TRANSPORT OF FARM ANIMALS: THE THERMAL ENVIRONMENT

SCHRAMA J.W.*, VAN DER HEL W.*, HENKEN A.M.*, GORSSEN J.* and VERSTEGEN M.W.A.**

Departments of * Animal Husbandry and ** Animal Nutrition, Agricultural University, Wageningen, The Netherlands

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SUMMARY

The conditions (total complex of stressors) during transport of animals vary strongly between and within transports. Adverse climatic conditions can be one of the stressors animals have to face during transport. Thermoregulation of animals is discussed with respect to threshold values for optimal climatic conditions. These thermal thresholds depend on animal related factors, and environmental conditions. The specific transport conditions, such as food and water deprivation, high stocking density, high humidity and high air velocity, and their impact on thermal thresholds are described.

INTRODUCTION

One of the characteristics of transport of animals is the large variability. Different species (pigs, poultry, cattle and sheep) are transported by various means (truck, boat, plane, etc.). Furthermore, the reasons for transport varies (breeding, slaughter, production). Moreover, the conditions (presence of stressors) during transport can differ strongly between but also within transports. Consequently, there are several perspectives to look at (or judge) the transportation of farm animals (e.g., welfare versus economic viewpoint).

In general, the quality of a transport should be judged against the change in 'quality'/value of the animal during transport. When transporting animals, this change in value (quality) may consist of short-time quality and of long-time quality. The short-time quality involves the welfare, mortality rate, and body weight loss during transport as well as the carcass quality. The long-term quality consists of the growth rate, feed efficiency and the health status of the animals as affected by transport. Essentially, for judgement of transport quality similar variables are used as those applied at farm level. At the farm, conditions are optimized as far as knowledge and possibilities are available. During transport, one normally accepts some deviation from optimum conditions as duration of transport is short relative to 'farm' life. The main question, however, is what the requirements of the animals are during transport with respect to environmental conditions, and how they are affected if these requirements are not met.

Transport of animals is generally accepted as a stressful event. Many factors affect the quality of transport. See for instance the books by and Moss (1982) and Grandin (1993). In this paper, we will focus on the thermal environment during transport, because climatic conditions can have a large impact on transport quality.

CONCEPT OF THERMOREGULATION IN HOMEOTHERMIC ANIMALS

Cattle, sheep, pigs as well as poultry are homeothermic animals. Homeothermic animals sustain a constant body temperature under varying environmental conditions by balancing heat loss and heat production (Mount, 1979). The principles of this thermoregulation have been extensively described (Mount, 1979; Curtis, 1983).

In Figure 1, the general concept of thermoregulation is shown. Within the zone BE, animals are able to maintain a constant body temperature irrespective of the environmental temperature. Temperatures below point B and above point E will cause a decrease (hypothermia) and an increase (hyperthermia) in body temperature, respectively. According to the type of body temperature regulation, the zone BE is divided into a zone (CE) where heat loss is regulated and a zone (BC) where heat production is regulated.

Within the zone CE, the zone of thermoneutrality, heat production is not affected by climatic condition, but depends on other factors such as feeding level, physical activity and the physiological status of the animal. The total heat loss is kept constant by regulation of both sensible heat loss (conduction, convection and radiation) and evaporative heat loss. With increasing temperature in the zone CE, the sensible heat loss diminishes, because the temperature gradient between the animal and its environment is reduced. Therefore, the animal needs to increase the evaporative heat loss by perspiration and/or panting.

In the zone BC, the mechanisms to reduce or to control the heat loss are depleted. Hence, with decreasing ambient temperatures the heat loss increases. In order to sustain homeothermia, the animal has to increase its heat production.

The lower limit of the thermoneutral zone (CE) is called the lower critical temperature (LCT) and the upper limit the upper critical temperature (UCT). The thermoneutral zone can be seen as a thermal indifferent zone. The climatic conditions in this zone are optimal for the animal (no stress). Hence, LCT and UCT are the threshold values (in terms of temperature) regarding to cold and heat stress, respectively. Above UCT animals are exposed to heat stress and below LCT to cold stress.

FACTORS AFFECTING THERMAL REQUIREMENTS (THRESHOLDS)

Thermal requirements of animals expressed by LCT and UCT are not fixed values. As summarized by Young et al. (1989), both LCT and UCT of animals depend on animal related factors as well as environmental factors (e.g., feeding level, stocking density, etc.). These factors can affect LCT and UCT by influences on the heat loss and/or by influences on the heat production (within the thermoneutral zone). Hence, it should be realised that the exact values of both LCT an UCT presented in this paper are only valid under specific conditions.

Animal related factors. Reviews of Blaxter (1989) and Christopherson (1985) demonstrated that there is a large variation in LCT between species of farm animals. Generally, sheep and cattle have lower LCT than pig and poultry.

Also within species, the thermoneutral zone is not fixed. The age (and/or body weight) is an other animal related factor affecting LCT and UCT. With increasing age both LCT and UCT decrease (Blaxter, 1989; Holmes and Close, 1977). Table 1 shows the effect of age (body weight) on the thermoneutral zone of individually housed pigs which are fed at their maintenance requirements (Verstegen, 1987). These data refer to the response under standard environmental conditions (low air velocity and no high relative humidity). Both LCT and UCT decrease with age (body weight). However, the decline in LCT is larger than in UCT. These data show that young animals have a smaller zone of thermal neutrality and thus have more precise demands regarding the air temperature than adult animals.

TABLE 1. Calculated age (weight) effect on lower (LCT) and upper critical temperature (UCT) and on width of thermoneutral zone (UCT-LCT) of individually housed pigs fed at maintenance (420 kJ/kg$^{0.75}$.d) (Verstegen, 1987).

Kind of animal	Weight (kg)	LCT (°C)	UCT (°C)	UCT-LCT (°C)
Baby pig	2	31	33	2
Growing pig	20	26	33	7
Finishing pig	60	24	32	8
Finishing pig	100	23	32	9

Apart from age, also the body condition of animals may affect the zone of thermoneutrality. Thin sows have a higher LCT than fat sows (Holmes and Close, 1977, De Hovell et al., 1977). On the other hand, they may have a lower UCT due to improved conductivity. Similarly, the fleece thickness of sheep (shorn or not) influences the zone of thermoneutrality (Blaxter, 1989; Christopherson, 1985). Calculations by Webster et al. (1993) showed that feather condition in poultry had a large impact on the thermoneutral range. They calculated that the thermoneutral range in transport crates was 8-18°C for well feathered hens (or broilers) and 24-28° for poorly feathered hens.

In conclusion, it should be realised that the intrinsic requirements regarding the air temperature during transport vary between, but also within farm animal species, irrespective of the environmental (extrinsic) conditions during transport.

Feeding level. One of the well known factors affecting LCT and UCT is the feeding level. At thermoneutral conditions, an increase in feed intake results in an increased heat production. As described by Curtis (1983) such an increase in heat production at thermoneutrality leads to a reduction in both LCT and UCT. The general response to an increased feed intake is depicted in Figure 2. The effect of feeding level for a 100 kg, individually housed pig is shown in Table 2. Again, these data refer to the response under standard environmental conditions. Table 2 clearly shows that the thermoneutral range is smaller at lower feeding levels, because the effect on LCT is larger than on UCT.

It is common practice, that animals are not fed during transport, or even from some hours before transport onwards. Quantitative information on LCT and UCT in fasted farm animals is scarce compared to fed animals. Theoretically, it can be expected that fasted animals have a higher LCT and a higher UCT. Heat production in fasted animals decreases curvilinearly with time since the last meal. This implies that the thermoneutral range of animals during transportation is dependent upon the time interval since the last meal.

TABLE 2. Calculated lower critical temperature (LCT), upper critical temperature (UCT) and width of the thermoneutral zone (UCT-LCT) of individually housed pigs weighing 100 kg at maintenance (M; 420 kJ/kg$^{0.75}$.d), 2 times maintenance (2M) and times maintenance (3M) (Verstegen, 1987).

Feed intake (× maintenance)	LCT (°C)	UCT (°C)	UCT-LCT (°C)
1 × M	23	32	9
2 × M	19	30	11
3 × M	14	28	14

Stocking density (group size). In general, variations in housing conditions are known to affect the thermoregulation of animals (NRC, 1981). An example of this is the difference in LCT between group versus individually housed pigs: group housed pigs have a lower LCT (Verstegen, 1987). This effect on LCT is related to the reduction of heat loss by huddling. In contrast to pigs (Boon, 1981), Webster et al. (1978) did not find a reduction in heat loss between pairs and single housed calves.

In contrast to cold conditions, animals will exhibit altered behaviour for enhancing the heat loss under warm conditions (near UCT) (Boon, 1981). Such behavioural responses are the selection of microclimate and the adjustment of the posture (e.g. spreading of the wings in birds; Webster 1993). As long as housing conditions do not interfere with the ability to perform this thermoregulatory behaviour, it can be expected that UCT will not be affected. However, under extremely high stocking densities, such as animals face during transport, thermoregulatory behaviour may be impaired. It can be expected that high stocking densities mainly affect the UCT, because of the restriction of postural thermoregulation. Calculations by Webster et al. (1993) demonstrated that restriction of postural thermoregulation results in a 12°C lower UCT for a well feathered broiler (or hen) and a 4°C lower UCT for a poorly feathered hen when housed in crates used during transport.

Apart from influences on the thermoregulatory behaviour of animals, the stocking density might also affect the total level of physical activity. In a study by Gorssen et al. (1994), the effect of available space on total and activity-related heat production of group housed pigeons was assessed. In this study, pigeons were housed in a metal crate and exposed to an air temperature of 36°C with water available. Results on total heat production and the percentage of activity related heat production are shown in Figure 3. During the light period, heat production was increased at the higher stocking densities (limited available space per animal). Furthermore it was shown that the effect of stocking density on heat production was caused by differences in physical activity. This implies that transport of animals at high stocking densities may lead to an elevated heat production and thereby both LCT and UCT might be lowered. Especially under warm climatic conditions, the interference of the higher activity and impaired thermoregulatory behaviour due to the high stocking densities might enhance the susceptibility to heat stress.

In conclusion, the influence of stocking density on thermoregulation (especially UCT) is caused by an effect on heat production as well as on the heat loss.

Water deprivation. In most studies on thermal requirements of farm animals, animals were not restricted in the consumption of water. However, during transportation, animals are commonly deprived of water for periods up to 24 hours. In cold environments, water availability is of minor importance with regard to sustaining constancy of body temperature, because evaporative heat loss is minimal (Figure 1). In hot environments, however, evaporative heat loss is crucial (Figure 1). Research on pigeons showed that water availability is a major factor affecting UCT (Gorssen and van der Hel, 1993). This research was performed with group housed pigeons, which were kept in crates used for transportation of racing pigeons. Measurements of heat production showed that in water deprived birds UCT was 32°C, whereas UCT of birds with access to water was above 37°C. Information on the impact of water availability on the thermal requirements of farm animals is, however, lacking.

Apart from the impact on evaporative heat loss, deprivation of water also withholds the beneficial effect of drinking cool water under hot environmental condition. However, the extra heat loss by drinking cold water is only a short thermoregulation mechanism.

General effects of stressors. The specific effects of water and food deprivation, and stocking densities on the thermal requirements of animals during transportation have been discussed above. These and other stressors (e.g., noise, vibration) imposed on the animals during transport may elicit stress. Stress in animals results in a wide range of behavioural and physiological changes in order to maintain their homeostasis (Moberg, 1985). The response to stressors comprises the activation of the sympathetic-adrenomedullary system, which involves the immediate release of catecholamines, or the hypothalamic-pituitary-adrenocortical system, which involves the more gradual release of glucocorticoids (Dantzer and Mormède, 1983; Moberg, 1985; Oliverio, 1987). In general, the release of catecholamines and glucocorticoids in a stressed animal are directed to the rapid mobilization of energy reserves for metabolic processes (Dantzer and Mormède, 1983).

When animals are stressed this also might affect their thermal requirements due to an alteration of their heat production. Cronin (1985) showed in sows, that chronic stress due to tethering enhanced the heat production by 20%. Measurements on the effect of the acute stress of transport on the heat production of animals are not present. However, many studies indicated that the heart-rate of animals are increased during transport (e.g., Stephens and Perry, 1990; Schouten et al., 1994). Heart-rate is strongly correlated with the heat production of animals (Dauncey and James, 1979) and is thus used as an indirect method to measure heat production under field conditions. Another indication for an enhanced energy expenditure during transportation has been found in 6-d-old calves (Schrama et al., 1994). Transported calves had an increased heat production during the first days after transport.

If animals, which are stressed during transportation, have an enhanced energy expenditure, their LCT and UCT will be lowered similar to the effect of an increased feed intake. The finding in young calves of an increase in LCT by 0.9°C/d during the first 5 days after transport (Schrama et al., 1993), supports this hypothesis. Besides the effect on heat production, stress might also influence the thermoregulation during transportation by effects on the heat loss.

Climatic conditions. Under most conditions there is a continuous net loss of heat from the animal's body by conduction, convection, radiation, and evaporation (Figure 1). The rate of this heat loss depends on the thermal demand of the environment ('cooling' power of environment). Up till this part of the paper the thermal requirements were discussed only in relation to air temperature. However, several other components of the climatic environment determine UCT and LCT, such as air velocity and vapour pressure (humidity).

Air velocity influences both LCT and UCT. An increase in air velocity will result in an enhanced heat loss. Consequently, this leads to a higher LCT and UCT. This has been demonstrated in pigs by Verstegen et al. (1987). This study, using operant supplementation heating, showed that the preferred air temperature increased with air velocity. Heat production measurements at various temperatures in young calves revealed that LCT increased with air velocity (Holmes and McLean, 1975). Under hot environmental conditions, the impact of air velocity on heat loss may have a positive effect on the animals during transport by reducing the heat stress. However, it can be expected that very high air velocities will have a negative impact. Under normal husbandry conditions, draught (movement of cold air at a high speed) is known to have a negative impact on the animals' health status (Verhagen, 1987; Scheepens, 1991). Knowledge on the optimal levels of air velocity during transport are lacking.

Vapour pressure (or relative humidity) is another climatic component which affects the animal's heat loss. Vapour pressure is of minor importance at cold conditions. However, it is of major importance under hot environmental conditions, since it determines the ability to lose heat by evaporation of water. Therefore, under hot conditions both air temperature and relative humidity (vapour pressure) determine the thermal demand of the environment ('cooling' power of environment). In the temperature-humidity index (THI), the effects of these two climatic factor on the animal's heat balance are combined by weighing the dry ($T_d \approx$ air temperature) and wet bulb temperature (T_w). According to Ingram (1965) the THI for pigs is:

$$THI = 0.65 \times T_d + 0.35 \times T_w$$

and for cattle:

$$THI = 0.35 \times T_d + 0.65 \times T_w$$

In 1-d-old chickens, THI was estimated as (Henken et al., 1987):

$$THI = 0.81 \times T_d + 0.19 \times T_w$$

These equations show that the importance of dry as compared to wet bulb temperature differs between species. This contrast is related to differences in the ratio between evaporation by sweating and by panting. Cattle are more susceptible to a high humidity as compared to pigs and poultry. The relative humidity does not affect LCT. However, relative humidity is of importance for UCT, because it determines the amount of heat an animal can loss to environment by evaporation. In air saturated with moisture, UCT (expressed as dry bold temperature) is lower than in dry air.

THERMAL THRESHOLDS (REQUIREMENTS) DURING TRANSPORT

Quantitative information on thermal thresholds (UCT and LCT) is import. These thresholds provide objective guidelines on optimal climatic conditions for animals during transport.

Lambooy et al. (1987) simulated a 2-d transport of 100 kg pigs at three ambient temperatures using climatic respiration chambers. Pigs were non-fed and kept at a stocking density of about 0.5 m^2/animal, but had access to water. In this study, heat production was observed to be lowest at 16°C compared to both 8 and 24°C. This suggests that LCT was below 8°C and UCT below 24°C. Van der Hel et al. (1991) assessed UCT of 1-d-old chickens during transport. In this study, the animals were housed in commercial cardboard chick boxes, and deprived of water and feed. Based on 24-h heat production measurements, UCT was fount to be between 36 and 37°C. Based on literature data, the calculated thermoneutral range for well and poorly feathered hens in transport crates was 8-18°C and 24-28°C, respectively (Webster et al., 1993).

Apart from these studies, their is little quantitative information on thermal thresholds for the environmental conditions encountered during transport. The qualitative aspects of the major factors affecting thermal thresholds were dealt with in the section above. Food deprivation and high air velocity are factors having a lowering effect on LCT and UCT. Hence, they increase and reduce the risk of exposure to cold and heat stress, respectively. Stocking density and the general response to stressors enhance the risk of heat stress but lower that of cold stress. In contrast to other factors, water deprivation and high relative humidity mainly affect UCT, by reducing the possibility of heat loss through evaporation. Consequently, water deprivation and high humidity make the animals more prone to heat stress. For providing objective guidelines for practice (transporters, and vehicle designers) more research is needed on thermal requirements of animals under the environmental conditions which they face during transport. For a good application in practice, contributing factors should not be studied separately under optimal conditions. The factors should be studied as part of the total complex, because interaction between factors will be of major importance.

MICRO-CLIMATE DURING TRANSPORT

The micro-climate around the animal determines whether they are exposed to climatic stress (cold or heat) or not. Figure 4 gives temperature data of a simulated air transport of 1-d-old chickens (Henken et al., 1987). The temperature outside the chicken boxes, which was representative for temperature inside the aircraft, was below UCT. The temperature inside the boxes was, however, 10 to 15°C higher. During some periods the temperature inside the boxes reached levels above UCT. These data clearly show that it is important to measure the climatic conditions near the animals for a proper judgement of the micro-climate.

The temperature within a vehicle (crate) is determined by the balance between the heat produced inside and the heat lost from the vehicle (crate). The former depends on the heat production per animal, and the number of animals within the vehicle (crate). Factors affecting the animal's heat production have been discussed previously. Regarding the stocking density it should be realised that apart from its impact on UCT and LCT, it also directly influences the temperature in the vehicle (crate). Heat is lost from the vehicle (crate) by conduction through the construction and by ventilation. Both types of these losses depend on the temperature gradient with the outside.

The importance of heat loss from crates has been shown by Henken et al. (1987). The box type as well as the loading configuration affected the temperature within the chicken boxes during air transport and thereby mortality rate. In naturally ventilated trucks, movement of the vehicle is the major factor determining the heat loss by ventilation. An example of the rapid build up of heat in a stationary vehicle was demonstrated in poultry by Kettlewell and Mitchell (1993). They found that the temperature within the crates during a transport break can rise by 10°C within 30 min.

Alike temperature, vapour pressure (humidity) within a vehicle (crate) depends on factors affecting vapour production inside and those affecting the loss of vapour from the vehicle. However, in contrast to temperature, vapour is only dissipated from the vehicle (crate) by ventilation.

CONSEQUENCES OF THERMAL STRESS

Temperatures below LCT as well as above UCT cause thermal stress in animals. During transport both cold and heat stress can occur. With regard to mortality rate during transport, heat stress is more important than cold stress. As is shown in Figure 1, temperatures above UCT will lead to changes in body temperatures and consequently may result in an increased mortality rate during transport. At temperatures below LCT (cold stress) animals are still able to maintain body temperature constant by increasing the heat production. As long as hypothermia does not occur, cold stress is of minor importance for the mortality rate during transport. However, cold stress during transport might lead to an impaired health status after transport as well as meat quality.

The stress imposed on the animals depends on the deviation from the threshold value. In Figure 5, the impact of heat stress (temperatures above UCT) on mortality rate in 1-d-old chickens is depicted (Henken et al., 1988). A larger deviation from UCT leads to a higher mortality. Furthermore, these results demonstrate that the duration of the exposure is a major determinant affecting the mortality. Hence, the ability of an animal to cope with a stress depends on the magnitude of the stressor and the duration of this stressor. Similarly, Warriss and Knowles (1993) demonstrated in broilers that the number of dead birds at arrival increased with the journey time.

A major problem of heat stress during transport is the fact that animals are deprived of water. As a consequence, heat stress often exposes animals to dehydration due to the dependency upon evaporative heat loss. This risk of depletion of body water reserves has for instance been demonstrated in pigeons (Gorssen and van der Hel, 1993; Figure 6). In pigeons deprived of water, the dry matter content of the breast part (breast bone with appending muscles) increased at high temperatures (above 33 °C; Figure 6), indicating the occurrence of dehydration. In pigeons with access to water this did not occur. In contrast to the short term effect of heat stress such as on meat quality and on survival rate during transport, little information is present on the long term effects. The importance of the long term effect of heat stress has been demonstrated in 1-d-old chickens (van der Hel et al., 1992). Apart from a high mortality rate during the 2-d exposure period, the heat stress also resulted in a higher mortality rate during the 2-w period after the exposure to high ambient temperatures. In general, little information is present on the long term effects of transportation on the performance of animals (e.g., growth rate, health status).

CONCLUSIONS

Within the thermoneutral zone, climatic conditions are optimal for the animal. The upper and lower limit of this zone are the thresholds values regarding thermal stress. Quantitative information on these thermal threshold for animals during transport is scarce. Thermal thresholds are not fixed values. Animal related as well as environmental factors affect thermal thresholds. Thermal thresholds of animals during transport will be variable, because of the large variability in conditions between and within transports. More quantitative knowledge on the short- and long-term effects of specific transport conditions (e.g., food and water deprivation, high stocking density) is needed in order to meet the requirements of the animals during transport. Especially, interaction effects should be considered. The impact of thermal stress on animals is dependent on the deviation from the threshold value and the duration of the exposure (transport).

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