral cavity, their number is probably higher in poultry compared to mammals. What is more, these buds are mainly located in the upper and lower parts of the oropharynx, near the openings of the salivary glands, and in the last section of the dorsal part of the tongue (Kurosawa et al., 1983). The response of chickens to different tastes was found to be stable from the growth period until sexual maturity (Ganchrow et al., 1990). Furthermore, differences were reported between hen types both in the number of taste buds and in taste sensitivity (Kudo et al., 2008; Kudo et al., 2010). Meat-type chickens are more sensitive to taste of diets than layer-type chickens. In general, hens discriminate between substances with an intensive taste, especially those dissolved in water. Feeds with strongly acidic, bitter and salty taste are not accepted. In addition, poultry are highly sensitive to the calcium, protein and fat in feed. Probably the main function of the sense of taste is to identify potentially harmful substances and the nutritive value of the diet (Roura et al., 2013).

The sense of smell in poultry has received limited attention to date. The nasal cavity is well developed. Histological examination showed that the olfactory epithelium has similar structure to that of mammals. Chicks raised with a dominant odour in the environment were found to prefer it in novel and potentially dangerous situations. In addition, in response to olfactory stimuli they modify their behaviour in a Y-maze choice test (Jones and Gentle, 1985). One-day-old chicks exhibit different sensitivity in their response to changes in the concentration of selected odours (Burne and Rogers, 1996; Porter et al., 1999). Furthermore, for several days after hatching they associate specific feed odour with negative post-ingestive consequences and adjust their feeding behaviour accordingly (Turro et al., 1994).

As with other farm animals, tactile sensations in domestic fowl are detected mainly by mechano- and thermoreceptors as well as nociceptors (Gentle, 1989). The receptors are located on the skin, especially in areas with few feathers. The surface of the beak contains mechanoreceptors acting as a tactile sensory organ to enable the birds to identify feed (Gentle and Breward, 1986).

The role of livestock perception in farm conditions

Cattle

The sense of sight is important for cattle as under natural conditions their physical activity is highest during circadian rhythm, reaching a maximum at sunrise and sunset (Linnanea et al., 2001; Guliński et al., 2014). Under production conditions, however, the maximums occur during certain animal management practices. For example, under loose-housing conditions, the maximum daily physical activity of dairy cows generally occurs during milking and feeding, depending on the extent to which the feeding system is voluntary/involuntary (Wagner-Storch and Palmer, 2003; Adamczyk et al., 2011 a, b).

In addition to smell and hearing, sight plays a major role in cattle reproduction, especially in connection with the mating and insemination of the animals (Petherick, 2005; Balasundaram and Jayalalitha, 2013). By way of example, bulls identify the inverted U shape as the hindquarters of a cow, which plays a significant role in using a phantom to collect bulls' semen (Phillips, 2002; Houpt, 2005).

Furthermore, sight is the basic sense used by cattle in human-animal relationships, especially during handling, for these animals are able to discriminate humans' faces and distinguish between the colours of their clothes. This is of importance to stockpersons/milkers whose activities must be positively perceived by the cows because negligence will reduce animal welfare and milk production (Munksgaard et al., 1997; Rybarczyk et al., 2001). Similarly, sight and hearing play an important role during the handling of bulls, which should be accounted for by the handlers to ensure safe handling procedures for the bulls (Kirkpatrick and Hopkins, 2007). In general, Grandin (2015) recommends that anthropomorphic perception of animals by humans should be avoided in human-cattle relationships. For instance, the author states that cattle prefer diffuse lighting and are afraid of the play of light and shadow, which may discourage animals from moving in this direction, because, unlike humans, they are incapable of abstract perception and reflection.

As the living environment of cattle becomes increasingly exposed to the sun, the ambient temperature also increases (Herbut and Angrecka, 2013). Especially sensitive to this are high-yielding cows, in which increasing ambient temperature above 24–25°C induces heat stress, leading to a rapid decrease in milk yield and fertility (St. Pierre et al., 2003; West, 2003; Jaśkowski et al., 2005; Brouček et al., 2009; Herbut et al., 2015). At sub-zero temperatures, it is of prime importance to protect animals from hypothermia, to provide them with dry and insulated lying areas (straw, mattresses), and to ensure appropriate amounts of fresh, high-quality feed. In this way, adult cows are able to tolerate temperatures as low as –20°C (Phillips, 2002; Praks et al., 2007; Angrecka and Herbut, 2015).

Cattle perception ability is also used to characterize individual animal behaviours under farm conditions – especially social behaviour. For example the effect of separation on dairy cows and calves was studied on the basis of animal perception (vision and hearing) as important factors in the cow-calf relationship. It was found that early separation of dairy calves (within 1 h of birth) was less stressful for calves than late separation (>2 days post-birth) (Hopster et al., 1995; Weary and Chua, 2000; Marchant-Forde et al., 2002).

It is also reported that cattle generally prefer the taste of concentrates rather than roughages, which is why during the preparation of Total Mixed Ration (TMR) the feed should be properly ground and mixed (Leonardi and Armentano, 2003; Beauchemin and Yang, 2005; DeVries et al., 2005). Moreover a stimulatory effect of calm music on the voluntary approach of cows to the Automatic Milking System was also reported (Uetake et al., 1997).

Since high-pitched noise stimulates cattle and low-pitched noise has a calming effect, handlers should generally be calm and use low-pitched sounds (Phillips, 2002). The appropriate use of sound and touch may relieve stress and help animals adjust to barn conditions (Abramowicz et al., 2013).

Sheep

Sheep are gregarious animals, therefore very strong social bonds exist among them. These animals get to know each other and maintain social interaction. In a well-integrated flock of sheep, the past record of affiliations among sheep facilitates the establishment of strong social contacts among them (Molik and Pieronkiewicz, 2011).

Sheep watch each other and get to know each other. The behaviour of the animal in the full reproductive cycle is affected by many external factors. Special time for mothers rearing offspring is a period when you can see how strong their maternal instinct is. At this time mothers' body functions are determined not only by the needs of the body, but primarily by the needs of their offspring. The most important moment of creating motherly bonds, recognition and acceptance of the lamb takes only a few hours, while the lamb learns to recognize the ewe for 3–6 days (Assante et al., 1999). The rearing period is very important also for the lambs as they learn to acquire feed. Learning is based on observation of the adult sheep, on the basis of which – in addition to the innate taste preferences – lambs learn to collect and identify specific foods and recognise pastures they can eat and which to avoid (Provenza et al., 1992). Moreover, this dependency is applicable only to lambs and their mothers: lambs do not imitate taste preferences of unrelated adult sheep (Mirza and Provenza, 1990; Thorhallsdottir et al., 1990). Proper care of the offspring by the mother is crucial not only for the survival of lambs, but also for their subsequent breeding value indicators.

An important factor influencing the behaviour of the animals in the herd is operating behaviour. People who handle sheep firmly but gently have a calming influence on them. This species is able to feel the kindness and strength attached to such behaviour, gets attached to the stockperson who is treated as an individual endowed with leadership qualities, and submits to them. Sheep react easily to a short command or gesture, but indecisive behaviour (continuous shouting) is not accepted. The visual memory allows sheep to remember the breeder, and auditory memory allows recognizing his voice, moreover, sheep have the ability to sense human intentions. It is central that every breeder should have an understanding of the social behaviour of sheep, as well as the practical use of the information collected. These senses are most useful in relation to the sheep-shepherd dog. Cooperation with a sheep dog is via the specific communication between the one and the other animal. Many dogs used for herding and guarding animals are endowed with an innate instinct called pastoral (Molik and Milejska, 2012). It results in specific behaviours, consisting for example of the tendency to rounding the herd and forcing the animals to remain in a tight group, as well as racing in a specific direction. In the case of Merino sheep that are more skittish, dogs need to be quiet, fast, viable, working in a wide range of the flock of sheep, without unduly disturbing the sheep. For other sheep breeds (long-woollen, meat) the best are dogs working near the herd. These behaviours have biological conditions resulting from biochemical changes in the body. Grazing sheep with the use of shepherd dogs is an interesting ethological element of mutual relations (Alvarez-Cordoba et al., 1999).

Goats

All senses in goats influence their productive potential and ability, as well as can be used by breeders and producers to optimize and maximize production. The sense of sight is mainly important for day length recognition. In the case of reproductive physiology goats are seasonal short day animals (Duarte et al., 2010). This is a disadvantage and makes caprine products also seasonal. Due to housing of goats in artificial light conditions with shortening day it is possible to break seasonal anestrus and introduce males and females to breeding season against natural day length (Delgadillo et al., 2002). The sense of hearing from the point of view of production is only supplementary to others. It makes possible to recognize offspring by the mother so as to maintain specific order in the flock. The socio-sexual relationship between sexes, called male effect, can be used to stimulate sexual activity of does during seasonal anestrus, or to synchronize and increase reproductive processes in females during breeding season (Delgadillo et al., 2009; Hawken and Martin, 2012).

The major sense responsible for reception of male effect is olfaction acting through male pheromones uptake, however, the other senses, like sight, hearing and touching are also important, increasing physiological and behavioural reaction of females (Perkins and Fitzgerald, 1994; Vielma et al., 2009). Senses of taste, smell and also touch cooperate during food recognition and selection. They can be used to increase food intake by composition of feedstuff with more preferable plants, or addition of substances intensifying or changing flavour to more preferable (Najrisse et al., 1996; Robertson et al., 2006). It is important in production conditions during periods of increased demand of organism with decreased appetite, like mating time, or parturition and early lactation. Increasing of appetite is especially important in nutritional flushing treatment aiming to improve reproductive performance (Dohi et al., 1996). Relatively low pain threshold and loud signaling of pain can be useful for shepherds housing goats in extensive outdoor system, making easier a search for injured or ill animals.

There are also some disadvantages of well developed sensory organs, high intelligence level and good memory (Langbein et al., 2008). Goats are difficult to lead as a flock, because of strong individual behaviour. They quickly learn to use equipment in livestock building which enables them the possibility to escape, or to damage farmyard and neighborhood facilities (Langbein et al., 2009). A goat's mouth is unaffected by hard and sharp parts of plants and thus they can potentially damage crops as well as ornamental plants, shrubs and trees (Cheeke and Dierenfield, 2010). As social animals, goats show a hierarchic structure of flock, establish dominance and sometimes display aggressive behaviour, which can be potentially a danger for humans or other livestock, especially in contact with large bucks (Shrader et al., 2007).

Horses

The most frequently in-depth studied equine sense is vision, probably due to its direct impact on horse's performance and rider's safety. When competing in disciplines involving jumping the fences, the horse approaches (usually differently coloured) obstacles in high speed (in canter), thus it should properly assess their height and width. Moreover, the visual recognition and generalisation of humans and objects plays a vital role when using the horse. It is commonly acknowledged that horses have poor generalisation of objects (Christensen et al., 2005, 2008). This affects the safety of rider as a horse may shy violently to the objects of different colours and shapes, or to the same objects that the horse sees for the repeated time but from another side. However, horses are able to differentiate visually between individual humans (Proops and McComb, 2012) and connect them to positive, neutral or negative experience (Stone, 2010) which is important for further horse-human interactions.

As per hearing, horses are particularly sensitive to sudden, loud sounds (McGreevy, 2004). The animal may react with instantaneous whole body orientation towards the source of the sound which may jeopardize the safety of both human and the horse.

Selective taste and smell in horses may be a reason for a refusal of feeding or drinking from unfamiliar buckets, which often happens when the horse is in a novel environment, e.g. at competitions. The role of smell which plays an incontestable role in equine reproduction is often neglected in equine breeding systems. It has been observed that adult males engage in olfactory investigation of other conspecifics and their secreta (Jezierski et al., 2015 a, b). The recognition of olfactory signals from an estrous mare is one of the elements of precopulatory ritual in horses. The absence of olfactory communication between males and females in semen production systems may be detrimental to stallions' behaviour and to semen production.

The high role of touch is incontestable for a horse to be a good mount, as in equitation and less in driving, the horse should be sensitive to particular tactile signals, but reduce the reaction to other ones, like for instance girth pressure or overall rider's weight. The possibility of the development of precise tactile human-horse communication is distinctive when compared to other farm animals and constitutes equine 'workability'. The insight into the literature concerning impressive ability of the horse to differentiate tactile signals in equitation goes beyond the frames of the present review. However, it should be noted here that also the mouth, the tongue, the diastema, the jaw and the palate are highly innervated organs which play a major role in tactile communication between the horse and its rider or handler. Coercive use of bits is one of major abuses in horse industry (Cook, 2003). Similarly, the role of whiskers, important tactile organs, is often neglected by persons clipping them for different reasons.

Pigs

Well-experienced pig producers are able to recognize the behavioural needs of pigs, which mostly result from the development of the senses. For example vision in pigs which is commonly known as rather poor, in fact enables discrimination between familiar and non-familiar people (Tanida and Nagano, 1998). Piglets have a preference for certain colours (Deligeorgis et al., 2006) and consume more water from red and blue drinkers compared to green drinkers. The time spent at the drinker to consume water was shorter for the green drinker compared to blue drinker. The results of Klocek et al. (2010) also indicate that pigs distinguish between colours and have a preference for certain colours, in particular red and blue. When pigs had food provided in blue, red and yellow feeders they mostly chose red and blue feeders. Moreover, Taylor et al. (2006) found that pigs prefer mostly to stay in the dim illumination (2.4 lx) and they avoid staying in the highly illuminated (400 lx) environment. It is suggested that pigs should rest at a light intensity of 2.4 lx for at least 6 h per day (Taylor et al., 2006).

Some of the sounds produced by pigs serve specific functions: nursing sows summon piglets to suckle by grunting, with grunt rate increasing during a short period when milk is secreted and can be consumed by the piglets (Whittemore, 1993), whereas piglets and their mothers use other forms to communicate (Hutson et al., 1992). Vocalizations are an important mode of communication between the sow and her piglets (Hutson et al., 1991) and may save the latter from crushing (Nowicki and Schwarz, 2010). So far the meaning of a relatively large number of sounds emitted by pigs has been identified. These include vocalizations (usually low-pitched) used for social communication; distress calls and fright calls (usually longer and louder high-pitched vocalizations, heard as shrieks) (Schrader and Todt, 1998; Manteufell et al., 2004). These sounds may reflect low welfare levels when pigs, which are gregarious animals, live in unnatural isolation (Weary et al., 1997), but are also generated by piglets in other highly stressful situations of compromised welfare: during castration (Taylor et al., 2001) and later after weaning (Weary et al., 1997). Proper interpretation of the vocalizations (especially high-pitched sounds) may considerably help determine the causes of compromised welfare in pigs.

Preference of pigs to specific flavours can be easily measured on farm by the observation of food consumption (Baldwin, 1976) but reliable results are only possible to obtain when there is *ad libitum* access to feed (Cairns et al., 2002). When given a choice, pigs show the strongest preference for sweet taste (Kennedy and Baldwin, 1972).

In the farming systems familiar odours of food are used to reduce fear of pigs (McLaughlin et al., 1983). Pigs are attracted to odours associated with familiar animals (Morrow-Tesch and McGlone, 1990; Parfet and Gonyou, 1991), however, Jones et al. (2000 b) found that the presence of artificial odourant Ambi-Pur had no effect on the pigs' readiness to enter the novel arena from a sheltered area or on other fear-related behaviours following entry. On the other hand, Nowicki and Klocek (2012) found that aromatized chewable and destructible toys can reduce the aggression in newly weaned piglets. Kristensen at al. (2001) found that pigs use the olfactory cues in social recognition and chronic exposure to ammonia did not disturb this ability. Olfaction is an efficient way of transmitting social information between pigs on farm. The sexual information, social status and aggressive attitude is transferred by the olfaction sense (Pearce et al., 1988; McGlone, 1990; Mendl et al., 2002). Pheromones play the important role in dominance hierarchy formation (Mendl et al., 2002), but they are also responsible for the transfer of alarm signals and influence the behaviour of conspecifics when the pig is stressed, for example during transport and slaughter (Amory and Pearce, 2000).

All the senses in the pig work together to receive environmental stimuli. This is important in establishing the requirements for an enriched environment for pigs. They should stimulate all senses and must be edible, chewable, rootable and destructible (Studnitz et al., 2007).

Poultry

In farm conditions vision ability of poultry is important in locating and exploring sources of water and food (Roper and Marples, 1997; Gamberale-Stille and Tullberg, 2001; Chagneau et al., 2003). In free range housing birds should effectively find additional food sources located outside the building in a much more complex environment than in intensive production. Moreover, colour, postures, displays and vocalizations are the basis for communication between individuals within the flock (Mench and Keeling, 2001). These senses play an important role in courtship sequences as part of mating rituals (Bilcik and Estevez, 2005; Duncan, 2009). They are also used when giving alarm calls, providing information about social status (Marler et al., 1986; Prescott et al., 2003), and forming the relationship between chicks and adults during social learning (Wauters et al., 2002; Melaku, 2012). Communication within the flock is particularly important when birds have access to an outdoor area, where they are potentially at risk of being attacked by predators.

The fact that domestic fowl can detect and respond to a wide range of light regime and sound changes has important practical implications. An artificial lighting in the production environment is of use as an effective tool to manipulate food intake, reproduction efficiency and social communication. In intensive rearing conditions chicks are stimulated to learn how to drink water by differentiating the pressure in nipple drinkers. By absorbing the eyes, shiny surfaces encourage the birds to peck (Appleby et al., 2004). Moreover, chicks can be attracted towards food by playing hen vocalization (Woodcock et al., 2004) near the feeder. The role of UVA perception in mate choice has potential applications in intensively-bred reproduction flocks in which problems with fertility are noted (Jones et al., 2001). In addition, the use of different colours of equipment during production of hatching and consumption eggs may increase the efficiency of resources such as nests (Huber-Eicher, 2004; Zupan et al., 2007) and environmental enrichments (Jones and Carmichael, 1998; Taylor et al., 2003). Also, light intensity and light wavelength via coloured light may be altered to reduce aggression in poultry flocks both during rearing and production. Activity levels in hens and turkey are reduced when exposed to blue light (Manser, 1996).

Physical characteristics of the food such as taste, colour and particle size affect food intake in poultry. Taste is probably important in food selection in the context of avoiding potentially toxic substance. Recently (Harlander-Matauschek et al., 2010), aversion to consume substance of intensive bitter taste was used to prevent aggression behaviour connected with feather pecking.

Nowadays, even if the interest for olfaction in birds has increased, knowledge about the possible role of odours in controlling feeding and social interactions in poultry production is still low. It has been suggested that in mallard ducks and Japanese quail, body odours may play a role in reproductive behaviour (Caro and Balthazart, 2010). In ducks the uropygial gland has a sexual olfactory signaling function.

Conclusions

Farm animals rely on information about the external environment, which they receive from the sense organs. The current state of research in this area reflects animal species specificity. All farm animals make extensive use of their senses so as to ensure optimal survival in their environments. This knowledge is all the more important considering that in the present production systems, especially the intensive ones (poultry, pigs, high-yielding dairy cows), farm animals have less opportunity to meet their sensory stimulation needs. It is necessary to emphasise that this knowledge is limited due to our failure to comprehend the sensory world of animals and the complex abilities of animals to receive and process environmental stimuli. This is particularly difficult in the case of phenomena that are intractable to humans, such as ultrasonic, infrasonic or chemical communication. Furthermore, the reception of a stimulus does not necessarily induce a behavioural change visible to humans, despite the fact that it will be evident for an animal of the same species. Thus, further research that will address the perceptual abilities of animals will be of great cognitive and practical significance in the future.

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