ABSTRACT: We review recent research in one of the oldest and most important applications of ethology: evaluating animal health. Traditionally, such evaluations have been based on subjective assessments of debilitating signs; animals are judged ill when they appear depressed or off feed. Such assessments are prone to error but can be dramatically improved with training using well-defined clinical criteria. The availability of new technology to automatically record behaviors allows for increased use of objective measures; automated measures of feeding behavior and intake are increasingly available in commercial agriculture, and recent work has shown these to be valuable indicators of illness. Research has also identified behaviors indicative of risk of disease or injury. For example, the time spent standing on wet, concrete surfaces can be used to predict susceptibility to hoof injuries in dairy cattle, and time spent nuzzling the udder of the sow can predict the risk of crushing in piglets. One conceptual advance has been to view decreased exploration, feeding, social, sexual, and other behaviors as a coordinated response that helps afflicted individuals recover from illness. We argue that the sickness behaviors most likely to decline are those that provide longer-term fitness benefits (such as play), as animals divert resources to those functions of critical short-term value such as maintaining body temperature. We urge future research assessing the strength of motivation to express sickness behaviors, allowing for quantitative estimates of how sick an animal feels. Finally, we call for new theoretical and empirical work on behaviors that may act to signal health status, including behaviors that have evolved as honest (i.e., reliable) signals of condition for offspring-parent, inter- and intra-sexual, and predator-prey communication.

Key words: behavior, illness, motivational testing, pain, sickness behavior, signaling

INTRODUCTION

Animal caregivers have honed their skills in disease detection since the dawn of animal agriculture. These skills were already reasonably refined among the ancient Egyptians; papyrus fragments from an Egyptian medical text dating 1850 BC describe diseases of cattle, dogs, birds, and fish and show that ancient Egyptians recognized signs associated with important diseases (Griffith, 1898). Hippocrates, the father of modern medicine, argued that disease was the product of environmental factors, including diet and living habits (Treatise: “On the Sacred Disease” ~400 BC). He also urged the use of careful observations to identify signs of disease and recognized that there were differences in how individuals express these signs (The Book of Prognostics ~400 BC).

Over the past few decades the relationship between behavior and animal health has emerged as a topic of active academic discussion through the creation of organizations such as the Society of Veterinary Ethology (now the International Society for Applied Ethology) and the publication of works like _Abnormal Behavior in Animals_ (Fox, 1968). The discussion has tended to focus on how to identify and solve problems of animal behavior as part of veterinary practice (e.g., McKeown and Luescher, 1988; Fraser and Quine, 1989). Here we review recent theoretical and empirical work addressing a much expanded view of the relationship between animal behavior and health. We show how the develop-
ment of sensitive behavioral indicators can improve our ability to identify ill health, and we provide a conceptual overview of how behavior can be used to predict, identify, and assess health problems in animals.

BEHAVIOR AS A REFLECTION OF PATHOLOGY

Behavioral signs have long been considered indicative of illness. For example, hydrophobia (aversion to drinking) is used in the diagnoses of rabies (Schoening, 1942), head-throwing seizures are used as an indicator of sodium salt toxicity in pigs (Smith, 1975), and staring is used as a sign of polioencephalomalacia in cattle (Olkowski, 1997). Abnormal feeding and drinking behavior and decreased activity are often considered to be indicative of more general malaise (e.g., Baumgartner and Ketz-Riley, 1999). Surprisingly, there is little scientific research that specifically addresses the value of behavior as a disease indicator. The lack of research interest may reflect the view that such changes are simple defects—the animal is assumed no longer to be able to perform its typical suite of adaptive behaviors (Wingfield, 2003; Dantzer, 2004). Whatever the reason, we see this as an important shortcoming in the literature and urge new applied research in this area. One reason for this need is that purported signs of illness may be misleading, and rates of successful detection might be much improved through the use of improved criteria and training.

One example comes from work on lameness in dairy cattle. Several studies have shown that untrained producers relying on the presence of an obvious limp are able to identify just a small fraction of animals that can be recognized as lame using more subtle clinical criteria (e.g., Whay et al., 2003; Espejo et al., 2006). Consequently, the reported incidence of lameness in dairy herds likely underestimates the true proportion of animals suffering from hoof and leg injuries. Recent research by our group (Flower and Weary, 2006) has shown that more detailed clinical measures can be applied reliably among and within observers and can be validated through correlations with direct measures of hoof injuries and disease.

Valid behavioral indicators are those that clearly identify illness. These can be positive (i.e., behaviors that increase in frequency or magnitude when the animal is ill) or negative indicators (i.e., behaviors that reduce in frequency or magnitude with illness). Some measures may be useful for detecting intraindividual effects over time, and others may be useful for distinguishing sick and healthy individuals at a given time. The best indicators are those with both high sensitivity and high specificity. Tests should rarely yield false positives (type I error; test shows positive when the animal is actually healthy) or false negatives (type II error; test shows negative when the animal is actually sick). The best assessment measures correctly identify sick animals (i.e., high sensitivity; the ratio of true positives to the total of true positives and false negatives) and healthy ones (i.e., high specificity; the ratio of true negatives to the total of false positives and true negatives).

Any approach to validation requires a gold standard against which the assessment measure is judged. Typically this is a clinical evaluation based on body temperature and other signs. Validation trials can either employ naturally occurring cases, or illness can be induced via controlled exposure to a pathogen or a lipopolysaccharide challenge. Both approaches have strengths and weaknesses. Naturally occurring cases may share certain clinical signs but arise from different pathogens that have varied effects on behavior. Induction models are also prone to variation; for example, individuals can react differently to a fixed exposure of pathogen due to differences in immunocompetence and other factors. Another potential problem associated with induction models is that they often fail to account for the physiological state or processes that are associated with the progression of the disease under natural conditions, where the time course of the illness is often very different than that observed under controlled experimental conditions. These models should thus be considered imperfect, and care is required in extrapolating the results to natural conditions where other factors may influence the progression and expression of the disease.

Until recently almost all behavioral assessments of illness have been based upon subjective clinical evaluation. Animals are judged ill when they appear depressed, listless, or off feed (see Hornbuckle, 1992; Speirs and Wrigley, 1997). These indicators are often based on the accumulated experience of livestock handlers. Unfortunately, subjective evaluations can be prone to poor reliability. The reliability of a measure refers to the potential of obtaining the same results when scoring is repeated. This can be evaluated by having the same observer re-score animals on multiple occasions (intraobserver reliability), or by having different observers independently score animals (interobserver reliability). New research has typically focused on objective quantitative measures, such as the feeding behavior measures described below.

BEHAVIOR AS A PART OF AN ADAPTIVE RESPONSE TO A HEALTH PROBLEM

Change in Behavior in Response to Pain

Physical injuries and diseases can cause a loss in normal functioning, regardless of whether the animal feels sick; these effects of physical incapacitation can be difficult to distinguish from the affective component of illness (i.e., feeling ill, sore, etc.). The affective state in animals that has received the most attention is pain (for review see Weary et al., 2006), and many illnesses and injuries are thought to cause pain. In such cases pain can be identified through the use of appropriate analgesics. For example, impaired gait due to pain should be
reversible through the use of analgesics. Empirical research on lameness has shown that gait defects in dairy cattle (Rushen et al., 2007; Flower et al., 2008) and broiler chickens (Danbury et al., 2000) are improved when animals are provided analgesics; however, some degree of lameness often persists, suggesting that the gait defects are also associated with factors other than pain (e.g., joint injuries that physically restrict normal movement) or that the analgesics tested were not entirely effective.

Change in Behavior in Response to a General Feeling of “Malaise”

In more recent years there has been an explosion of interest in behavioral indicators of disease following the development of a new conceptual perspective. Hart (1988) and others (see Dantzer, 2004) have argued that many of the behaviors shown by ill animals are part of a coordinated strategy to fight disease. Heat conservation during infection is achieved through physiological (vasoconstriction) and behavioral responses (postural changes). Behavior is an important means of influencing energy expenditure; sick individuals usually decrease feeding and reproductive activities while increasing time at rest, likely as a means of conserving energy for the febrile response and for mounting an immune response (Hart, 1988). Fever occurs in all vertebrates (Wingfield, 2003) and is thought to enhance the effectiveness of the immune system and create an environment detrimental for bacteria (Johnson, 2002). Maintaining an elevated core temperature can involve heat production and conservation. Increased heat production is mediated through the action of proinflammatory cytokines on the hypothalamus, preventing the compensatory responses responsible for maintaining standard body temperatures (Kluger, 1991).

Many experiments on laboratory animals have shown the relationship between cytokine concentrations and other signs of disease such as anorexia and lethargy. Cytokines are also involved in the onset of depression in humans, which widely overlaps with sickness behavior in animals (Pollmächer et al., 2002). Proinflammatory cytokines, particularly IL-1β, reduce motivation to eat. For example, Finck and Johnson (1997) showed that rats receiving IL-1β consumed less feed than the control rats and lost BW. This reduction in appetite helps to promote recovery (Johnson, 2002), as illustrated in an experiment by Murray and Murray (1979). Researchers experimentally infected mice with Listeria monocytogenes and let some consume food ad libitum, whereas others were force-fed to the level of uninfected controls. Infected mice that were allowed to regulate their own intake ate only 58% as much as the controls and were much more likely to survive than mice that were force-fed.

Dantzer (2004) predicted that animals should be able to reorganize elements of their sickness behavior depending on its consequences and the internal and external constraints; this idea opens the door to a new line of research using motivational testing techniques, well developed in the animal welfare assessment literature (see Kirkden and Pajor, 2006). We see much potential for future research exploring how the expression of sickness behaviors varies in response to changing motivation for food and other important resources, allowing for quantitative estimates of how sick an animal feels.

Declines in feed intake can be very useful in identifying sick animals. The idea that declines in intake are associated with illness is not new, and there are many studies showing this relationship. For example, in one recent experimental study, Waldron et al. (2006) showed that feed intake of lactating dairy cows declined in response to a lipopolysaccharide challenge.

Which Behaviors Respond and Why?

Unfortunately, there are few theories to predict what behaviors will be most likely to change as a result of sickness. We suggest that behaviors that offer only longer-term fitness will be most likely to decline with illness, as animals divert resources to those functions of critical short-term value such as maintaining body temperature. Maintenance (e.g., grooming) and sexual behaviors, although ultimately of key value to the animal, may be considered less urgent at least under some conditions. Play behavior may provide an especially promising case because all purported functions (e.g., improving physical and social skills; Spinka et al., 2001) are of longer-term value.

Other types of behavior that allow the animal to learn about its environment may also be good candidates. For example, although feed intake serves an immediate function, environmental sampling allows animals to learn where and when food is likely to become available in the future (Stephens and Krebs, 1986). We predict this sampling behavior to reduce in response to illness. Support for this prediction comes from a recent study on calves provided limited amounts of milk from an automated milk feeder (Svensson and Jensen, 2007). Calves diagnosed with disease did not reduce the number of nutritive visits to the feeder in which they actually received milk; rather, calves reduced the number of nonnutritive visits in which calves were allocated no milk (Figure 1). We argue that these nonnutritive visits can be viewed as sampling—calves are visiting the feeder to test if milk is available.

An alternative (and we suggest complementary) interpretation to this decline in sampling behavior comes from the psychological literature. People in sad moods rate their probability of success less than do happy individuals in tasks involving some risk, so performance in tasks involving risk might also be used to assess depression in animals (Paul et al., 2005). To our knowledge this approach has not been explicitly applied to assessing sickness, but we encourage research in this area.

Thus theory from both the psychology and behavioral ecology literatures seems to make similar predictions:
that animals will reduce the frequency of sampling behaviors with the onset of illness. However, it should be noted that these theories act at different levels—one functional, the other mechanistic. The evolutionary approach requires only that the animal derive some fitness benefit from reduced investment in sampling while ill; the psychological approach demands that the animal actually feels ill.

How can we know if animals feel ill? For many animal scientists this question may seem more philosophical than scientific, but the issue lies at the heart of much discussion in the animal welfare literature (Fraser et al., 1997). The current example is of interest in part because it shows the shift from considering behavior as signs of debilitation to a motivated response to illness. This shift implies the animal cares about the outcome (i.e., that the animal experiences either positive or negative affective states that motivate the behavior).

Inferences regarding the affective condition of others are normally based on J. S. Mill’s argument by analogy (see Dawkins, 1980): we can see that we share similarities in ancestry, anatomy, etc., and that we respond in a similar way to similar situations. This does not allow us to conclude that the animal experiences the identical feelings that we do, but we can use the strength of the similarities to justify inferences about the subjective state of the individual. Properly identifying emotional responses to disease will require careful experimentation and interpretation. Here the pain literature provides useful approaches. For example, animals can be trained to self-medicate with analgesics, and researchers can directly assess the frequency and amounts administered. Danbury et al. (2000) trained lame and sound broilers to discriminate between 2 feeds, one containing an analgesic, and found that lame birds consumed more of the feed containing analgesic. To our knowledge no research to date has successfully used measures of self-medication to examine the emotional component to illness, but we see this as an area of much promise.

BEHAVIOR CAN BE PART OF A COMMUNICATION SYSTEM

Behavior as a Signal of Vigor

The practical aim of this research area is to identify behaviors useful in identifying which animals are or will become ill. Of course we are not the only individuals who might benefit from good skills in picking out the weak and infirm—these skills are also important for predators. For this reason we expect that prey species (including all the common farm animals) should normally be stoic; where possible sick animals should mask any signs of vulnerability, especially if the illness makes them an easier target for predation. This stoicism creates a special challenge for researchers and clinicians; measures need to be sufficiently sensitive to detect the very subtle changes in behavior that animals are unable to hide. This challenge is likely to be especially important for early or mild stages of the disease because animals may be less able to mask their state if the ailment is severe. We suggest that automated measures (such as those described for feeding behavior below) may be particularly useful in this respect. Automated measures have the added benefit of not requiring the presence of human observers because the human presence itself may increase the likelihood of animals masking any vulnerability.

In contrast to hiding signs of illness, we might also expect healthy animals to sometimes signal their good health using condition-dependent signals of quality. There is a well-developed scientific literature showing how animals differentially signal depending upon their health status. The proposed mechanism is that cost of signaling is condition-dependent, such that healthy animals can afford to signal more than sick animals. From a mate choice perspective, females benefit by preferentially responding to healthy males by acquiring for their offspring any disease resistance that is heritable and avoiding horizontally transmitted parasites such as ectoparasites and venereal diseases (for review see Garamszegi, 2005). In some cases we might also expect prey to encode information about their quality (including health status) in signals directed to predators. Signals such as stotting in deer inform the predator that the prey is aware of its presence and that chance of capture is thus diminished (e.g., FitzGibbon and Fanshawe, 1988); both signaler and receiver benefit from the signaling by avoiding the costs of a futile chase. If healthy animals are better able to evade capture than sick animals, we might expect prey to encode health information into signals used for prey-predator communication. One study (Laiolo et al., 2007) on lesser short-toed larks (Calandrella rufescens) provided some evidence in support this idea: birds infected with a poxvirus used shorter and lower pitched alarm calls than virus-free birds. It is not clear in this example if predators responded differentially to the different
Behavior As a Signal of Need

In some cases we might predict that animals benefit from signaling their infirmity, for example, the begging of young in an attempt to solicit parental care (for review see Kilner and Johnstone, 1997; Wright and Leonard, 2002). Although both theoretical and applied approaches (Weary and Fraser, 1995) have focused on need for food, dependent young may also signal their increased need for other types of parental care (including heat) when they are ill. This need-dependent signaling hinges on the idea that all animals pay some fitness costs associated with producing the signal, but animals with the greatest need (and thus the most to gain) signal more.

Changes in behavior are most informative when they are associated with clear fitness costs for the animal. For example, piglets must approach the sow and muzzle her udder to stimulate a milk ejection, but one of the largest risks to the young piglet is inadvertent crushing by the sow. All piglets face this trade-off, but piglets are highly variable in how much time they spend in the risky position near the udder of the sow. Not surprisingly, those piglets most tolerant of this increased risk of crushing are those that are in most need of milk from the sow—piglets that are hungry and malnourished (Weary et al., 1996). Detailed observations of such risky behaviors may be of value directly (because the behavior puts the animal at increased risk of poor health) and indirectly (because it provides information about the animal’s own view of its condition). Well-developed theory is available for how animals trade off certain risks and benefits, such as the benefits of foraging relative to the risks of predation (Lima and Dill, 1990). Unfortunately, much less thought has been put into how animals may trade off risks of exposure to disease with other benefits. We believe that this approach has promise in monitoring animal health and encourage new research in this area.

In summary, behavioral signals can encode information relating to health, including those signals designed for offspring-parent, sexual, and predator-prey communication. As these signals have been shaped by evolution to provide this information, we suggest that they may provide a particularly promising area for new applied research on health monitoring.

BEHAVIORS PREDICTIVE OF ILLNESS

Until now we have focused on approaches to recognizing when animals are ill. Arguably more useful still are those measures that help us identify which animals are at greatest risk of becoming ill sometime in the future. Below we describe examples on using feeding behavior and social behavior.

Feeding Behaviors Predictive of Illness

Much empirical research has focused on feeding behavior because of the obvious links between feed intake and production. Moreover, commercially developed equipment is readily available for monitoring activity at the feeder. These systems provide ready access to vast quantities of accurate and repeatable measures including feeding frequency, duration, and intake. Research to date has shown that these measures can be very useful in identifying sick animals.

Using an electronic feed monitoring system Sowell et al. (1998) found that healthy feedlot steers spent 30% more time at the feed bunk than morbid steers, and a greater percentage of healthy steers visited the feed bunk immediately following feed delivery. In a follow-up study, Sowell et al. (1999) found that healthy steers spent more time at the feed bunk and had more feeding bouts than morbid steers. Quimby et al. (2001), using the same electronic behavior monitoring system, detected animal morbidity approximately 4.1 d earlier than conventional clinical evaluations employed by pen riders in commercial feedlots.

Our group has shown that cows with decreased feeding times are more likely to become ill with metritis. Huzzey et al. (2007) electronically monitored the feeding behavior of 101 cows from 2 wk before until 3 wk after calving. After calving cows were assessed for the presence or absence of early metritis, a common reproductive disorder. A retrospective comparison of the feeding behavior of healthy and metritic cows revealed differences during the period of uterine infection: cows with severe and mild forms of metritis had decreased feeding times and intakes relative to healthy cows. In addition, these differences in feeding behavior and intake could be detected even 2 wk before calving and any clinical signs of infection (Figure 2). This research helps to identify cows at risk and to propose interventions that can reduce this risk. For example, one approach that we are pursuing in current research is to provide at-risk cows with special management such as access to less competitive feeding environments (e.g., DeVries and von Keyserlingk, 2006) designed to facilitate easy access and greater intakes.

Social Behaviors Predictive of Illness

The reduced intakes and feeding behavior described above can be driven in part by social competition common in some housing systems. For example, cows rarely benefit by competitively excluding others from access to pasture, but competitive interactions over feed are common for cows housed indoors (Huzzey et al., 2006). In this situation the ability to compete can be of direct concern. For example, cows least able to compete for access to feed may be at greatest risk of metabolic diseases such as ketosis because they cannot maintain their net energy balance. In addition, competition and changes in the social environment can impose social
stressors and have long been recognized as key factors in disease (Koolhaas et al., 1999; Zelena et al., 1999). In a classic study, Natelson et al. (1977) reported that some monkeys subjected to psychological stressors developed gastric ulcers, whereas others remained healthy. He concluded that certain animals were vulnerable to these stressors and their inability to cope increased their risk of disease. Thus, it appears that animals vary in their ability to cope with environmental and social stressors and that inability to cope increases disease risk. Successful coping is thought to depend partly on the ability of the individual to control and predict stressors (Ursin and Olff, 1993).

Koolhaas et al. (1999) discussed 2 different coping strategies: proactive coping, involving an active response to a social challenge including high activity and aggression; and reactive coping, characterized by immobility and low aggression. Problems can arise when the coping strategy of an animal is unable to mitigate the effects of the stressor or when very demanding coping efforts are required. Sustained overactivation of various neuroendocrine systems related to proactive and reactive coping styles may lead to specific types of pathology (Koolhaas et al., 1999). Animals exhibiting a reactive coping strategy tend to have greater activation of the hypothalamic-pituitary-adrenal axis with greater concentrations of circulating cortisol (Koolhaas et al., 1999). For example, Mendl et al. (1992) evaluated the coping strategies of pregnant pigs competing for access to feed. Three groups of pigs were distinguished: high success pigs were able to displace at least as many individuals as displaced them at the feed bunk and were most aggressive and active; no success pigs never displaced others from the feed bunk and were the least aggressive and active; low success pigs frequently engaged in aggressive interactions but were displaced more often than they displaced others. These low success pigs had the greatest concentrations of salivary cortisol.

Figure 2. Average (±SE) daily DMI (kg/d) of healthy (n = 23), mildly metritic (n = 27), and severely metritic (n = 12) Holstein dairy cows from 13 d before until 21 d after calving (adapted from Huzzey et al., 2007).

Sustained overactivation of hypothalamic-pituitary-adrenal axis with greater concentrations of circulating cortisol has been linked with immunosuppression in dairy cows (Hopster et al., 1998) and pigs (Tuchscherer et al., 2004). In the study by Hopster et al. (1998), cows were identified as being high or low responders to stress (with associated increased or decreased cortisol concentrations) in response to a novel environment test. One year later these same animals were subjected to social isolation and were injected with endotoxin to assess various aspects of their immunocompetence. Cows that had previously been identified as high responders showed a stronger stress response to isolation and handling (in body temperature, cortisol, and vocalizations) and were less successful in mounting an immune response to the endotoxin relative to the low responders.

The categorization of coping styles remains controversial. One criticism is that researchers often select animals exhibiting specific coping styles and do not assess many other animals that do not fall neatly into the existing categories. Moreover, using behavioral differences to categorize animals is difficult because it will depend both on what the animals do and how successful they are at doing it. Finally, the link between the behaviors and risk of illness is mediated by the physiological response to stress by the animal, so the extent that the behavioral differences will actually be able to predict health outcomes remains uncertain.

In both the social and feeding behavior examples reviewed above, it is important to think carefully about the causal links: does the behavior increase the risks of illness or does illness cause changes in behavior? In
some cases these links can be complex. Changes in social and feeding behavior might be due to undiagnosed disease, and the behavioral changes may exacerbate the original condition or increase the risk of the animal succumbing to other ailments.

CONCLUSIONS

Clinicians and caregivers have traditionally relied on simple subjective evaluations of behavior, but more recent research is showing that more detailed quantitative assessments are more reliable and more sensitive at detecting disease. New technologies that allow researchers to continuously monitor feeding and other behaviors have proven particularly valuable. Researchers have traditionally viewed behavioral changes as simple signs of the debilitative effects of disease, but more recently thinking has shifted to seeing these as motivated sickness behaviors that represent a coordinated and adaptive response to illness. Although disease detection is of value, better still are measures that can be used to identify animals that are most at risk of developing disease in the future. Our hope is that research will increasingly focus on identifying those measures that better predict the onset of illness in animals, with the ultimate aim of minimizing or preventing illness.

In addition to the practical relevance, this area of research is also conceptually rich. For example, viewing behaviors as signals that encode information relating to health opens a rich area of theory and allows for the development of entirely new approaches. Asking questions not just about the functional consequences of ill health, but also how animals feel when they are ill, introduces new areas of theory and shows the potential for new research on the motivation to express sickness behaviors and self-selection of medications. From this viewpoint we eagerly await research on behavior and illness in the years to come.

LITERATURE CITED


Illness and behavior


