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ODOUR INFLUENCE ON WELL-BEING AND HEALTH WITH SPECIFIC FOCUS ON ANIMAL PRODUCTION EMISSIONS

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Abstract: Odour and odorants may affect the quality of life of exposed individuals. A review of the literature on olfaction and reactions to odours was carried out with the aim of reaching an understanding of their influence on well-being and health, and to suggest possible improvements in odour environment. This review has focussed specifically on the impact of animal production emissions. Factors like emission and air movements form the physical odour levels, and individual parameters involving psychological and social factors determine the human response. An odour may have positive as well as negative effects on well-being. Learning may be important for induced approach or avoidance behaviour. Common sites of irritation and injury from odorants are the respiratory organs and the nose. In most cases, the protection system triggered by the trigeminal nerve prevents severe effects. Increased frequencies of a number of respiratory and stress-related symptoms are found in the vicinity of animal production facilities. Explanations may be odour-mediated symptoms through annoyance and/or co-existing compounds like dust and gases with synergistic effects. Besides hydrogen sulphide, a number of gases related to animal production have hazardous properties and might be contributory elements despite their low concentrations. Important factors affecting mood, stress, and perceived health are odour levels, exposure time, sensitivity, unpleasantness, cognition and coping. Odour unpleasantness influences annoyance and might be interesting for regulatory purposes.

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INTRODUCTION

The understanding of human reactions to odours and their importance for human well-being and health is of major concern in the control of malodours and manipulation of odours in the environment. The World Health Organization (WHO) defines health as: *a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity* [149]. Odorants are defined as: *substances which stimulate the human olfactory system so that an odour is perceived* [51], and odour as: an *organoleptic attribute perceptible by the olfactory organ on sniffing certain volatile substances* [20] These may affect well-being as well as health. Depending on the type and concentration of odorants, evoked responses may be positive as well as negative. Adverse environmental impact and excessive air pollution, apart from possible psychological [13] and depressive [90] effects, may also have a physical impact on exposed individuals.

Gaseous emissions in the work environment in agriculture and elsewhere may be a health problem for

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exposed workers, and odours from livestock and poultry production facilities [65] affect the quality of life of nearby residents by causing nuisance, etc. Complaints are a problem for the breeders [138]. Odour from animal production facilities as well as malodour from a number of industrial operations constitute a major problem.

The hypothesis of the study was that the quality of life for exposed human individuals can be improved by changing and modifying their odour environment. Therefore, the aim of the study was to find possible ways and guidelines for improvement by reviewing the literature regarding olfaction, olfactory responses, and odour influence on well-being and health. Targeting a deep understanding, the general literature as well as that with specific focus on animal production was reviewed.

OLFACTION

There are 5 different receptors or elements of neural systems localized in the nasal chambers of most land mammals: (1) the main olfactory system, (2) the trigeminal somatosensory system (common chemical sense), (3) the vomeronasal system (VNO), (4) the terminal nerve, and (5) the septal organ [36]. The main olfactory system mediates what we usually call odour sensations. A large number of different receptors in the olfactory epithelium are connected to the olfactory bulbs at the base of the brain. The septal organ may have the same function as the main olfactory system in those species possessing it [36]. The trigeminal somatosensory system mediates both chemical sensations like burning, stinging, etc. and non-chemical sensations e.g. pain, tickling and cooling. Research has shown that the vomeronasal organ plays a role regarding sexual and social behaviour for a number of animal species. Whether VNO is a functioning system or not for human beings is under debate [16, 36, 91, 92, 124, 125]. Fibers that could be considered as constituting the terminal nerve have been seen in humans [68]. The terminal nerve might help to convey stimuli into the VNO [152], and might also modify the olfactory information [153]. It is questioned whether the terminal nerve has any function in humans [36].

The stimulation of a certain chemical may involve more than one of the neural systems, for example, ammonia [31], producing a distinct odour at low concentrations and a burning or tingling sensation mediated by the trigeminal system at higher concentrations.

CHARACTERIZATION OF ODOURS

Odours can be characterized by concentration, intensity, persistence, hedonic tone and character [63]. The odour concentration, which is a multiple of the concentration at detection level measured with the help of a panel and an olfactometer diluting the odorous sample, can be measured in, for example, European Odour Units per cubic metre (OU_E/m^3) [20]. Odour measurement using electronic noses still cannot be considered as an equivalent alternative to olfactometry [97]. The odour intensity refers to the perceived strength of the odour sensation, and may be described [20] by a logarithmic expression according to Fechner or by a power function according to Stevens. Odour intensity is often based on the intensity of a reference gas [63] such as n-butanol. An example of intensity scaling is intensity categories from “no odour” and “very faint” up to “very strong” represented by water solutions of n-butanol with increasing concentrations [5]. The perceived intensity decreases when the odour concentration decreases, but the rate of change in intensity is not the same for all odours and odour persistence describes this rate of change [62].

The pleasantness of an odour is described by the hedonic tone. On a hedonic tone scale where +5 is extremely pleasant and -5 extremely unpleasant, odour from strawberries and apples has been found to have values of about +3, and odour from urine, manure and dead animals has been found to have values of between -3 and -4 [50]. The hedonic tone of an odour usually decreases by concentration or intensity [62], but a pleasant-rated odour may, up to a certain concentration level, increase in pleasantness before a decrease takes place. Regression of the hedonic tone (on a scale from +10 to -10) versus odour concentration of air samples from swine nurseries has been shown to result in a value of -1 at concentrations of about 10 OU/m^3 and -7 at about 300 OU/m^3 [74]. The character or quality of an odour describes in words (odour descriptors) what an odour smells, like for instance, earthy, floral, fruity etc. An odour can be described using words from defined lists [154]. A problem is that a classification may be influenced by individual differences in labelling related to differences in hedonics, social convention and semantics [133].

OLFACTORY INFORMATION AND IMPORTANCE

Stimulation of the olfactory system induces approach or avoidance behaviour, both in a social context and related to food [20], and odorants related to food interfere with taste [108]. An odour may be a warning for human beings [15] and for animals [139].

Induced reactions to an odour may involve learning, which is one way to retrieve the most important information in an environment; enhanced sensitivity to odours with ecological relevance may occur [55]. Reactions to an odour also involve odour memory and it has been suggested that memory based on recollection may not be fully developed in children and impaired in the elderly [73]. In some cases, smells can be a powerful reminder of autobiographical experience (Proust phenomenon) [22]. Avoidance behaviour for odorants may be used in various medical treatment programmes [46, 113]. Odorants may also be used for relaxation [113].

Smells play an important role in the sensory quality of the landscape and in the specific topic of inhabitants being able to identify their landscape [25].

It has been suggested that odours are important in the social context and that they might induce hormonal change [45, 56, 84, 102, 104, 132, 145]. The existence of human pheromones however is questioned [36].

ODOUR ADAPTATION AND SENSITIZATION

Repeated or prolonged exposure to an odorant typically leads to adaptation i.e. a decrease in sensitivity to that odorant [30]. Adaptation allows the organism to react primarily on changes in stimulation. Adaptation occurs quite fast, and in experiments with acetone a considerable decrease was obtained after about 3 minutes [29]. There seem to be 2 types of adaptation, short-term and long-term. Long-term adaptation to odour from animals for people working daily with livestock might change their perceptual world and lead to a non-understanding of odour complaints from neighbours with intermittent exposure [116]. The type of odorant or its physical properties may affect adaptation. The olfactory system has been shown to adapt faster and to a greater degree to malodours than to pleasant odours. However, a greater increase in sensitivity was found for increased concentrations of the malodours than for increased concentrations of the pleasant odours [60].

Sensitization with a decreased odour threshold may occur after exposure to an odorant [28, 147, 156]. Sensitization for one odour may be partially transferred to other odours in some, but not all, cases [144].

DEMOGRAPHIC VARIABLES IN ODOUR PERCEPTION

Since the late 1800s, research has revealed gender differences in olfactory sensitivity where women often show better results than men in studies regarding odour detection, odour discrimination and odour identification [101]. Differences in attention and hormonal change in women are some suggested reasons [60]. There is a possibility that increased sensitivity in women may lead to more environmental complaints from them [28]. A decline in the olfactory function by age has been shown in a number of experiments [38], and elderly with poor general health have shown lower values of odour perception than those in good or reasonably good general health [47]. Besides better scores on olfactory tests for women and decreased scores by age, smokers performed worse than non-smokers in a Chinese survey [77].

Rhinosinosis, alcoholism and previous exposure to high concentrations of a chemical is connected to decreased sensitivity to odours as well as a number of disorders [36] and diseases like schizophrenia [89]. In Alzheimer’s and Parkinson’s disease, changes in olfaction and changes in the olfactory mucosa are early signs [15], and odour identification tests may be used for diagnosis [93].

ENVIRONMENTAL INFLUENCE ON ODOUR

An increased temperature may increase odorant emission [76] and may decrease the acceptability or quality of the air, but an increased temperature does not seem to significantly increase odour perception [39, 40, 67]. Increased humidity may increase odour emission [76, 105], and peaks in emission observed at rapid moisture increase [58], might indicate that wetting a material can release previously produced gases. It is reported that a reduction of the moisture content reduces the odour production in manure [99, 61], and less anaerobic conditions at low moisture levels may be an explanation [99]. Increased humidity may decrease the acceptability of the air without any change in the odour perception [39, 40], but a decrease in odour intensity may also occur [67]. Odorous compounds adhere to dust particles and there are indications that the removal of dust can reduce the odour in the air from swine houses by 65% [52] and an even higher reduction (76%) has been found in experiments [54]. Spraying water or a mixture of water and oil has resulted in a significant decrease in dust levels in animal houses, where the generation of dust is influenced by factors such as animal activity, animal weight, type of ventilation and type of housing system [48, 49].

ODOUR AND ODORANT DETECTION AND IMPACT

Odour thresholds vary largely in the human population. It has been found that about 95% of the population have an individual odour threshold for a certain compound within the interval 1/16–16 times the reported average odour threshold [98, 3]. Of about 330 identified volatile compounds related to livestock production [110], carbon dioxide and methane are odourless, and ammonia can first be detected by the human nose at quite high concentrations ($\approx 10^{-2}$ mg/m^3 [100]). However, other compounds like thiols (mercaptans) that are also present in garlic and in skunk spray [155]) can be detected at very low concentrations ($\approx 10^{-7}$ mg/m^3 [100]). An odour is usually a complex mixture of numerous gaseous compounds and the mix gives its specific character. Interactions between odorants and their individual concentration in a mixture change the perceived strength of the mix, and there are models that try to explain such phenomena as masking, counteraction, neutralization, addition, synergism etc. [14]. In a study, the perceived odour intensity from a mixture was less than the sum of their intensities but greater than the intensity of each individual constituent [70].

The lowest concentration level at which a chemical causes irritant effects in human beings may be below odour threshold level although odour precedes irritation for most industrial chemicals [121]. Studies of brain waves, EEG (ElectroEncephaloGram) and ERP (Event-Related-Potentials), suggest that chemicals present in ambient air in low or below odour threshold

Table 1. Symptoms with observed increased frequency in the vicinity of animal production facilities and selected observed chemicals with ability to cause the symptoms.

Symptoms with suggested increased frequency		Chemical compounds with ability to cause observed symptoms at hazardous concentrations [95]
Site/type of irritation	Symptoms found	On symptom and harmfulness basis selected volatiles (from a list containing 168 compounds present in animal production [100])
Nose	Irritation in nose [66, 123, 150]	Ethanol, 2-methoxy- ; Ammonia; Benzene; Formaldehyde; Hydrazine; 2-Butenal (Crotonaldehyde); Sulphur dioxide
Eyes	Irritation in eyes [66, 140]	Ethanol, 2-methoxy-; Ammonia; Benzene; Formaldehyde; Hydrazine; Carbon disulphide; 2-Butenal (Crotonaldehyde); Sulphur dioxide; Hydrogen sulphide
Throat	Irritation in throat [66, 123, 150]	Ethanol, 2-methoxy- ; Ammonia; Benzene; Formaldehyde; Hydrazine; 2-Butenal (Crotonaldehyde); Sulphur dioxide
Respiratory	Breathing difficulties [123], Breathing problems [140], Chest tightness [66, 140], Cough [66, 150]	Ethanol, 2-methoxy-; 2-Propenal (Acrolein); Ammonia; Benzene; Formaldehyde; Hydrazine; Carbon disulphide; 2-Butenal (Crotonaldehyde); Sulphur dioxide; Hydrogen sulphide
Skin	Skin irritation [66]	Ammonia; Benzene; Formaldehyde; Hydrazine; Carbon disulphide; 2-Butenal (Crotonaldehyde); Sulphur dioxide
Head	Headache [123, 140, 150]	Ethanol, 2-methoxy- ; Ammonia; Benzene; Hydrazine; Carbon disulphide, Methanol, Sulphur dioxide, Hydrogen sulphide
Gastric	Nausea [123, 140]	Ammonia; Benzene; Hydrazine; Carbon disulphide; Methanol; Sulphur dioxide; Hydrogen sulphide
Gastric	Diarrhoea [66, 150]	(Microorganisms or ingested compounds?) *
Mental	Tiredness [66, 112], Weakness [140], Less vigour [112]	Ethanol, 2-methoxy-; Carbon disulphide
Mental	Confusion [112]	Hydrogen sulphide
Mental	Depressions [112]	Carbon disulphide
Mental	Tension, Anger [112]	Ethanol, 2-methoxy-, and Carbon disulphide may cause changes of the personality
Mental	Sleeping difficulties [123]	Hydrogen sulphide
Mental	Annoyance [123]	(All odorous compounds at high concentrations) *
-	Reduced quality of life [150]	(Odorant mix) *

* Authors comment: CAS Numbers: 2-Butenal (Crotonaldehyde) - Cas No. 4170-30-3); 2-Propenal (Acrolein) - Cas No. 107-02-8); Ammonia - Cas No. 7664-41-7; Benzene - Cas No. 71-43-2; Carbon disulphide - Cas No. 75-15-0; Ethanol, 2-methoxy - Cas No. 109-86-4; Formaldehyde - Cas No. 50-00-0; Hydrazine - Cas No. 302-01-2; Hydrogen sulphide - Cas No. 7783-06-4; Methanol - Cas No. 67-56-1; Sulphur dioxide - Cas No. 7446-09-5.

concentrations may affect the nervous system without our being conscious of it [78], and brain activity has also been localized for chemicals not detected by the olfactory system [127]. Regarding occupational Threshold Limit Values (TLVs), by far most of the odorants related to animal houses are present in very small concentrations [110]. Present substances may, however, affect health (Tab. 1).

High concentrations of chemicals in inhaled air can damage the respiratory and olfactory system. Initial impact sites of irritants like ammonia and organic acids, etc., with high water solubility, are the eyes and the nose where they can dissolve in the mucous membrane that protects the lower respiratory tract [122, 143]. Protection against injury in the nose and respiratory system caused by a chemical or by thermal environmental conditions is minimized or prevented by secretion in the nasal cavity or by halting inhalation. These reflexive responses are connected to stimulation of the trigeminal nerve [36].

Airborne irritants have various effects on the upper airways and it can be difficult to distinguish between irritant and allergic effects [122]. Sensitivity to odour may be connected to migraine [126] and also to poor sleep and food intolerances (milk products) [11]. For some people, odour or very small concentrations of volatile chemicals trigger Multiple Chemical Sensitivity (MCS) and cause asthma-like symptoms (sensory hyper reactivity), and also symptoms such as fatigue, headache, dizziness and depressive mood [57, 87, 88, 107]. Climatic conditions that include gases and dust are considered to be critical for asthma, nasal symptoms, and rhinitis (running, itching nose or eyes) [14]. Filtration is accomplished mechanically in the nose (upper airway) and a considerable amount of large-diameter particles are caught while finer particles are more likely to reach the lower respiratory tract [122]. Nasal irritation thresholds and nasal pungency have been studied [1, 27] and intra-individual variation as well as inter-individual variation may be important regarding symptoms caused by pollution [122].

An odorant may change respiration and decreased tidal volume has been observed concerning, for example, acetic acid, and some inverse relation to nasal irritation seems to exist [148]. Carbon dioxide is reported to increase heart rate [37].

The absence of a blood-brain barrier (BBB) along the olfactory nerve into the olfactory bulb in the brain is of importance when considering the nose as a site for delivery of drugs, viruses, and environmental toxins associated with neurological disease [10, 18, 71, 137]. Several chemicals have been observed to cause necrosis of neurons and other cells in the olfactory mucosa, and toxic effects in the olfactory mucosa may result in secondary effects within the brain [15]. Toxins may enter the central nervous system (CNS) and damage the CNS structures [35]. Low concentrations of most odorous VOCs are taken care of by the detoxification system in the nose [116], but the mechanisms like halted inhalation, increased secretion, sneezing, and engorgement of the tissue in the nasal passages, do not always protect the olfactory system from the chemicals, and especially not from those that are present long-term (chronic) or those that do not activate the trigeminal nerve [35]. Industrial processes and substances found to adversely alter the sense of smell are, for example, metallurgical, wastewater, fragrance processes, exposure to metals, dust from cement, and chemicals, and further exposure to compounds like ammonia, sulphur dioxide, acetone, benzene and trichlorethylene [4, 35]. Chemicals can directly cause damage to the olfactory epithelium, but olfactory dysfunction caused by toxic exposure is less common than dysfunction caused by, for example, respiratory infections, head trauma, chronic rhinitis or rhinosinusitis [35].

ODOUR, STRESS AND MOOD

Odour is a part of air pollution which, together with noise, crowding and heat represent environmental stressors [37]. The short-term effects of stress may be positive, but in a longer perspective illnesses may be the outcome, especially heart and blood vessel diseases together with other disorders on account of a weakened immune system. The human body responds to stress by releasing the stress hormones adrenaline, noradrenaline and cortisol in the body. Associations between levels of cortisol in individuals and odour exposure (from a mushroom fertilizer plant) have been found [130]. The cortisol levels decreased after closure of the plant; however, the relationship between odour in the environment and cortisol level was not considered proven. In experiments exposing females to citral odour, a positive correlation was found between the peripheral cortisol level and olfactory sensitivity [103].

It is common belief that anxiety, stress (i.e. stress caused by an odour), and depressions are related to each other. More depression has been observed for people reporting symptoms of MCS where sensitivity to smell is a characteristic complaint [34]. Complex interactions where genetic as well as developmental aspects must be considered may lead to pathogenic response to stressors [44].

Stressing and relaxing effects of odours are found in a number of studies. They may cause severe stress in animals [157]. An increase in blood pressure and alterations in blood sugar levels (stress reactions) have been observed in humans inhaling irritating odours [83]. Inhaling a pleasant odour resulted in a lower increase of the diastolic blood pressure in a physical test [94]. In another study, a pleasant odour was observed to significantly decrease the heart rate, systolic and diastolic blood pressure, and to reduce the respiratory rate [32]. In experiments measuring autonomic nervous system (ANS) responses (heart rate, blood pressure, skin resistance, etc.), the results suggested that malodour caused stress, and further, that a favourite odour was not effective for relaxing but accelerated relief from stress [142]. Exposure of patients waiting for dental treatment to ambient orange odour indicated relaxing effects and a more positive mood [72].

Significant effects of aromas on mood, cognition and social behaviour have been found in science-based studies, although many reports of beneficial effects on human health by aromas (aromatherapy) are based on non-scientific evidence [83]. Significantly fewer symptoms of ill health were reported by a group exposed to lemon odour compared to a group exposed to the smell of dimethyl sulphide [69]. With regard to person perceptions and social behaviour related to perfume use and pleasant scents, significant changes have been found as well as more positive attitudes [7, 8, 9]. Moreover, pleasant odours may decrease pain perception [82]. In studies, food and fruit odours [115], as well as underarm odours [21], have been found to affect and relieve self-reported depressive moods. Exposure to androstenol (an androstenone-like compound) may affect the mood of women [12]. Daily use of cologne has been found to improve the mood for both middle-aged men [114] and middle-aged women [111]. Cognitive improvement in tasks like photo-recognition, word recall, alphabetization and clerical work were found to be related to pleasant odour exposure [6, 7]. In a study of exposure to lavender odour, a decrease in arithmetic task performance was found [79]. According to the general arousal theory, high or moderate odour levels causing more than low stress would be expected to increase performance in simple tasks such as clerical work, etc., and decrease performance in difficult tasks such as arithmetic.

Emotional responses to odours may occur and it has been stated that exposure to pollutants may, up to a point, increase aggression [37]. Studies where measured responses of the ANS were linked to emotions, suggest that the unpleasant odours of acetic acid and butyric acid evoke disgust and anger [146], and that pleasant-rated odours (vanillin, menthol) may evoke mainly happiness and surprise [2].

ODOUR, ANNOYANCE AND HEALTH

Response to a chemical is affected both by the perceived odour and by the cognitive expectations [29]. An annoyance response to an odour means disturbed well-being after cognitive evaluation of the environment, and annoyance has been defined as *a feeling of displeasure associated with any agent or condition believed to affect adversely an individual or a group* [75]. In the relationship between olfactory stimulation and annoyance several physical as well as individual parameters interact [134]. In a number of studies, health related symptoms are found to be connected to odour annoyance. Tobacco smoke causes annoyance as well as irritation of the mucous membranes, the eyes, nose, and throat [24]. Following adaptation, experienced odour intensity rapidly decreases with time; on the other hand, irritation increases with time [23, 67].

Odour perception and annoyance were indicated to represent the principal factors mediating reports of ill-health in a study of the health impact of an oil refinery in Oakville, Canada [80]. In field studies with interviews of individuals in the neighbourhood of a fertilizer plant for mushrooms and a pig production facility, increased annoyance and symptoms were correlated with increased odour exposure, and it was concluded that environmental odours may be considered as a risk factor regarding well-being and health [129, 131]. The symptoms reported by the individuals living in the vicinity of the pig production facility were found to be mediated by annoyance, but this could not explain all the symptoms (especially those of a gastric nature: nausea, loss of appetite, vomiting, retching, etc.), occurring in people living around the fertilizer facility with "particularly offensive" odour emission. It was stated that under extreme conditions the odour itself was associated with (gastric) symptoms and health complaints, but under moderate odour conditions (the pig production facility) the symptoms and health complaints were mediated through annoyance.

Research indicates that neighbours of swine production facilities can experience health problems more frequently than comparable population groups [66, 112, 123, 140, 141, 150]. *Frequently reported symptoms of odours are irritations in the nose, eye and throat, cough, shortness of breath, hoarseness and nasal congestion, drowsiness, stress, headache, nausea, palpitations, and also alternations of mood* [109]. Table 1 shows symptoms with observed increased frequency in the vicinity of animal production facilities, and selected observed chemicals with ability to cause the symptoms. The development of psychological problems in neighbours of swine production facilities has been discussed [85], and significantly more tension, more depression, more anger, less vigour, more fatigue, and more confusion have been found for people living near intensive swine operations [112]. In Utah (USA), a very large pig farm was established in 1993 with a production based on 44,000 sows a couple of years later, and in a study of the population around the facility a large increase in both diarrhoeal and respiratory illnesses was found [66], but their causes remained undiscovered [128]. A study of neighbours of a large-scale swine operation (4,000 sows) showed increased frequencies of a number of symptoms [140], and the same was found in the vicinity of another large-scale swine production facility [123]. Increased symptom frequencies were found for residents near a swine production facility (6,000 hogs) compared to frequencies for residents in the vicinity of 2 intensive cattle operations, and in an area without animal production facilities using liquid waste management [150]. Reduced quality of life was also indicated near the swine operation by the number of times when the residents *could not open their windows or go outside* [150].

Residents living near composting sites had more complaints and there were greater frequencies of symptoms than those found in the German population [53] where headache, gastric symptoms such as abdominal pain, bloating and food intolerance, and palpitations are frequently reported [106]. In studies of individuals in California exposed to offensive odours near industrial and/or hazardous waste sites, reported symptoms of headache, nausea, eye and throat irritations were found to be related to both odour and worry, and furthermore, seemed to be synergistic determinants of the above symptoms [119, 121]. However, in experiments exposing individuals (mostly for 4 hours) to 8 different chemicals, only a weak influence was found of trait anxiety (and chemical sensitivity) on annoyance, bad odour and irritation [118].

The degree of annoyance in response to odours from industrial sources in the vicinity should be modulated by the general stress-coping style together with age and perceived health [151]. Problem-oriented coping styles with attempts to solve the problem are found to increase annoyance and avoidance-coping appears to reduce annoyance [151]. Emotional-oriented strategies using measures for mental distraction have, in some studies, showed a weak negative correlation with annoyance [134]. Important factors for odour nuisance are frequency (number of times detected during a time period), intensity, duration (time period in which the odour is detectable), and offensiveness (character and quality of the odour) [117]. Location of the receptor, i.e. the odour expectation at the specific place is also important [64]. Models have been developed describing the relationship between odour concentration exceeding 2% of the time per annual basis and the percentage of highly annoyed individuals, and it was found that odour pleasantness affected the number of highly annoyed individuals [86]. Odour frequency is an important factor in odour impact on society, and in a number of cases it is used as a base for regulations, and setback models, for example, the German regulations

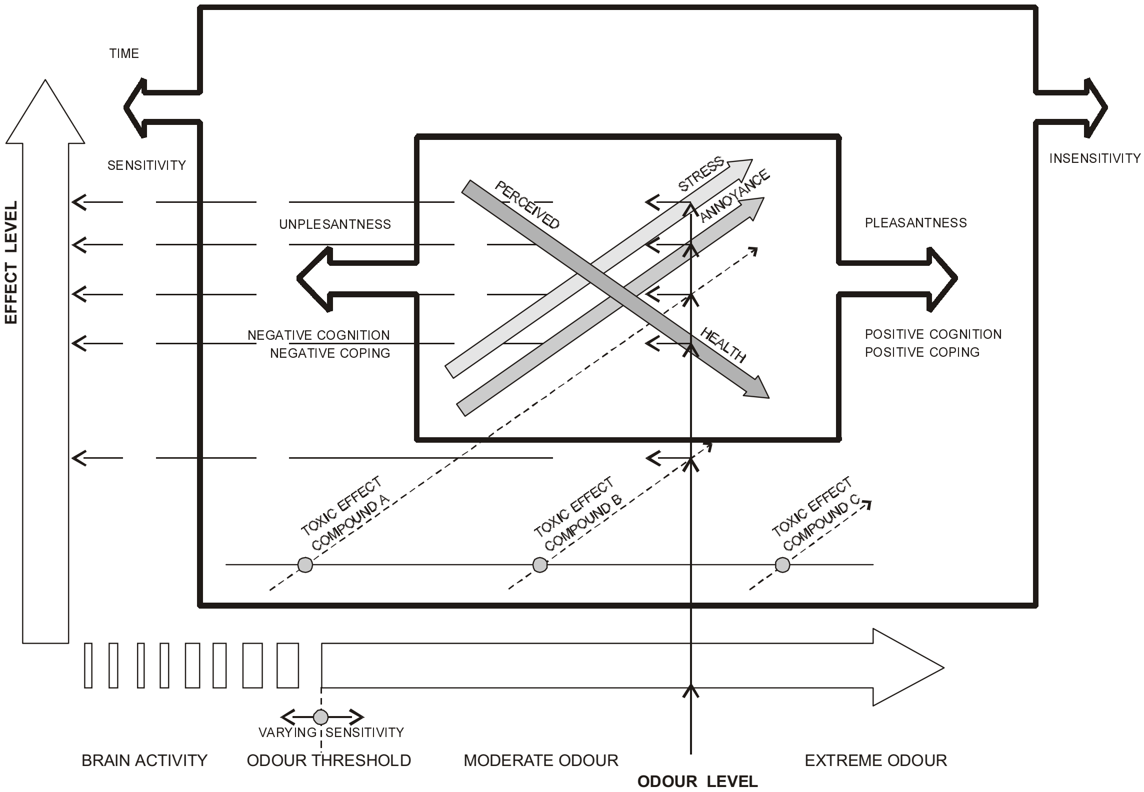

Figure 1. Schematic illustration of health related response to odour and odorants. Moving boxes illustrate the influence of main factors affecting response levels. For example, increased time moves the large box to the left in the diagram, resulting in more annoyance, more stress, lower perceived health and higher toxic effects for compounds present at the same odour level.

[17]. A relationship between odour frequency (odour hours per year) and annoyance has been found [129, 134]. Odour frequency explains a considerable part of the annoyance and values of the annoyance on a scale from "no disturbance at all" to "unbearable disturbance" have been linked to the percentage of unacceptability [134].

An attempt to schematically visualize the relationship between odour and human reactions related to well-being and health is made in Figure 1.

DISCUSSION

Odour (malodour) can produce symptoms without toxicological irritation. It can be a marker present when the toxicological effect of emissions occurs, or it can be a part of a mixture of co-pollutants [109]. A number of health problems, especially those of a respiratory nature, are present in workers in swine production facilities [26]. Similar symptoms and frequencies manifested in neighbours seem inexplicable in the light of the far lower pollutant concentrations at the neighbours' sites [33]. Among 168 listed compounds present in and around animal production facilities [100], about 80 have hazardous properties [136]. Among these are compounds with a documented risk to cause symptoms reported by exposed individuals (Tab. 1), and of these, 2-propenal (acrolein), benzene, formaldehyde, hydrazine, and 2-methoxy-ethanol may be harmful at 1 ppm or below [95]. However, the concentrations found are far below TLVs [110]. Simultaneous exposure to different air-contaminants may produce additive or reinforced (synergistic) effects far exceeding the sum of the single effects [135], and the mix of gases and airborne elements like dust particles in the farm odour is declared to have inter-active and synergistic effects [141]. However, these are not likely to be an explanation of similar symptom frequencies.

The Bunsen-Roscoe law states that *the biological effect is dependent only on the product of the stimulus intensity and duration of exposure* [19, 60]. Regarding reactions to odours, annoyance (involving the hedonic tone) might represent the "intensity" having an effect on the well-being. Annoyance-mediated perceived health may be a part of an explanation of similar experienced health problems in workers in swine production and in neighbours, and adaptation in workers, together with pleasantness, cognition and coping are factors involved (Fig. 1). Cognition involves individual psychological and social factors such as perceived environmental risk, expectations of illness, toxicity, opinions in society and in the social grouping. To have an income from an operation which generates malodours, would most likely reduce annoyance and perceived risk, compared to living in malodour without benefit and without control.

In the late 1980s, odour concentration was suggested as a measure of air quality for buildings such as offices [41, 42, 43]. Regarding air quality in animal production facilities, pollution levels are often characterized by concentrations of ammonia, hydrogen sulphide, carbon dioxide and amounts of organic dust. Regarding well-being and health as well as the work environment in animal houses, odour levels might serve as a good general complementary indicator. Following adaptation and positive cognition, acceptable odour levels in the work environment should be very much higher than the low levels discussed at neighbours' sites. In the surroundings, odour-free periods followed by peaks of odour [96] stimulate the olfactory system to react and sensitization, negative cognition and negative coping may contribute to low levels of acceptable odour.

There are different approaches to odour regulation around the world [81] and basically 5 are used for agricultural odours around the facilities namely: (1) setback distances specifying only source (animal type) and receptor (single house, urban area, etc.); (2) setback distances calculated by formulas using site-specific information, for example, the source; (3) concentration limits for a specific compound in the ambient air, such as hydrogen sulphide; (4) OU (similar to OU/m^3) limits referring to dispersion modelling; and (5) legislation prohibiting annoyance found by field inspectors. In a recent report from Iowa, it was suggested that the 3 substances hydrogen sulphide, ammonia and odours should be considered for regulatory purposes, and for odour, concentrations of 7 OU with limited excess is suggested [59]. Odour pleasantness which is influenced by concentration has been found to have a bearing on the annoyance level [86]. A certain level (value) of pleasantness (hedonic tone) with limited excess regarding time might perhaps be an alternative for odour regulation.

CONCLUSIONS

Odorants and chemicals may affect human beings in a number of ways, and this may even occur at below odour threshold concentrations. Common sites of irritation and injury are the upper and lower respiratory tracts. The sense of smell can be damaged by high concentrations of chemicals; moreover, in some cases, chemicals may enter the brain. The protection system triggered by the trigeminal nerve prevents severe effects in most cases. An odour may affect mood and emotions, stress level, and perceived health. An aversive odour may trigger avoidance behaviour and mask other olfactory information. Regarding odour from animal production, the following conclusions can be made:

- In the vicinity of animal production facilities increased frequencies have been found of a number of respiratory symptoms, eye irritation, stress, palpitations, headache, and nausea, together with alterations of mood. The symptoms may be caused by odour-mediation through stress and annoyance, by co-existing compounds and/or gases where synergistic effects increase the influence, or by a combined impact.
- Hydrogen sulphide, and perhaps ammonia, may contribute to the symptoms. The pollutants 2-propenal (acrolein), benzene, formaldehyde, hydrazine, and 2-methoxy-ethanol are harmful at low concentrations and might perhaps contribute, since they can cause one or more of the observed symptoms.
- Important factors affecting mood, stress, and perceived health are odour levels, time of exposure, sensitivity, pleasantness, cognition and coping. Odour impact on humans can be reduced by careful planning of suitable sites, technical arrangements, and information influencing cognition and the individual coping styles.
- Pleasantness (hedonic tone) influences annoyance and might be considered for regulatory purposes.

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