A new animal welfare concept based on allostasis

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Abstract

Animal welfare is an increasing issue of public concern and debate. As a result, many countries are reconsidering the way animal welfare is embedded in the legislation and rules for housing and care of animals. This requires general agreement of what animal welfare is. Unfortunately, the current science of animal welfare is less scientific than what has been claimed. In our view, it is overly guided by anthropocentric thinking about how animals ought to be handled and neglects the latest concept of physiology: ‘The Allostasis Concept’. Allostasis, which means stability through change, has the potential to replace homeostasis as the core model of physiological regulation. Not constancy or freedoms, but capacity to change is crucial to good physical and mental health and good animal welfare. Therefore, not homeostasis but allostasis is at the basis of our new animal welfare concept. This paper is aimed at a broader scientific discussion of animal welfare that includes knowledge from the latest scientific developments in neurobiology and behavioral physiology, and generates views that are extremely relevant for the animal welfare discussion.

Keywords: Animal welfare; Stress; Homeostasis; Allostasis; Allostatic state; Allostatic load; Disease

1. Introduction

Animal welfare research is facing a fundamental problem. The field is less scientific than claimed, because welfare was part of a social discourse actuated by emotion rather than reason before it became the subject of scientific research [1]. In response to the public outcry over Ruth Harrison’s 1964 book, \textit{Animal Machines} [2], the British government commissioned an investigation, chaired by F. Rogers Brambell, into the animal welfare of intensively farmed veal calves, pigs, and chickens [3]. It was concluded that animals should be able to stand up, lie down, turn around, stretch limbs and interact with conspecifics. These freedoms were primarily based on space requirements and not specifically aimed at important welfare needs. In 1993 the UK Farm Animal Welfare Council [4] published “The Five
“Freedoms” of animal welfare, which mainly describe housing conditions and care, and were thought to be an improvement upon what originally was recommended by the Brambell committee. Recently ideas on how to keep animals have rapidly changed in Europe, because in the last decennia society has been confronted with epidemics such as mad cow disease (BSE), foot and mouth disease and avian influenza. This has affected farmers but also society on a large scale. In European law, animals now are defined as “sentient” creatures, indicating that they are considered as conscious feeling animals, no longer just as agricultural products, and they have a value of their own. This is an understandable change, because conscious feeling animals are crucial to animal welfare, but without scientific background it opens the door for anthropocentric (public) thinking of how animals ought to be handled. This increases the risk that subjectivity, cultural and non-scientific opinions will largely affect legislation on how to keep and treat animals. This creates a considerable obstacle for progress on animal welfare on a more global scale.

However, this anthropocentric thinking of how animals ought to be handled should be rejected because the latest developments in neurobiology and behavioral physiology make it possible to objectively investigate the relationships between emotional individual beings and their environment to understand and improve animal welfare where needed. To understand animal welfare in conscious feeling animals it is crucial to investigate both brain and periphery states in relation to the environmental challenges that have led to these states. According to Antonio R. Damasio [5] consciousness highly depends on the image of knowing, which originates in neural structures fundamentally associated with the representation of body (brain and periphery) states, thus the image of knowing is a feeling”. Altered brain and periphery states play a crucial role in the concept of allostatic. That’s why the concept of allostatic is so important for animal welfare. We have to admit that some scientists have recently started to investigate consciousness, emotions, positive feelings and animal welfare (e.g. [6,7]), but not many are examining the possibility of refining over-arching principles.

2. Why do we need a new concept of animal welfare?

2.1. Freedoms

As mentioned above, the UK Farm Animal Welfare Council formulated the “Five Freedoms” of animal welfare and provisions associated with each of these freedoms are: 1) Freedom from hunger and thirst by ready access to fresh water and a diet to maintain full health; 2) Freedom from discomfort by providing a suitable environment including shelter and a comfortable resting area; 3) Freedom from pain, injury and disease by prevention or rapid diagnosis and treatment; 4) Freedom to express normal behavior by providing sufficient space, proper facilities and company of the animal’s own kind; and 5) Freedom from fear and distress by ensuring conditions which avoid mental suffering. Remarkably, this approach is at the basis of present European (EU) legislation on animal welfare [8]. Although the EU claims that its animal welfare legislation should be based on sound scientific evidence, the freedoms principle reflects a more ethical view than a science-based approach. In fact, complete freedom is undesirable. Here, arguments will be given why the concept of the “Five Freedoms” is no longer helpful.

First, freedom from fear and distress is a typical anthropocentric construct. Fear is an emotion produced by the perceptions of impending danger and is normal in appropriate situations. It is a vital evolutionary legacy that leads an organism to avoid threat. Without fear, few vertebrates in the wild would survive long enough to reproduce. Thus, fear has fitness value. However, this does not mean that in the absence of threats animals should feel fear.

Freedom from distress, what does this mean? Recently, the Animal and Plant Health Inspection Service of the U.S. Department of Agriculture requested comments to help it decide on a formal definition of “distress” as part of its responsibilities under the Animal Welfare Act [9]. They came up with a working definition of distress: “a state in which an animal cannot escape from or adapt to the internal or external stressors or conditions it experiences, resulting in negative effects on its well-being”. The Federation of American Societies for Experimental Biology objected that this definition is “vague and could lead to widely varying, highly subjective interpretations”, and “there are no simple physiological or behavioral criteria to mark the point where an animal that experiences stress becomes distressed” [10]. Previously, it has been concluded that the term (dis)stress has so many different meanings that it becomes counterproductive by inhibiting a proper application and critical interpretation of experimental results [11]. Distress has mostly been associated with negative events and consequences. There is, however, no justification for the assumption that the expression of stress responses always compromise health or welfare. Indeed, the functional aspects of stress have often been neglected [12]. The paradox of stress lies in the simultaneity of its adaptive nature and its possible maladaptive consequences [13,14]. The best known stress hormones are corticosteroids, but their name could also be anti-stress hormones [15], because their primary function is protective and adaptive [16–18]. Corticosteroids are well known for their inverted-U curve of concentration and effect [16] (see also Fig 1). Because these hormones may have damaging effects as well, there may be a price to be paid for the adaptive nature of the stress response. The scientific challenge is to make a cost-benefit analysis, i.e. to determine under which conditions the costs outweigh the benefits and vice versa.

Second, one might expect that natural selection will shape a body for maximum health and longevity. Unfortunately, this is not always true. Health is not the outcome of natural selection, maximal reproduction is. If a mutation causes a disease, but yields a net increased reproductive success, it will be selected for [19]. Here is exactly where fitness and animal welfare depart: something can benefit reproductive success but involve negative experiences for the individual, causing poor animal welfare.
Goal Reproduction in order to Purpose Animal fitness Animal production Health and disease
Wild, farm and experimental animals are kept for different reasons, each with different consequences for selection, animal welfare and ethics

Table 1

<table>
<thead>
<tr>
<th>Purpose</th>
<th>Wild animals</th>
<th>Farm animals</th>
<th>Experimental animals</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal</td>
<td>Animal fitness Reproduction in order to increase genes in the population</td>
<td>Animal production Production of food with increased quality and/or quantity</td>
<td>Health and disease Understanding of Biology and development of both Human and Veterinary Medicine to the treatment of diseases</td>
</tr>
<tr>
<td>Consequences Ethics</td>
<td>Natural selection Survival of the fittest</td>
<td>Artificial Genetic Selection (incl. domestication) Maintain mental health and avoid mental diseases Maintain physical health and avoid disease and mutilation</td>
<td>Animal models (incl. inducing disease) Experiments on living animals should only be carried out when no other suitable alternative methods are available and the expected benefits to mankind outweighs the costs to animals</td>
</tr>
</tbody>
</table>

Fig. 1. Animal welfare in relation to environmental challenges as shown by the out-dated concept based homeostasis and the new concept based on the inverted U-curve of (di)stress.

Third, freedom from pain, injury or disease is a utopia. For example, pain is a natural defense mechanism that helps to protect organisms from potential threats and dangerous substances. Pain, nausea, fever, vomiting and diarrhea are products of natural selection. Although they produce suffering, they are defense mechanisms that protect organisms [20].

Fourth, intuitively it is appealing to improve animal welfare by respecting the nature of the animals. However, one has to realize that due to natural selection, nature is by no way a paradise. For instance, mice from some laboratory lines can survive as long as three years, while free-living wild mice are likely to die much earlier from disease, competition, or predators [21]. Male mice will tolerate their own offspring, but will kill offspring born to females that belong to other demes [22]. Wild animals try to increase their genes in a population. In contrast, many farm and laboratory animals are docile, due to artificial selection on the calmest animals. Consequently, behavior, temperament and associated physiology of these animals may have been modified during domestication. It is important to realize that wild, farm and experimental animals differ in the way genetic (natural or artificial) selection takes place with different consequences for ethics and animal welfare (see Table 1).

Fifth, freedom of hunger or ad libitum food availability in farm animals and zoo animals also produces problems [23]. Freedom from hunger together with an impoverished environment may disturb mental health as reflected by stereotypic and compulsive behaviors in zoo, circus and farm animals. Quantitatively this is the world’s largest animal welfare problem. In addition, mammals that are fed a restricted calorie diet live longer. Thus, longevity and hunger are part of a healthy mammal’s life.

2.2. Homeostasis

Broom [24] defined the welfare of an animal as “its state as regards its attempts to cope with its environment”. Any evidence of attempting to cope with the environment, whether successful or not, would be reflective of an animal’s welfare. Welfare is seen as a continuum, ranging from very poor to very good, and the ethical question becomes one of what level of welfare is considered acceptable.

This approach implies that when an animal is confronted with environmental challenges it reacts with behavioral and physiological feedback mechanisms to maintain constant internal characteristics of the body (milieu intérieur). This is called homeostasis [25]. Homeostasis implies that the controlled physiological variables are kept at their ‘set point’. This definition refers in a general way to the balance which exists between the animal and its surroundings. So, implicitly it suggests that without environmental challenges good animal welfare can be guaranteed. In our opinion this is an out-dated concept (see Fig. 1), because it ignores the absence of environmental challenges which produces hypostimulation in the animal and consequently bad animal welfare (see also Section 2.3).

2.3. Allostasis, allostatic state and allostatic load

To be fair to early thinkers about animal welfare; they used professional judgment and available information to come up with concepts like the “Five Freedoms”. Until today, however, the latest concept of physiology, the allostatic concept, has been neglected. “Stability through change”, coined by Peter Sterling as allostatics, involves mechanisms that change the controlled physiological variable by predicting what level will be needed to meet anticipated demand [26]. Natural selection has sculpted physiology and behavior to meet the most likely environmental demands plus a modest safety margin [18]. Thus, allostatics considers an unusual physiological parameter value not as a
Table 2
The different mediators of allostasis, associated allostatic state and allostatic load due to hypostimulation or hyperstimulation, respectively

<table>
<thead>
<tr>
<th>Mediators of allostasis</th>
<th>Assessment of allostatic state</th>
<th>Measures of allostatic load</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Central nervous system</strong></td>
<td>Glucocorticoids, Amino acids, Cytokines, Serotonin, Dopamine, Norepinephrine, Neuropeptides like CRF, etc.</td>
<td>– change in central MR/GR balance</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– altered hippocampal CA3 dendritic tree atrophy</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– altered DG cell turnover</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– expression and function of 5-HT1A/5-HT2C receptors</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– elevated levels of overnight urinary catecholamines</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– decreased vagal activity</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Cardio-vascular system</strong></td>
<td>Catecholamines: e.g. adrenaline</td>
<td></td>
</tr>
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<td></td>
<td></td>
<td></td>
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<tr>
<td><strong>Immune system</strong></td>
<td>Glucocorticoids, Cytokines: e.g. IL-1,-4,-6,-10, TNF-α, TNF-γ, etc.</td>
<td>– decreased plasma cortisol levels and decreased mobility of white cells</td>
</tr>
<tr>
<td></td>
<td></td>
<td>– increased levels of inflammatory cytokines</td>
</tr>
<tr>
<td><strong>Metabolic system</strong></td>
<td>Glucocorticoids</td>
<td>– elevated and flattened diurnal urinary cortisol</td>
</tr>
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</tbody>
</table>

Abbreviations: CRF — Corticotropin releasing factor; MR — mineralocorticoid receptor; GR — glucocorticoid receptor; DG — Dentate Gyrus; 5-HT — 5 hydroxytryptophan; IL — interleukine; TNF — tumor necrosis factor.

failure to defend a set point, but rather as a response to some prediction [27]. Coordinated plasticity is needed to optimize performance at minimal cost. The emotional brain plays a central role in allostasis [28]. By controlling all the mechanisms simultaneously, the brain can enforce its command and incorporate influential factors such as experience, feelings, memories, and re-evaluation of needs in anticipation of physiological requirements. A shift in the probability of demand should shift the integrated response, and when the prediction reverses, so should the response [27]. This response, involving the release of mediators of allostasis (e.g. adrenal hormones, neurotransmitters, and cytokines (see Table 2)), works via receptors in various tissues and organs to produce changes that are adaptive to metabolism, immune, and cardiovascular systems in the short term [11,13,14,17,22,29,30].

A fit animal has a wide regulatory range of allostatic mechanisms. Activation of these mechanisms outside this range can result in: failure to habituate with repeated challenges, failure to shut off the physiological response if the challenge is over, or failure to mount an adequate response [12]. This produces a state of chronic deviation of the regulatory system from its normal operating level [28]. This new equilibrium, coined by George Koob as allostatic state [28], is characterized by a narrower regulatory range (see Fig. 3) and hence by an enhanced chance of hyper- or hypostimulation. This can be described as the cumulative load to the brain and periphery, coined by Bruce McEwen as allostatic load [11]. When allostatic load is chronically high, pathologies may develop due to “wear and tear” [11] (Table 3). Allostatic load may also be very low as a consequence of hypostimulation, for instance, different diseases like allergic reactions, inflammatory/autoimmune disease, fatigue states and atypical depression are associated with blunted hypothalamic–pituitary adrenal axis [31]. Also, in the brain, chronic hypostimulation (e.g. low mental activity) may produce negative effects For instance neuronal survival highly depends on whether the new neural cells are sufficiently activated by incoming signals [32], a process that may be termed “use it or lose it” [33]. Remarkably, voluntary physical activity also increases cell proliferation and neurogenesis in the adult mouse brain, especially the hippocampal dentate gyrus [34]. Voluntary physical activity is also good for muscle tissue (incl. heart) and bone tissue.

In Fig. 2 it is shown that organisms may show different stress response profiles and different types of allostatic load exist [12].

Table 3
Animal welfare and the associated behavioral outcome

<table>
<thead>
<tr>
<th>Animal Welfare</th>
<th>Neutral</th>
<th>Good</th>
<th>Neutral</th>
<th>Bad</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chronic fatigue</td>
<td>Hypersomnia</td>
<td>Arousal</td>
<td>Insomnia</td>
<td>Hypervigilance</td>
</tr>
<tr>
<td>Chronic hunger and starvation</td>
<td>Hunger</td>
<td>Foraging</td>
<td>Satiety and obesity</td>
<td>Metabolic syndrome</td>
</tr>
<tr>
<td>Violence and stereotypy</td>
<td>Aggression and impulsivity</td>
<td>Exploration</td>
<td>Fear and avoidance</td>
<td>Generalized anxiety</td>
</tr>
<tr>
<td>Compulsive desires</td>
<td>Sensation seeking</td>
<td>Pleasure and aversion</td>
<td>Pain</td>
<td>Chronic pain</td>
</tr>
</tbody>
</table>
Normally habituation takes place in the stress response when the stimulus is repeated (see profile a). The response profiles b, c, d may produce costs due to the longer exposure and higher concentrations of stress mediators. In contrast, the hyporesponses (profile e) also produce costs, but these are due to hypostimulation.

3. Dawn of a new concept of animal welfare based on allostatics

Allostasis, which means stability through change, has the potential to replace homeostasis as the core model of physiological regulation [27]. Not constancy or freedoms, but capacity to change is crucial to good health and good animal welfare. Following this line of reasoning, good animal welfare is characterized by a broad predictive physiological and behavioral capacity to anticipate environmental challenges. Thus, good animal welfare is guaranteed when the regulatory range of allostatic mechanisms matches the environmental demands. In captive animals, housing conditions usually require quite some adaptation resulting in an allostatic state characterized by a reduced regulatory capacity.

However, in the absence of any further environmental demands, welfare is not always at stake (see Fig 3.). In this view, only conditions that produce high allostatic load or inadequately low allostatic load may threaten good health and good animal welfare. Such conditions render animals vulnerable to diseases or pathology including violence, stereotypy, chronic fatigue, atrophy of brain regions, metabolic syndrome etc. (see Table 3).

Consequently, animal welfare research must find a science-based answer to the adaptive nature and maladaptive consequences of the stress response. This is not an easy task, but our line of reasoning implies that allostatic state is reflected by a new equilibrium and a narrower regulatory range (see Fig. 3) with consequences for the reactivity of stress systems rather than merely the level of stress parameters. Moreover, the irreversible nature of changes in reactivity, reduced resilience and consequently the damage to tissues and organs can be used as a measure of allostatic load [12–14,17,28,29]. See also Table 2 for the different types of allostatic load due to hypo- or hyperstimulation.

4. Discussion

Why do we need a new concept of animal welfare? First, there is a growing sense that animal welfare science is at an impasse, and that ethical and scientific questions about animal welfare have become hopelessly entangled [35]. Second, the concept of the “Five Freedoms” reflects a more ethical view than a science-based approach. In fact, complete freedom is undesirable. Third, scientific methods are misused by those who seek to obtain so-called “objective” measurement of that which they preconceive to be stress [36], whereas there is growing evidence that stress hormones are also involved in healthy adaptation [13]. Fourth, the welfare state of a sentient animal is a very complex affair and cannot be embraced by any single scientific discipline, be it ethology, physiology, molecular or neurobiology [36]. Fifth, animal welfare should not
be based on homeostasis, because not constancy or freedoms, but stability through change (allostasis) and capacity to change are crucial to good health [27]. Sixth, genetic selection specifically on product quantity in farm animals (e.g. broiler chickens) have produced structural designs of organs in the body that are in disbalance. In organisms, structural design (of e.g. all internal compartments of the respiratory system like blood, heart, muscle capillaries, and mitochondria) should match functional demand. This is called symmorphosis [37]. In many farm animals (especially broiler chickens) the structural design of internal organs does not match functional demand [38]. This disbalance is responsible for many health problems in farm animals. It’s time to change how we view animal welfare. The “Concept of Animal Welfare based on Allostasis” is a better alternative that incorporates recent scientific developments in behavioral physiology and neurobiology.

The “Concept of Animal Welfare based on Allostasis” can be summarized as follows:

- Stability through change (allostasis) and capacity to change are crucial to good health and good animal welfare. “Health” in this concept has the same meaning as defined in the World Health Organization’s (WHO) constitution as “a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” [39].
- Good animal welfare is characterized by a broad predictive physiological and behavioral capacity to anticipate environmental challenges.
- Good animal welfare is guaranteed when the regulatory range of allostatic mechanisms matches the environmental demands.
- A low allostatic load (not very low or zero) is key for good health and good animal welfare.
- In organisms, structural design should match functional demand (symmorphosis).
- Interpreting behavior and physiology in terms of animal perceptions and not exclusively in terms of human values.

This new concept of animal welfare can help to increase the quality of animal welfare. But first, we want to draw attention to the fact that human’s compassion for animals seems to be very inconsequent [40], see also Table 4. As Andrew Moore [41] wrote: “When mice do little more than nibble our food, we can be of help in detecting elevated or depressed allostatic loads and in finding ways to reduce or normalize allostatic loads. This approach will lead to new ways to improve animal welfare. By introducing this new animal welfare concept we are convinced that it offers new opportunities for a breakthrough in the animal welfare science impasse, and we hope that more progress in animal welfare can be made on a global scale in the near future.

Acknowledgement

We thank Megan Breuer for editorial assistance.

Table 4

<table>
<thead>
<tr>
<th>Species</th>
<th>Number</th>
<th>Costs</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laboratory mice and rats</td>
<td>&lt;3</td>
<td>Costs that are allowed highly depend on the benefits for mankind; pain killers and anesthesia are often prescribed to reduce suffering</td>
<td>Health and science</td>
</tr>
<tr>
<td>Wild mice and rats</td>
<td>ca. 17*</td>
<td>Die slowly from poison</td>
<td>Pest control</td>
</tr>
<tr>
<td>Fattening pigs</td>
<td>ca. 48</td>
<td>Violence, compulsive disorders, stereotypies and mutilations</td>
<td>Food</td>
</tr>
<tr>
<td>Broiler chickens</td>
<td>ca. 1268</td>
<td>Compulsive disorders, stereotypies and mutilations</td>
<td>Food</td>
</tr>
<tr>
<td>Zoo/circus animals (polar bear, tiger, lion etc.)</td>
<td>n.a.</td>
<td>Compulsive disorders and stereotypies</td>
<td>Entertainment</td>
</tr>
</tbody>
</table>

* Pest control numbers are from the UK and are corrected for differences in population size and country size [40].
References


