Coping styles in animals: current status in behavior and stress-physiology

J.M. Koolhaas[a,*], S.M. Korte[b], S.F. De Boer[a], B.J. Van Der Vegt[a], C.G. Van Reenen[b],
H. Hopster[b], I.C. De Jong[a,b], M.A.W. Ruis[b], H.J. Blokhuis[b]

[a]*Department of Animal Physiology, University of Groningen, P.O. Box 14, 9750 AA Haren, The Netherlands*
[b]*DLO-Institute for Animal Science and Health (ID-DLO), Department of Behavior, Stress Physiology and Management, P.O. Box 65, 8200 AB Lelystad,
The Netherlands*

Received 1 May 1999

Abstract

This paper summarizes the current views on coping styles as a useful concept in understanding individual adaptive capacity and vulnerability to stress-related disease. Studies in feral populations indicate the existence of a proactive and a reactive coping style. These coping styles seem to play a role in the population ecology of the species. Despite domestication, genetic selection and inbreeding, the same coping styles can, to some extent, also be observed in laboratory and farm animals. Coping styles are characterized by consistent behavioral and neuroendocrine characteristics, some of which seem to be causally linked to each other. Evidence is accumulating that the two coping styles might explain a differential vulnerability to stress mediated disease due to the differential adaptive value of the two coping styles and the accompanying neuroendocrine differentiation. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Coping; Aggression; Stress; Disease; Corticosterone

1. Introduction

Psychosocial factors have long been recognized as important in health and disease both in man and in animals. It is not the physical characteristics of a certain aversive stimulus but rather the cognitive appraisal of that stimulus, which determines its aversive character and whether a state commonly described as stress is induced. The impact of aversive stimuli or stressors is determined by the ability of the organism to cope with the situation [1,2]. Several definitions of coping can be given [3]. In the present paper, we prefer to use the term coping as the behavioral and physiological efforts to master the situation [3,4]. Successful coping depends highly on the controllability and predictability of the stressor [5,6]. A consistent finding across species is that whenever environmental stressors are too demanding and the individual cannot cope, its health is in danger. For this reason, it is important to understand the mechanisms and factors underlying the individual's capacity to cope with environmental challenges. A wide variety of medical, psychological and animal studies demonstrate that individuals may differ in their coping capacities. Factors that have been shown to affect the individual's

coping capacity include genotype, development, early experience, social support, etc. Since many studies in humans indicate that coping mechanisms are important in health and disease [7], researchers have tried for a long time to determine the individual vulnerability to stress-related diseases using estimates of the individual coping capacity. One approach concerns attempts to classify coping responses into distinct coping styles. A coping style can be defined as a coherent set of behavioral and physiological stress responses which is consistent over time and which is characteristic to a certain group of individuals. It seems that coping styles have been shaped by evolution and form general adaptive response patterns in reaction to everyday challenges in the natural habitat. The concept of coping styles has been used in a wide variety of animal species (see Table 1). Despite the widespread use of the concept, it is not without debate [8]. This is due to several flaws in the studies using the concept. First, not all studies fulfill the criterion of coping style as a coherent set of behavioral and physiological characteristics because only one parameter has been studied. Second, the extent to which clearly distinct coping styles can be distinguished has been questioned [8,9]. Special attention will be given here to the frequency distribution of coping styles in a population, the consistency over time and the one-dimensional character of the concept of coping styles. Finally, one may wonder to

* Corresponding author. Tel.: +31-50-3632338; fax: +31-50-3632331.
E-mail address: koolhaas@biol.rug.nl (J.M. Koolhaas)

Table 1
Overview of the species in which a strong individual differentiation has been observed that may reflect coping styles. The plus signs give a rough indication of the number of parameters on which the individual differentiation is based, i.e. + indicates a single parameter study, + + indicates a multi-parameter study

Species	Behavioral parameters	Physiological parameters	Reference
Mouse (*Mus musculus domesticus*)	+ +	+ +	[13]
Rat (*Rattus norvegicus*)	+ +	+ +	[77]
Pig (*Sus scrofa*)	+ +	+ +	[20,37]
Tree shrew (*Tupaja belangeri*)	+ +	+ +	[78]
Cattle (*Bos taurus*)	+	+ +	[23]
Great tit (*Parus major*)	+ +		[19]
Chicken (*Gallus domesticus*)	+	+ +	[79]
Beech marten (*Martes foina*)	+		[80]
Stickleback (*Gasterosteus aculeatus*)	+ +		[24]
Rainbow trout (*Oncorhynchus mykiss*)	+	+	[81]
Rhesus monkey (*Macaca mulatta*)	+ +	+ +	[82]
Human (*Homo sapiens*)	+ +	+ +	[26]
Octopus (*Octopus rubescens*)	+ +		[25]

what extent the concept of coping styles is really related to the individual vulnerability to stress-mediated disease.

This review will discuss these major issues and it will be argued that the clustering of various behavioral characteristics may to some extent be causally related to differences in (re)activity of the neuroendocrine system.

2. Behavioral characteristics of coping styles

Much of our current thinking on coping styles is derived from the work of Jim Henry [10]. He suggested, on the basis of social stress research in animals and man, that two stress response patterns may be distinguished. The first type, the active response, was originally described by Cannon [11] as the fight-flight response. Behaviorally, the active response is characterized by territorial control and aggression. Engel and Schmale [12] originally described the second type of stress response as the conservation-withdrawal response. This response pattern is characterized behaviorally by immobility and low levels of aggression.

Table 2
Summary of the behavioral differences between proactive and reactive male rats and mice

Behavioral characteristics

	Proactive	Reactive	References
Attack latency	Low	High	[14]
Active avoidance	High	Low	[70,83]
Defensive burying	High	Low	[84], this paper
Nest-building	High	Low	[85]
Routine formation	High	Low	[16]
Cue dependency	Low	High	[17,84]
Conditioned immobility	Low	High	[17]
Flexibility	Low	High	[77]

These ideas led to the hypothesis that the individual level of aggressive behavior, i.e. the tendency to defend the home territory, is related to the way individual males react to environmental challenges in general. The hypothesis was tested by Benus [13] using male house mice that were genetically selected for either short attack latency (SAL) or long attack latency (LAL). Also when other indices of aggressive behavior are taken into account, the SAL males are considered extremely aggressive whereas the LAL males have very low levels of intermale aggressive behavior [14]. The results of a series of experiments not only in mice, but also in rats, suggest the existence of at least two coping styles, which are summarized in Table 2. We prefer to use the terms proactive coping rather than active coping and reactive rather than passive coping (see further). Several conclusions can be drawn from these results. First, the individual level of aggressive behavior is indeed related to the way in which the animals react to a wide variety of environmental challenges. Second, it seems that aggressive males have a more proactive type of behavioral response, whereas non-aggressive or reactive males seem to be more adaptive and flexible, responding only when absolutely necessary.

An important fundamental question is whether the two types of behavior patterns can be considered to represent styles of coping in the sense that they are both aimed at successful environmental control [15]. Several experiments indicate that the different behavior patterns can indeed be considered as coping styles aimed at environmental control. This is, for example, shown in a recent experiment using wild-type rats. This strain of rats shows a large individual variation in aggressive behavior similar to the variation in wild house mice. After being tested for their tendency to defend the home cage against an unfamiliar male conspecific, the males were tested in a shock prod defensive burying test. In this test, the animal is confronted with a small,
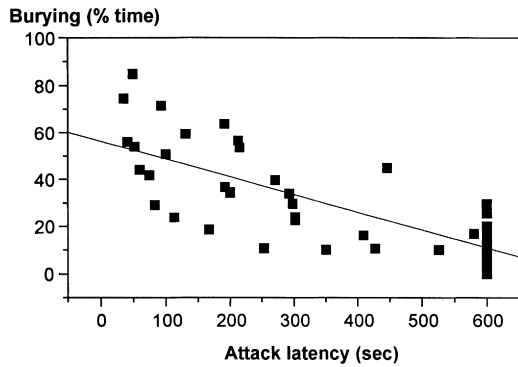
Fig. 1. Correlation ($R = 0.72$) between attack latency score in rats as measured in the resident intruder paradigm and the percentage of time spent burying in the defensive burying test of 10 min duration.

electrified prod in its home cage. Because this prod is a novel object, the experimental animal will explore it by sniffing at the object. Consequently, the animal receives a mild but aversive shock. As soon as it has experienced the shock, the animal has two options to avoid further shocks. It may either hide in a corner of the cage to avoid further contact with the shock prod, or it may actively bury the shock prod with the bedding material of the cage. Under these free choice conditions, aggressive males spend most of the test-time (10 min) burying (Fig. 1) while non-aggressive males show immobility behavior. Notice, however, that the two types of responding are equally successful in avoiding further shocks. In this particular test, successful coping can be defined operationally as avoidance of further shocks. The terms active and passive coping are frequently used to indicate the differences between the two styles. However, these terms may lead to some confusion, because the terms

do not properly describe the fundamental differences. A very fundamental difference seems to be the degree in which behavior is guided by environmental stimuli [16,17]. Aggressive males easily develop routines, i.e. a rather intrinsically driven rigid type of behavior. Non-aggressive males in contrast are more flexible and react to environmental stimuli all the time. For that reason, we prefer to use the terms proactive coping and reactive coping. This differential degree of flexibility may explain why aggressive males are more successful under stable colony conditions, whereas non-aggressive males do better in a variable or unpredictable environment, for example during migration [18].

It is important to emphasize that the differentiation in coping styles may not be expressed equally clearly in all challenging situations. In particular, tests that measure aspects of initiative or proactivity seem to be most discriminative. This holds, for example, for latency measures such as the attack latency test in males or the defensive burying test, which allow the animal a choice between proactive and reactive coping. Although female mice usually do not show territorial aggression, females of the short attack latency selection line show much more defensive burying than female mice of the long attack latency selection line. This supports our view that aggression is only one of a larger set of behavioral characteristics that make up the proactive coping style.

3. Distinct coping styles: distribution and consistency over time

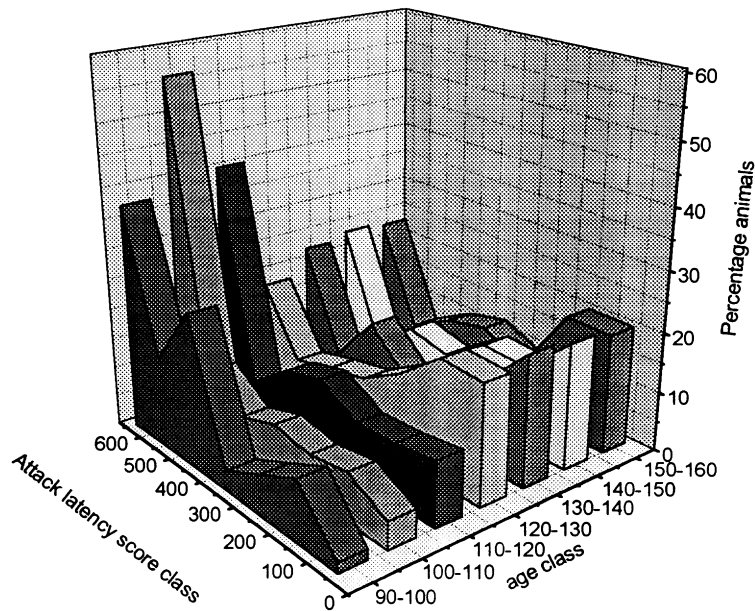The concept of coping style and the way it is generally

Fig. 2. Frequency distribution of attack latency scores (seconds) obtained in the 5th to the 12th generation of laboratory bred wild-type male rats ($N = 2500$) in different age classes (postnatal days).

presented in the literature suggests that there are distinct phenotypes, which are more or less stable over time in their response to stressors. The early studies by Oortmerssen and colleagues, on a feral population of house mice suggest a bimodal distribution of male phenotypes as measured by the individual latency to attack a standard intruder into the home cage [18]. The idea of bimodal distributions has been strengthened by the fact that the phenotypical differences appeared to have a rather strong genetic component. Genetic selection for either of the extremes of the variation in a certain behavioral or physiological characteristic generally results in distinct genotypes within a few generations. Many studies on coping styles and individual vulnerability to stress mediated disease are based on the use of such genetic selection lines. Selection lines have rather stable characteristics, which are relatively insensitive to environmental influences. However, there is confusion in the literature on this issue, because several investigators using unselected strains of animals were unable to find clearly distinct and stable coping styles. The main problem seems to be the large diversity in origin, age and gender of the experimental animals involved. In the few studies that consider feral populations, distinct phenotypes are found. Both in wild house mice and in a small bird, the great tit (*Parus major*), latency measures seem to have a bimodal distribution [18,19]. However, one has to realize that the distribution is not truly bimodal because latency measures are generally finite, i.e. above a certain time the latency is set to the maximum value. This leads to an accumulation of individual scores in the distribution curve at this maximum value. Nevertheless, the individual behavioral scores in wild populations are certainly not normally distributed. An analysis of a large database of aggressive behavior of a population of 2500 laboratory-bred adult male wild rats reveals an age-dependent change in the distribution of attack latencies. Above a certain age, three peaks emerge in the frequency distribution, with a clear intermediate group (see Fig. 2). This difference with the wild situation may be explained by the fact that there is little or no selection pressure in the laboratory. It is tempting to consider the possibility that intermediate animals are less successful in nature. Few studies address the survival value of distinct proactive and reactive coping styles. However, recent, yet unpublished studies in feral populations of birds indicate that the fitness of different coping styles depends on the stability of the environment in terms of social structure and food availability.

Many studies use laboratory strains of animals or heavily domesticated farm animals like pigs. Usually, individual behavioral scores are normally distributed in these studies. For example, several studies in pigs show that the distribution of individual scores in the back-test is normally distributed [20,21]. Moreover, it is hard to tell how a certain inbred or domesticated strain relates to the original and presumably functional distribution of its wild ancestors. However, it is intriguing that the extremes of this normal distribution still

fulfill the criteria for proactive and reactive coping styles, both behaviorally and physiologically [20]. Although the discussion on the shape of the distribution curve is important from an evolutionary point of view, it does not seem to matter much when individual vulnerability to stress-related diseases is concerned. Afterall, it has been repeatedly shown that the extremes in a population, irrespective of the detailed distribution curve, may differ not only quantitatively, but also qualitatively in their behavioral and physiological response pattern to stress (see Table 1). Evidence has been found in different species that the behavioral and physiological response of individual animals to a specific stressor is consistent over time. In pigs, for example, individual gilts that displayed relatively long latency times to contact a novel object and spent relatively little time near the object during their first exposure showed a similar response when re-tested one week later [22]. Also in dairy cows, consistency was measured in behavior, in heart rate and in plasma cortisol concentrations when individual animals were repeatedly tested in a novel environment test over one week. Moreover, consistent stress responses to the same test were also found for cardiac and adrenocortical responses over one year [23].

Another important issue concerns the one-dimensional character of the concept of coping styles. Several studies have used a factor analytical approach to reduce the sources of individual variation in a population to a limited number of components [24–26]. This statistical approach usually reveals two or three factors that explain a considerable part of the individual variation. Although some of these factors relate to trait characteristics or aspects of personality similar to coping styles, others may relate to state variables such as stress and fear. These studies, both in humans and in animals, emphasize the multidimensional character of individual (personality) traits. However, aspects of aggression such as hostility, impulsivity, anger or proactivity are often found as an important dimension. In an experimental study in Roman High and Roman Low avoidance lines of rats, Steimer et al. [27] includes the dimension of emotional reactivity as a second trait characteristic. By correlating behavior of individual animals in a number of coping style and emotion/anxiety related tests, he found evidence for two independent dimensions, i.e. coping style and emotional reactivity. Individual behavioral profiles calculated either on indices of emotional reactivity or on indices of exploratory activity as an indirect measure of coping style resulted in different clustering of individuals. These two dimensions together might explain individual vulnerability to anxiety.

4. Neuroendocrine characteristics of coping styles

Differences in coping style have been observed in male rodents during both social and non-social stressful conditions (see Table 2). Coping styles are not only characterized

Table 3
Summary of the physiological and neuroendocrine differences between proactive and reactive animals

Physiological and neuroendocrine characteristics			
	Proactive	Reactive	References
HPA axis activity	Low	Normal	[33,38,56,70,86]
HPA axis reactivity	Low	High	[20,28,56,87]
Sympathetic reactivity	High	Low	[38,77,88]
Parasympathetic reactivity	Low	High	[37,39]
Testosterone activity	High	Low	[34,35]

by differences in behavior but also by differences in physiology and neuroendocrinology. As mentioned earlier, tests that measure aspects of initiative or proactivity seem to be most discriminative. The defensive burying tests in rodents is such a test, which allows the animal a choice between proactive and reactive coping. In general, defensive burying is accompanied by high plasma noradrenaline and relatively low plasma adrenaline and corticosterone, while freezing behavior is associated with relatively low plasma noradrenaline and high plasma corticosterone levels [28,29]. In a strain of wild-type rats, the more aggressive males showed the highest levels of burying behavior and showed a larger catecholaminergic (both plasma noradrenaline and adrenaline) reactivity after electrified prod exposure and after social defeat than did the non-aggressive rats [30]. Previously, it was shown that during social defeat the more competitive proactive male rats reacted with higher responses of blood pressure and catecholamines than the more reactive rats. In addition, these competitive males had higher baseline levels of noradrenaline [31]. The same holds for strain differences. The aggressive Wild type-rats responded to social defeat with larger sympathetic (plasma noradrenaline levels) reactivity and concomitantly lower parasympathetic reactivity (as measured by increased heart rate response and decreased heart rate variability) than the less aggressive Wistar rats [32]. Thus, proactive coping rodents show in response to stressful stimulation a low HPA-axis reactivity (low plasma corticosterone response), but high sympathetic reactivity (high levels of catecholamines). In contrast, reactive coping rodents show higher HPA axis reactivity and higher parasympathetic reactivity (Table 3).

Differences in endocrine activity have also been observed for HPA axis and gonadal axis activity under baseline conditions. In aggressive mice, reduced circadian peak plasma corticosterone levels have been observed as compared to non-aggressive mice [33]. In mice of the short attack latency selection line and in wild-type male rats, high baseline levels of testosterone have been observed [34,35].

There is a growing body of evidence that similar coping styles can be found in farm animals as well. Hessing and colleagues showed that male castrated pigs could be characterized as high resistant or low resistant at an early age (1–2 weeks) by means of a back-test (manual restraint) [36]. In this back-test, a piglet is put on its back and the number of bouts of resistance is used to characterize the animal. The high-resistant pigs made more escape attempts and mean heart rate frequency was higher than in low-resistant pigs [36]. At three and at eight weeks of age, the high-resistant ones were less inhibited in approaches to novel objects in an open field. But the high-resistant pigs spent less time in exploring the novel object than low-resistant pigs [36]. Heart rate frequency of high-resistant pigs was also substantially increased in reaction to a falling novel object, while heart rate frequency of low-resistant animals was only slightly increased or even decreased (bradycardia), suggesting that parasympathetic reactivity was higher in low-resistant pigs [37]. Hessing and colleagues did not find clear differences in HPA axis reactivity between the high- and low-resistant animals, although basal plasma cortisol levels were higher in low-resistant than in high-resistant pigs and this was accompanied by adrenal hypertrophy. Recently, however, Ruis et al. [20,21] showed clear differences in HPA axis reactivity in high- and low-resistant female pigs. The low-resistant animals had higher HPA axis reactivity than the high-resistant ones. This was shown by higher salivary cortisol responses to a novel environment test, to routine weighing at 25 weeks of age, and to administration of a high dose of ACTH [20]. Interestingly, the low-resistant animals with high HPA axis reactivity at 24 weeks of age, showed less aggression in group-feeding competition tests, hesitated longer to leave their home pens and to contact a human than did high-resistant animals. Altogether, pigs that showed high resistance in the back-test and low HPA-axis reactivity and high sympathetic reactivity in response to stressful stimulation are thought to be representatives of the proactive coping style. In contrast, pigs that showed low resistance in the back-test and high HPA axis reactivity and high parasympathetic reactivity are thought to be representatives of the reactive coping style.

Recently, it was shown that laying hens, from two lines with high or low propensity to feather peck, also show individual differences in physiological and behavioral responses to stress that are similar to the described coping styles. During manual restraint (keeping the bird on its side by hand for 8 min), the high feather pecking line showed more resistance and higher mean heart rate frequency and lower parasympathetic reactivity than the low feather pecking line [38,39]. HPA axis reactivity (plasma corticosterone levels) was highest in the low feather pecking line, while the sympathetic reactivity (plasma noradrenaline levels) was the highest in the high feather pecking line. These data suggest that chickens of the high feather pecking line are representatives of the proactive coping style, whereas birds of the low feather pecking line are representatives of the reactive coping style.

5. Causal relationship between neuroendocrine and behavioral characteristics of coping

One may wonder to what extent the behavioral and

physiological characteristics are causally related. Of course, it is highly unlikely that all differences in coping style can be reduced to one single causal factor. However, evidence is accumulating that a differential HPA axis reactivity may explain some of the behavioral differences. In different species, freezing behavior as part of the reactive coping response can be observed in response to an inescapable stressor or predator. In rats, a large number of studies have shown that corticosteroids play a permissive role in this fear-induced freezing behavior. Adrenalectomy (ADX) impaired the duration of fear-induced freezing compared to sham-ADX controls, suggesting the involvement of adrenal hormones. This behavioral deficit in ADX animals could be restored by the application of corticosterone [40]. In line with these experiments, treatment with metyrapone, a corticosteroid synthesis inhibitor, reduced fear-induced freezing behavior, suggesting that corticosterone is a key hormone in the expression of fear-induced immobility [41]. Since corticosterone can bind to both the mineralocorticoid and glucocorticoid receptor, further experiments were performed to find out which specific receptor type was involved. Intracerebroventricularly administered mineralocorticoid receptor antagonist RU28318 reduced the fear-induced freezing response, whereas the glucocorticoid receptor antagonist RU38486 was without effect [42]. The modulation of freezing via a mineralocorticoid receptor-dependent mechanism did not come as a surprise. Limbic mineralocorticoid receptors bind corticosterone with about 10 times higher affinity than glucocorticoid receptors, and low circulating levels of the corticosteroid hormone almost completely occupy mineralocorticoid receptors [43,44]. The biological background could be that a glucocorticoid receptor-dependent mechanism would have been too slow because glucocorticoid receptors are only occupied at much higher hormone levels that are reached several minutes after the stressor. In nature, the permissive steroid mineralocorticoid receptor action makes an immediate freezing response possible during a sudden appearance of a predator. There is a growing body of evidence that corticosteroids also play a role in fear-induced behavioral inhibition in farm animals. In laying hens, it has been shown that the birds with the shortest tonic immobility response have the lowest corticosterone levels [45]. Further, chronic administration of corticosterone moderately increased plasma levels of corticosterone and prolonged the tonic immobility reaction in hens suggesting a causal role for corticosteroids [46]. Also, in dairy calves, a positive correlation was observed between plasma cortisol levels and the latency to approach a novel object (van Reenen, unpublished observation).

6. Coping styles and differences in disease vulnerability

The concept of coping styles implies that animals have a differential way to adapt to various environmental conditions. Negative health consequences might arise if an animal cannot cope with the stressor or needs very demanding coping efforts. Sustained over-activation of various neuroendocrine systems may lead to specific types of pathology. Hence, in view of the differential neuroendocrine reactivity and neurobiological make-up, one may expect different types of stress-pathology to develop under conditions in which a particular coping style fails. Although there are only a limited number of studies performed concerning pathology in relation to the type of coping style adopted, there are some indications that the two coping styles differ in susceptibility to develop cardiovascular pathology, ulcer formation, stereotypies and infectious disease.

6.1. Cardiovascular disease

Various studies emphasize the differences between the two coping styles in autonomic balance. Because of the role of the two branches of the autonomic nervous system in cardiovascular control, one may expect in conditions of over-activation of these systems, a differential vulnerability for various types of cardiovascular pathology as well. Indeed, a number of experiments found evidence that the proactive coping animal is more vulnerable to develop hypertension, atherosclerosis and tachyarhythmia due to the high sympathetic reactivity [32,37,47–49]. However, hypertension has never been observed after conditions of uncontrollable stress. In social groups, hypertension generally develops in dominant or subdominant males that have difficulties to maintain their social position. Therefore, it seems that these types of cardiovascular pathology only develop under conditions of threat to control rather than loss of control [15]. The reactive coping style seems to be characterized by a shift in the autonomic balance towards a higher parasympathetic tone and reactivity as can be observed by a strong bradycardia response in reaction to a sudden unpredicted stressor. Although there have been no systematic studies of the cardiovascular consequences of this characteristic, one may suggest that these types of animals are more vulnerable to sudden cardiac death due to bradyarhythmia.

6.2. Gastric ulceration and stereotopies

There are numerous studies to indicate that the controllability of stressors is an extremely important factor in ulcer formation. The development of ulcers is low when animals are able to actively control or predict the stressor or divert their attention away from the stressor. For example, if rats can terminate the inescapable shock, or can chew wood during inescapable shock [50], or can bite on a wooden stick during cold restraint stress less, ulcers are observed [51].

The classical studies of Weiss [50] showed that the development of ulcers was high when the number of active coping attempts was high in the absence of informational feedback or with negative informational feedback present. In the experimental animal that could actively control the

aversive shock by either pressing a lever during the warning signal or during the shock itself, the total length of stomach wall erosions was much smaller than in the yoked partner, which received exactly the same number of shocks, but could not control them. Also, when a feedback tone was given after each correct avoidance–escape response, the amount of gastric ulceration was further reduced. However, when brief punishment shock was given to the avoidance–escape and yoked animals whenever an avoidance–escape was made, then the avoidance–escape group showed more severe ulcer formation than the yoked partners. Further, in the absence of informational feedback, a positive correlation was observed between the number of active coping attempts and the amount of gastric ulceration.

In line with these results is an observation in Roman high avoidance (RHA) and Roman low avoidance (RLA) rats, which can be considered to represent the proactive and reactive coping style, respectively. It was shown that RHA rats, after stress of food-deprivation for five days, had more stomach lesions than RLA rats [52]. A negative correlation between attack latency in the intruder test and gastric ulceration induced by restraint-in-water stress [53], also suggests that animals that prefer a proactive coping style are more vulnerable to the formation of ulcers during uncontrollable stress. In rat colonies, dominant animals that are usually representatives of the proactive coping style are reported to develop stomach wall erosions when they have lost their leading position (social outcast) after frequent attacks by other colony members [15].

Another example of a possible relationship between behavioral coping characteristics and pathology has been found in veal calves. It was shown that veal calves fed only with milk developed tongue-playing as a stereotypy [54]. However, not all calves did this with the same intensity. Those calves that developed a lot of oral stereotypies showed less stomach wall ulcers when slaughtered at 20 weeks of age. However, calves that did not develop tongue-playing, all had such ulcers at the same slaughter age [54]. Recently these results were confirmed in a larger study involving 300 veal calves (van Reenen et al., in preparation). Also in tethered breeding sows that were housed individually, two separate groups could be distinguished: some cows spent up to 80% of their active time in this behavior while others hardly developed stereotypies. Surprisingly, the sows that showed less initial resistance in the back-test were the ones to develop high levels of stereotypy later on [55]. Recently, it was shown that high levels of stereotypies are associated with a reduced sympathetic activation caused by the chronic stress of tethering as was shown by a decrease in heart rate during bouts of stereotyped behavior. In this view, stereotypies help the animal to cope with the adverse situation of tethering [56].

There is increasing evidence that individual animals that adopt the proactive or reactive coping style differ in sensitivity of the dopaminergic system and consequently they may differ in vulnerability to the development of stereotypies. For instance, in mice, the dopamine receptor agonist apomorphine produced a greater enhancement of stereotyped behavior in proactive coping animals than in reactive coping animals, suggesting that proactive coping animals may be associated with a more sensitive dopaminergic system [57]. Similar correlations were found in rat lines previously selected for high and low expression of stereotyped behavior (gnawing) in response to apomorphine. The apomorphine-susceptible rats showed more proactive coping behavior (fleeing), whereas the apomorphine-unsusceptible rats showed more reactive behavior (freezing) in reaction to an open-field [58]. A similar relation between coping style and stereotypy has been demonstrated in pigs. Individual proactive (high resistant) and reactive (low resistant) coping pigs can be distinguished in the back-test in which the reaction to manual restraint is measured [59]. Recently it was shown that the high-resistant pigs have a higher oral stereotypic response (snout contact-fixation with floor) to apomorphine as compared to low-resistant pigs [60]. Thus, also in pigs there is a relationship between coping style, sensitivity of the dopaminergic system and development of stereotypies. Moreover, it has been shown that the dopaminergic-sensitivity factor, i.e. the latency to initiate stereotypic gnawing induced by apomorphine, also predicted ulcerogenic vulnerability [61].

The underlying mechanism of increased vulnerability of proactive coping animals to develop stereotypies is not well understood. Here it is hypothesized that altered HPA-axis regulation plays a crucial role in the development of stereotypies. In farm animals it has been suggested that stereotypies are performed to lower the state of arousal and anxiety and to lower corticosteroid levels; however, not all studies show this correlation [62]. A possible explanation for the conflicting data may be the differential effects of corticosteroid hormones at the stage when the stereotypy starts to develop and at the stage when a full-blown stereotypy continues to exist. It is hypothesized that stress levels of corticosteroids may enhance the acquisition and expression of stereotypies, whereas an already developed stereotypy may reduce corticosteroid levels. This is supported by the following two examples in rodents. First, amphetamine activates dopamine pathways and induces stereotyped behavior (e.g. gnawing) that can be potentiated by high levels of corticosterone [63]. This suggests that brain glucocorticoid receptors are involved. Moreover, corticosteroids sensitize the dopaminergic system, probably through binding to the glucocorticoid receptors [64]. Second, dopamine-depleting lesions of the caudate-putamen are associated with a reduction in stereotyped behavior but an enhanced corticosterone response [65]. Thus, glucocorticoids via glucocorticoid receptors may play an important role in the sensitization of the dopaminergic system. Interestingly, apomorphine-susceptible rats do differ in glucocorticoid receptor and mineralocorticoid receptor expression in different brain nuclei and have higher (and more prolonged) plasma ACTH and total plasma corticosterone responses than

apomorphine-unsusceptible rats [58]. Further studies are needed to investigate whether these differences in corticosteroid receptor expression are responsible for the differences in sensitivity in the dopaminergic system and whether this is the underlying mechanism which, under conditions of severe stress, increases the vulnerability of the proactive coping animal to develop stereotypies.

6.3. Immunological defense during coping or non-coping

Contemporary psychoneuroimmunology emphasizes the role of the HPA axis and the sympathetic branch of the autonomic nervous system in communication between the brain and the immune system [66]. In view of the differential reactivity of these two systems in the two coping styles, one may expect to see differences in the immune system as well. Indeed, several studies in rats and mice demonstrate that individual differentiation in coping is an important factor in stress and immunity. In the social stress models in particular, the individual level of social activity seems to be an important explanatory variable in some studies [67,68]. Although these studies do not specifically address the issue of coping styles, it is tempting to consider the possibility that these socially active animals represent the proactive coping style. Sandi et al. [69] specifically addressed the question of the significance of individual differentiation in emotional responsiveness to the differentiation in immunology. They used the Roman-high (RHA) and low-avoidance (RLA) rats that have been genetically selected on the basis of their active avoidance behavior [70]. These selection lines have been shown to differ in a number of behavioral and neuroendocrine stress responses in a similar way as the proactive and reactive coping styles mentioned above. It was shown that the NK cell activity and the proliferation response of splenocytes to mitogenic stimulation was lowest in the RLA males, a difference that was even more pronounced after the stress of active shock-avoidance learning. Other evidence that emotionality may interact with the immunological response has been found in dairy cows. During endotoxin mastitis in cows that were socially isolated, animals that were selected one year earlier for a strong adrenocortical response to isolation, showed a significantly larger reduction in peripheral blood lymphocyte numbers than cows that were previously classified as weak responders [71].

In a study of pigs, Hessing [72] demonstrated that aggressive, resistant pigs had a higher in vivo and in vitro cell mediated immune response to specific and non-specific antigens than non-aggressive, non-resistant pigs. After stress, the aggressive, resistant pigs showed the strongest immunosuppression. This difference in immunological reactivity in relation to coping style may explain the differential disease susceptibility associated with social rank in group-housed pigs after challenge with Aujeszky virus. These observations in pigs are consistent with similar data obtained in colony housed male rats [67]. Finally, a recent observation

shows that proactive coping male rats are more vulnerable to the experimental induction of the autoimmune disease EAE (experimental allergic encephalomyelitis), which is considered to be an animal model for multiple sclerosis in humans. This high vulnerability seems to be due to the high sympathetic reactivity in the proactive coping males [73].

7. Concluding comments

The concept of coping style has been frequently used in many studies and in an increasing number of species. However, only a few studies have a sufficiently broad approach to the individual behavioral and physiological characteristics and their consistency over time to be conclusive on the generality of the typology across species. Nevertheless, the available literature makes it tempting to consider the possibility that the distinctions between proactive and reactive coping styles represent rather fundamental biological trait characteristics that can be observed in many species. Species or strains may differ in their degree of differentiation depending on the strength of the selection pressure in nature or in the laboratory (genetic selection, domestication), but the extremes within a certain population differ generally in the same behavioral and physiological parameters and in the same direction. This may be partially due to the possibility that some of the characteristics share a common causal physiological basis. The few studies in feral populations suggest that the individual differentiation in coping style may be highly functional in population dynamics. Phenotypes within one species seem to have a differential fitness depending on the environmental conditions such as population density, social stability, food availability, etc. This idea is strengthened by the ecological studies of Wilson and co-authors [74,75]. Although these authors use the term shyness and boldness to indicate individual differences within a population, they argue that this differentiation represents adaptive individual differences in resource use and response to risk.

Different coping styles are based on a differential use of various physiological and neuroendocrine mechanisms. The general impression is that these mechanisms vary in the same direction consistently over species. However, the degree of variation and the organizational level at which the variation is expressed may differ. It is likely that genetic selection will artificially exaggerate trait characteristics up to a level, which may not normally be found in a natural population. There are certainly more dimensions that may account for the individual differentiation in behavior and physiology. It will be a major challenge for behavioral physiologists to refine the scales for individual differences in order to improve their predictive power for health, welfare and disease.

Little is currently known about the origin of coping styles. The few genetic selection lines that have been sufficiently characterized both behaviorally and physiologically

indicate a strong genetic basis. Some recent studies suggest that perinatal factors might play a role as well. However, the use of genetic selection lines may overestimate the role of the genotype. Indeed, the fact that cross-fostering and embryo transfer did not affect aggressive behavior in our selection lines of mice indicates that these lines are devoid of any perinatal plasticity [76]. Unfortunately, the large number of recent studies on the influence of perinatal factors in adult stress-reactivity rarely considers a sufficiently wide spectrum of behavioral and physiological characteristics to be conclusive on the effects on coping styles as a coherent set of characteristics. The same holds for the influence of adult (social) experiences. Clearly, stress at an adult age may produce enduring changes in behavior and physiology. Whether it changes coping styles as a trait characteristic is virtually unknown. So far, we prefer to consider coping styles as rather stable trait characteristics originating from genetic factors in combination with epigenetic factors early in life. Experiences in adult life may alter the state of the animal for a long period of time as expressed in some behavioral and physiological parameters, but they do not seem to change the coping style as a whole. In contrast, coping style is not a rigid characteristic that allows the individual only to respond according to one specific coping style in all situations. The absence of sawdust in the defensive burying test, for example, also elicits freezing behavior in the proactive animal. In this case, the environment was restrictive and consequently the animal did not follow its preferred coping style.

The available evidence so far confirms the idea that coping style helps to determine individual vulnerability for stress-related disease. First, the concept implies that animals may be differentially adapted to different environmental conditions. Second, the differences in physiological reactivity make the two coping styles vulnerable to different types of disease. Hence, in our view, psychopathology can only be understood as a function of the individual coping style and the environmental demands. Understanding this complex relationship is of crucial importance in understanding human and animal health and welfare.

References

[1] Ursin H, Olff M. Aggression, defense, and coping in humans. Aggressive Behavior 1995;21:13–9.

[2] Ursin H. The psychology in psychoneuroendocrinology. Psychoneuroendocrinology 1998;23:555–70.

[3] Wechsler B. Coping and coping strategies: a behavioural view. Applied Animal Behaviour Science 1995;43:123–34.

[4] Lazarus R. Psychosocial stress and the coping process, New York: McGraw-Hill, 1966.

[5] Ursin H, Olff M. Psychobiology of coping and defence strategies. Neuropsychobiology 1993;28:66–71.

[6] Weiss JM. Effects of coping responses on stress. J Comp Physiol Psychol 1968;65:251–60.

[7] Olff M, Brosschot JF, Godaert GLR. Coping styles and health. Personality and Individual Differences 1993;15:81–90.

[8] Jensen P, Rushen J, Forkman B. Behavioural strategies or just individual variation in behaviour? A lack of evidence for active and passive piglets. Applied Animal Behaviour Science 1995;43:135–9.

[9] Jensen P, Forkman B, Thodberg K, Koster E. Individual variation and consistency in piglet behaviour. Applied Animal Behaviour Science 1995;45:43–52.

[10] Henry JP, Stephens PM. Stress, Health and the social environment: a sociobiological approach to medicine, Berlin: Springer, 1977.

[11] Cannon WB. Bodily changes in pain, hunger, fear and rage, New York: Appleton, 1915.

[12] Engel GL, Schmale AH. Conservation withdrawal: a primary regulatory process for organic homeostasis. Physiology, emotions and psychosomatic illness, New York: Elsevier, 1972. p. 57–95.

[13] Benus RF, Bohus B, Koolhaas JM, Oortmerssen GAv. Heritable variation in aggression as a reflection of individual coping strategies. Experientia 1991;47:1008–19.

[14] Oortmerssen GAv, Bakker TCM. Artificial selection for short and long attack latencies in wild Mus musculus domesticus. Behav Genet 1981;11:115–26.

[15] Koolhaas JM, Bohus B. Social control in relation to neuroendocrine and immunological responses. In: Steptoe A, Appels A, editors. Stress, personal control and health, Brussels: Wiley, 1989. p. 295–304.

[16] Benus RF, Den Daas S, Koolhaas JM, Van Oortmerssen GA. Routine formation and flexibility in social and non-social behaviour of aggressive and non-aggressive male mice. Behaviour 1990;112:176–93.

[17] Benus RF, Koolhaas JM, van Oortmerssen GA. Individual differences in behavioural reaction to a changing environment in mice and rats. Behaviour 1987;100:105–22.

[18] Oortmerssen GAv, Busser J. Studies in wild house mice III: disruptive selection on aggression as a possible force in evolution. In: Brain PF, Mainardi D, Parmigiani S, editors. House mouse aggression: a model for understanding the evolution of social behavior, Chur: Harwood Academic Publishers, 1989. p. 87–117.

[19] Verbeek MEM, Drent PJ, Wiepkema PR. Consistent individual differences in early exploratory behavior of male great tits. Anim Behav 1994;48:1113–21.

[20] Ruis MAW, Brake JHAt, Burgwal JAvd, Jong ICd, Blokhuis HJ, Koolhaas JM. Personalities in female domesticated pigs: behavioral and physiological indications. Applied Animal Behaviour Science, 1999. In press.

[21] Ruis MAW, te Brake JHA, Engel B, Ekkel ED, Buist WG, Blokhuis HJ, Koolhaas JM. The circadian rhythm of salivary cortisol in growing pigs: effects of age, gender, and stress. Physiol Behav 1997;62:623–30.

[22] Spoolder HAM, Burbidge JA, Lawrence AB, Simmins PH, Edwards SA. Individual behavioral differences in pigs: intra- and inter-test consistency. Appl Anim Behav Sci 1996;49:185–98.

[23] Hopster H. Coping strategies in dairy cows. Thesis, Agricultural University, Wageningen, 1998.

[24] Huntingford FA. The relationship between anti-predator behaviour and aggression among conspecifics in the three-spined stickleback, gasterosteus aculeatus. Anim Behav 1976;24:245–60.

[25] Mather JA, Anderson RC. Personalities of octopuses (Octopus rubescens). Journal of Comparative Psychology 1993;107:336–40.

[26] Ursin H. Personality, activation and somatic health: a new psychosomatic theory. In: Levine S, Ursin H, editors. Coping and health, New York: Plenum Press, 1980. p. 259–79.

[27] Steimer T, La-Fleur S, Schulz PE. Neuroendocrine correlates of emotional reactivity and coping in male rats from the Roman high (RHA/Verh)- and low (RLA/Verh)-avoidance lines. Behavior Genetics 1997;27:503–12.

[28] De Boer SF, Slangen JL, Van der Gugten J. Plasma catecholamine and corticosterone levels during active and passive shock-prod avoidance behavior in rats: effects of chlordiazepoxide. Physiol Behav 1990;47:1089–98.

[29] Korte SM, Buwalda B, Bouws GAH, Koolhaas JM, Maes FW, Bohus B. Conditioned neuroendocrine and cardiovascular stress

responsiveness accompanying behavioral passivity and activity in aged and in young rats. Physiol Behav 1992;51:815–22.

[30] Sgoifo A, De Boer SF, Haller J, Koolhaas JM. Individual differences in plasma catecholamine and corticosterone stress responses of wild-type rats: relationship with aggression. Physiol Behav 1996;60:1403–7.

[31] Fokkema D, Smit K, Van der Gugten J, Koolhaas JM. A coherent pattern among social behavior, blood pressure, corticosterone, and catecholamines measures in individual male rats. Physiol Behav 1988;42:485–9.

[32] Sgoifo A, De Boer SF, Westenbroek C, Maes FW, Beldhuis H, Suzuki T, Koolhaas JM. Incidence of arrhythmias and heart rate variability in wild-type rats exposed to social stress. Am J Physiol 1997;273:H1754–60.

[33] Korte SM, Meijer OC, De Kloet ER, Buwalda B, Keijser J, Sluyter F, van Oortmerssen G, Bohus B. Enhanced 5-HT1A receptor expression in forebrain regions of aggressive house mice. Brain Res 1996;736:338–43.

[34] Ruiter AJHd, Koolhaas JM, Keijser JN, Oortmerssen GAv, Bohus B. Differential testosterone secretory capacity of the testes of aggressive and non-aggressive house mice during ontogeny. Aggressive Behavior 1992;18:149–57.

[35] Schuurman T. Hormonal correlates of aggressive behavior in adult male rats. In: McConnel PS, Boer GJ, Romijn HJ, Van de Pool NE, Corner MA, editors. Adaptive capabilities of the nervous system, Amsterdam: Elsevier, 1981. p. 415–20.

[36] Hessing M. Individual behavioural characteristics in pigs and their consequences for pig husbandry. PhD thesis, Agricultural University, Wageningen, 1994.

[37] Hessing MJC, Hagelso AM, Schouten WGP, Wiepkema PR, Van Beek JAM. Indiviual behavioral and physiological strategies in pigs. Physiol Behav 1994;55:39–46.

[38] Korte SM, Beuving G, Ruesink W, Blokhuis HJ. Plasma catecholamine and corticosterone levels during manual restraint in chicks from a high and low feather pecking line of laying hens. Physiol Behav 1997;62:437–41.

[39] Korte SM, Ruesink W, Blokhuis HJ. Heart rate variability during manual restraint in chicks from high- and low-feather pecking lines in laying hens. Physiol Behav 1999;65:649–52.

[40] Bohus B. In: Hellhammer D, Florin L, Weiner H, editors. Limbic-midbrain mechanisms and behavioral physiology of interactions with CRF, ACTH and adrenal hormones, Toronto: Huber, 1987. p. 267–85.

[41] Roozendaal B, Bohus B, McGaugh JL. Dose-dependent suppression of adrenocortical activity with metyrapone: effects on emotion and memory. Psychoneuroendocrinol 1996;21:681–93.

[42] Korte SM, De Boer SF, De Kloet ER, Bohus B. Anxiolytic-like effects of selective mineralocorticoid and glucocorticoid antagonists on fear-enhanced behavior in the elevated plus-maze. Psychoneuroendocrinology 1995;20:385–94.

[43] De Kloet ER, Vreugdenhil E, Oitzl MS, Joels M. Brain corticosteroid receptor balance in health and disease. Endocr Rev 1998;19:269–301.

[44] Kloet ERd. Brain corticosteroid receptor balance and homeostatic control. Frontiers in Neuroendocrinology 1991;12:95–164.

[45] Beuving G, Jones RB, Blokhuis HJ. Adrenocortical and heterophil/lymphocyte responses to challenge in hens showing short and long tonic immobility reactions. British Poultry Science 1989;30:175–84.

[46] Jones RB, Beuving G, Blokhuis HJ. Tonic immobility and heterophil/lymphocyte responses of the domestic fowl to corticosterone infusion. Physiol Behav 1988;42:249–53.

[47] Ely DL. Hypertension, social rank, and aortic arteriosclerosis in CBA/J mice. Physiol Behav 1981;26:655–61.

[48] Henry JP, Liu YY, Nadra WE, Qian CG, Mormede P, Lemaire V, Ely D, Hendley ED. Psychosocial stress can induce chronic hypertension in normotensive strains of rats. Hypertension 1993;21:714–23.

[49] Manuck SB, Kaplan JR, Clarkson TB. Behaviorally induced heart rate reactivity and atherosclerosis in cynomolgous monkeys. Psychosomatic Medicine 1983;45:95–108.

[50] Weiss JM. Influence of psychological variables on stress-induced pathology. In: Porter R, Knight J, editors. Physiology, emotion and psychosomatic illness, Amsterdam: Elsevier, 1972 CIBA Foundation Symposium.

[51] Tanaka T, Yoshida M, Yokoo H, Tomita M, Tanaka M. Expression of aggression attenuates both stress-induced gastric ulcer formation and increases in noradrenaline release in the rat amygdala assessed by intracerebral microdialysis. Pharmacol Biochem Behav 1998;59:27–31.

[52] Driscoll P, Kugler P. Genetic and histological aspects of stomach lesions induced by systemic injection of phenylbutazone in the rat. Experientia 1984;40:967–9.

[53] Murison R, Skjerve A. Individual behavioral characteristic and extent of stress-induced gastric ulceration in rats. Acta Physiologica Hungarica 1992;80:127–33.

[54] Wiepkema PR, Adrichem PWMv. Biology of stress in farm animals, Dordrecht: Nijhoff, 1987.

[55] Wiepkema PR, Schouten WGP. Stereotypies in sows during chronic stress. Psychother Psychosom 1992;57:194–9.

[56] Schouten WG, Wiegant VM. Individual responses to acute and chronic stress in pigs. Acta Physiol Scand Suppl 1997;640:88–91.

[57] Benus RF, Bohus B, Koolhaas JM, Van Oortmerssen GA. Behavioural differences between artificially selected aggressive and non-aggressive mice: response to apomorphine. Behavioural Brain Research 1991;43:203–8.

[58] Cools AR, Brachten R, Heeren D, Willemen A, Ellenbroek B. Search after neurobiological profile of individual-specific features of wistar rats. Brain Res Bull 1990;24:49–69.

[59] Hessing MJC, Hagelso AM, Van Beek JAM, Wiepkema PR, Schouten WGP, Krukow R. Individual behavioural characteristics in pigs. Applied Animal Behaviour Science 1993;37:285–95.

[60] Bolhuis JE, Schouten EGW, Wiegant VM, de Jong IC. Individual differences in pigs: behavioral response to apomorphine. Proc. 32nd Int. Soc. for Appl. Ethology, 821998 (abstract).

[61] Overmier JB, Murison R, Johnsen TB. Prediction of individual vulnerability to stress-induced gastric ulcerations in rats: a factor analysis of selected behavioral and biological indices. Physiol Behav 1997;61:555–62.

[62] Mason GJ. Stereotypies: a critical review. Anim Behav 1991;41:1015–37.

[63] Pauly JR, Robinson SF, Collins AC. Chronic corticosterone administration enhances behavioral sensitization to amphetamine in mice. Brain Res 1993;620:195–202.

[64] Rivet JM, Stinus L, LeMoal M, Mormede P. Behavioral sensitization to amphetamine is dependent on corticosteroid receptor activation. Brain Res 1989;498:149–53.

[65] Jones GH, Mittleman G, Robbins TW. Attenuation of amphetamine-stereotypy by mesostriatal dopamine depletion enhances plasma corticosterone: implications for stereotypy as a coping response. Behav Neural Biol 1989;51:80–91.

[66] Felten DL, Felten SY, Bellinger DL, Carlson SL, Ackerman KD, Madden KS, Olschowka AJA, Ivnat S. Noradrenergic sympathetic neural interactions with the immune system: structure and function. Immunol Rev 1987;100:225–60.

[67] Bohus B, Koolhaas JM. Psychoimmunology of social factors in rodents and other subprimate vertebrates. In: Ader R, Felten DL, Cohen N, editors. Psychoneuroimmunology, New York: Academic Press, 1990. pp. 807–30.

[68] Raab A, Dantzer R, Michaud B, Mormede P, Taghzouti K, Simon H. Behavioral physiological and immunological consequences of social status and aggression in chronically coexisting resident–intruder dyads of male rats. Physiol Behav 1986;36:223–8.

[69] Sandi C, Castanon N, Vitiello S, Neveu PJ, Mormede P. Different responsiveness of spleen lymphocytes from two lines of psychogenetically selected rats (Roman high and low avoidance). Journal of Neuroimmunology 1991;31:27–33.

[70] Driscoll P, Demek J, D'Angio M, Claustre Y, Scatton B. A genetically-based model for divergent stress responses: behavioral, neurochemical and hormonal aspects. In: Pliska V, Stranzinger G, editors. Farm animals in biomedical research, Hamburg: Verlag Paul Parey, 1990. p. 97–107.

[71] Hopster H, Van der Werf JNT, Blokhuis HJ. Stress enhances reduction in peripheral blood lymphocyte numbers in dairy cows during endotoxin-induced mastitis. Vet Immunol Immunopathol 1998; 66:83–97.

[72] Hessing MJ, Coenen GJ, Vaiman M, Renard C. Individual differences in cell-mediated and humoral immunity in pigs. Vet Immunol Immunopathol 1995;45:97–113.

[73] Kavelaars A, Heijnen CJ, Tennekens R, Bruggink J, Koolhaas JM. Individual behavioral characteristics predict vulnerability to EAE in wild-type rats. Brain Behav Immun 1999. In press.

[74] Wilson DS. Adaptive individual differences within single populations. Phil Trans R Soc Lond 1998;353:199–205.

[75] Wilson DS, Clark AB, Coleman K, Dearstyne T. Shyness and boldness in humans and other animals. Tree 1994;9:442–6.

[76] Sluyter F, van der Vlugt JJ, Van Oortmerssen GA, Koolhaas JM, van der Hoeven F, De Boer P. Studies on wild house mice. VII. Prenatal maternal environment and aggression. Behav Genet 1996;26:513–8.

[77] Bohus B, Benus RF, Fokkema DS, Koolhaas JM, Nyakas C, Van Oortmerssen GA, Prins AJA, De Ruiter AJH, Scheurink AJW, Steffens AB. Neuroendocrine states and behavioral and physiological stress responses. In: De Kloet ER, Wiegant VM, De Wied D, editors. Progress in brain research, Amsterdam: Elsevier, 1987. p. 57–70.

[78] Holst Dv. Vegetative and somatic components of tree shrew's behaviour. J Auton Nerv Syst suppl 1986;657–70.

[79] Blokhuis HJ, Metz JHM. Integration of animal welfare into housing systems for laying hens. Netherlands Journal of Agricultural Science 1992;40:327–37.

[80] Hansen SW, Damgaard BM. Behavioural and adrenocortical coping strategies and the effect on eosinophil leucocyte level and heterophil-lymphocyte ratio in beech marten (Martes foina). Applied Animal Behaviour Science 1993;35:369–88.

[81] Van Raaij MT, Pit DS, Balm PH, Steffens AB, van den Thillart GE. Behavioral strategy and the physiological stress response in rainbow trout exposed to severe hypoxia. Horm Behav 1996;30:85–92.

[82] Suomi SJ. Uptight and laid-back monkeys: individual differences in the response to social challenges. In: Brauth SE, Hall WS, Dooling RJ, editors. Plasticity of development, Cambridge, MA: MIT Press, 1991. p. 27–56.

[83] Benus RF, Bohus B, Koolhaas JM, Oortmerssen GAv. Behavioral strategies of aggressive and non-aggressive male mice in active shock avoidance. Behav Processes 1989;20:1–12.

[84] Sluyter F, Korte SM, Bohus B, Van Oortmerssen GA. Behavioral stress response of genetically selected aggressive and nonaggressive wild house mice in the shock-probe/defensive burying test. Pharmacol Biochem Behav 1996;54:113–6.

[85] Sluyter F, Bult A, Lynch CB, Oortmerssen GAv, Koolhaas JM. A comparison between house mouse lines selected for attack latency or nest-building: evidence for a genetic basis for alternative behavioral strategies. Behavior Genetics 1995;25:247–52.

[86] Boer SFd, Beun Rd, Slangen JL, Gugten Jvd. Dynamics of plasma catecholamines and corticosterone concentrations during reinforced and extinguished operant behavior in rats. Physiol Behav 1990;47:691–8.

[87] Korte SM, Buwalda B, Bouws GAH, Koolhaas JM, Maes FW, Bohus B. Conditioned neuroendocrine and cardiovascular stress responsiveness accompanying behavioral passivity and activity in aged and in young rats. Physiol Behav 1992;51:815–22.

[88] Fokkema DS, Koolhaas JM, Gugten Jvd. Individual characteristics of behavior, blood pressure, and adrenal hormones in colony rats. Physiol Behav 1995;57:857–62.