

Tools to measure and improve animal welfare: reward-related behaviour

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Abstract

There is an increasing requirement for tools to assess and improve animal welfare in an objective and scientifically based manner. In our research a concept of welfare is applied which states that welfare is determined by the balance between positive and negative experiences. This concept implies that an interaction exists between stress systems and reward systems in the brain and, as a consequence: (I) negative experiences induce an increased sensitivity (ie need) for positive experiences; and (II) negative experiences can be compensated for by positive experiences. On this basis, two uses of reward-related behaviour can be hypothesised: (I) reward sensitivity may be used as a tool to assess the state of an animal in terms of welfare because it can indicate the current state of the balance that is dependent on previous (stressful) experiences; and (II) regular presentation of rewards may serve as a tool to counteract stress by shifting the balance to the positive side and, thus, to improve welfare. In order to investigate this, we used the rat as a model. Reward sensitivity was determined by the spontaneous behavioural response shown during expectation of a reward (ie anticipatory behaviour). A third (III) use of reward-related behaviour derives from the fact that anticipatory behaviour is influenced by the (rewarding) properties of the forthcoming reward (or other event) and, thus, may serve as a tool to assess the animal's perception of this reward/event. This paper presents a descriptive overview of the evidence obtained thus far for the three proposed uses of reward-related behaviour. The biological background of our concept of welfare can be generalised to all (vertebrate) species, and anticipatory behaviour can be evoked in a wide range of other species. Therefore, this tool for measuring and improving the welfare of captive animals has great potential and will contribute to a good quality of life for captive animals.

Keywords: animal welfare, anticipatory behaviour, behavioural therapy, neuro-ethology, reward, welfare indicator

Introduction

Animals are kept in captivity by man for several different purposes. According to many, society is responsible for assuring good welfare and inherent quality of life of these animals. Currently, there is an increasing requirement for tools to assess and improve animal welfare in an objective and scientifically based manner. It is now generally accepted that animal welfare is not solely related to physical health but also to mental health. Animal welfare is dependent on the brain processes that are involved in the animal's subjective evaluation of its internal state and its environment. Thus, to be able to determine the state of animals in terms of (good or poor) welfare, we need to find ways to 'read their minds'. In other words, we need a tool to enable us to 'ask' an animal how it feels and be able to understand the 'answer'.

Behaviour is the ultimate product of various complex interacting mechanisms in the brain. A behavioural response can be described as the animal's answer to challenges in its external and internal environment. Recently, cognitive ethologists and psychologists have developed new methods for studying the animal mind by combining knowledge of evolutionary biology with behavioural and brain research. In our research, such a multidisciplinary approach has been

adopted to develop a tool to assess the state of animals' welfare by means of posing 'questions' to animals and deducing the 'answers' from their behaviour. This tool is based on how an animal evaluates its own situation, adapts its behaviour and selects the most efficient (ie most rewarding) response under natural conditions. We consider reward-evaluating mechanisms in the brain to play an important role in an animal's subjective evaluation of its internal state and its environment, resulting in the most effective behavioural response.

The concept of welfare we apply in our research states that welfare is determined by the balance between positive and negative experiences (Spruijt *et al* 2001). The outcome of the integration of these experiences eventually determines the state of an animal in terms of welfare. Impaired welfare does not refer to acute positive or negative experiences but refers to a chronic imbalance between these experiences causing a chronic failure to cope. As long as signs of satisfaction are in balance with signs of stress, adaptation is still possible. Continuously changing reward sensitivity is an adaptive response that allows the organism to fulfil its needs and maintain a balance between negative and positive experiences.

This concept of welfare implies that an interaction exists between stress systems and reward systems in the brain, which function together as the animal's 'bank account' in terms of welfare. If too many bills come in (due to negative experiences) and the balance of the bank account threatens to become negative, the brain will signal an increased need for deposits (positive experiences), reflected by an increased reward sensitivity. This implies that all humans and animals are hedonistic and are in fact 'pleasure-seekers' (eg Spruijt *et al* 2001; Cohen & Blum 2002), which is in line with the ideas of Cabanac, who states that 'pleasant is useful' (1971) and proposes pleasure to be the common currency of the brain (1992).

Use of reward-related behaviour as a tool to assess and improve welfare

Uses I and II

The above-described concept and theory imply that: (I) negative experiences induce an increased sensitivity (ie need) for positive experiences; and (II) negative experiences (eg stress) can be compensated for by positive experiences (eg reward). On this basis, we propose the following uses of reward sensitivity and reward-related behaviour: (I) reward sensitivity may be used as a tool to assess the state of an animal in terms of welfare, since it can indicate the current state of the balance that is dependent on previous (stressful) experiences; and (II) regular presentation of rewards may serve as a tool to counteract stress by shifting the balance to the positive side and, thus, to improve welfare.

Reward sensitivity can be measured by the spontaneous behavioural response that an animal shows in expectation of a reward (ie anticipatory behaviour), which can be evoked by a classical (Pavlovian) conditioning paradigm (Von Frijtag *et al* 2000). This behavioural activation in anticipation of a reward is representative of the activation of the reward centres in the brain (Spruijt *et al* 2001). Thus, to 'read the minds' of animals, we address the reward system by announcing rewarding stimuli (through classical conditioning), and we deduce the 'answer' from their behavioural response in anticipation of the forthcoming stimulus.

Use III

A third (III) use of reward-related behaviour derives from the fact that anticipatory behaviour is influenced by the (rewarding) properties of the forthcoming reward (or other event) and, thus, (III) anticipatory behaviour may serve as a tool to assess the animal's perception of this reward/event.

In recent years we have been collecting scientific evidence for these proposed uses of reward-related behaviour (Van der Harst 2003; Van der Harst *et al* 2003a,b, 2005; Dudink *et al* 2006). This paper presents a descriptive overview of the evidence obtained thus far for each of these three uses. Before presenting more details of these studies, it is important to describe or define what can be considered a reward and to explain how anticipatory behaviour is evoked and investigated.

Reward

Food is generally considered to be rewarding to all animals, as are social interactions and sexual behaviour. It is argued

that certain (species-specific) behaviour can be rewarding, based on the evolutionary theory that behaviours that are important for survival (eg exploration/foraging, self-grooming, sexual behaviour) activate the neural reward system, thereby stimulating their display (Spruijt *et al* 2001). These behaviours are considered to be 'ethological needs', which are those activities the display of which is guaranteed by their rewarding properties (Poole 1992; Spruijt *et al* 2001). In general, any reduction in the difference between the current state and the desired state of a motivational system is considered to be rewarding; even a diminishment of stress can have rewarding properties.

Anticipatory behaviour

Anticipatory behaviour is an important parameter in our research. Anticipatory behaviour is evoked in a classical conditioning paradigm in which an initially neutral stimulus (eg sound and/or light) is repeatedly paired with the arrival of a reward. Consequently, an association will be established between this stimulus and the reward. Subsequently, the stimulus serves as an announcement and the animal will display anticipatory behaviour at the presentation of the stimulus. This behavioural response can be investigated during the interval between the announcement and the actual arrival of the reward and is characterised by an increase in activity. In general, this anticipatory increase in activity is quantifiable by the number of behavioural transitions; it became apparent (Van der Harst *et al* 2003b) that rats display their full repertoire of behaviours during the interval between the announcement and the reward but the number of transitions between these behavioural elements is increased. These transitions can be quantified by the total frequency of all behavioural elements that the animals display during the anticipatory phase (ie between the announcement and the actual arrival of the reward).

Anticipatory behaviour was described as early as 1918 by Craig as a typical arousal with goal-directed activity that occurs during the appetitive phase when the actual reward is not present yet. Thus, anticipation requires the ability to internally represent expectations of a forthcoming reward or other event (Spruijt 2001). The underlying neurocircuitry of this anticipatory response in expectation of a reward involves mesolimbic dopaminergic systems (Pfaus & Phillips 1991; Schultz *et al* 1997), which are known to be sensitised by stressors (Cabib & Puglisi-Allegra 1996). Anticipatory behaviour is described as being an expression of biologically significant 'preparatory behaviour' (Matthews *et al* 1996). It occurs during the appetitive phase ('wanting', dopamine-mediated [Berridge 1996]), and it is argued to prepare an animal for a forthcoming change; it leads to and facilitates (Blackburn *et al* 1989) the consummatory phase ('liking', opioid-mediated [Berridge 1996]).

To test our proposed use of anticipatory behaviour in a scientific and standardised manner, we first used the rat as a model (Van der Harst 2003a); we have since been able to evoke and investigate anticipatory behaviour in several other species also, including mink (Vinke *et al* 2004), pigs (Dudink *et al* 2006), cats (Van den Bos *et al* 2003), and farmed silver foxes (Moe *et al* 2006). Recently, marmosets can be added to this

Table 1 Schematic overview of the uses of reward-related behaviour and investigative approaches.

	Previous experiences (positive/negative)			Unconditioned stimulus (reward)			Use
	A	B	C	R1	R1	R1	
I	A	B	C	R1	R1	R1	Assessing the welfare state (as a result of previous positive and negative experiences [A, B, C]) of animals by their reward sensitivity, reflected by the level of anticipatory behaviour after announcement of a reward (R1) (Van der Harst <i>et al</i> 2003a).
II	D or	(E	F)	R1 or	(R2	R3)	Improving the state of animals by regularly activating the reward system via announcements of rewards (R1 or other types of reward R2/R3), thereby counteracting negative experiences (D or E/F) (Van der Harst <i>et al</i> 2005; Dudink <i>et al</i> 2006).
III	A	A	A	R1	R2	R3	Assessing the perception of different stimuli/events (R1, R2, R3) by the level of anticipatory behaviour displayed after announcement of these stimuli/events to animals with the same previous experience (A) (Van der Harst <i>et al</i> 2003b).

The dependent and independent variables (ie previous experiences and unconditioned stimuli) vary according to the research question. (I) Reward sensitivity of animals with different previous experiences such as (A) standard and (B) enriched housing conditions or (C) stressful events that influence welfare can be investigated by announcing the same reward (R1) to all groups and observing anticipatory behaviour in the period before delivery of the reward. (II) The welfare state of animals can be improved by regularly activating their reward system by means of reward announcements (R1), thereby counteracting negative experiences (eg stress) (D or E/F). (III) Perception of different stimuli or events (R1, R2, R3) can be investigated by announcing these stimuli to animals with the same previous experiences (A).

list, as Badihi and Buchanan-Smith (2007, see p xxx, this issue) have applied our concept and approach to investigate the significance of positive and negative events to these animals. Also, in a research project on overtraining in horses in which brief social contact was used to investigate social interest, anticipatory behaviour was observed (described by Van Dierendonck 2006) and is now being further studied.

Evidence in support of the three uses of reward-related behaviour for animal welfare research

Some evidence in support of each of our proposed uses of reward-related behaviour will now be described. The approach used in each study is presented in Table 1. All experiments were performed in adherence to the legal requirements of The Netherlands concerning research on laboratory animals and have been approved by the Ethical Committee of Utrecht University.

Evidence in support of use I

First, we argued that reward sensitivity is influenced by previous experiences and, thus, may serve as a tool to assess welfare. From addiction studies in humans, it has long been known that previous experiences such as stress can alter the sensitivity to rewarding (ie addictive) stimuli (Piazza *et al* 1990). Much information has been collected over the years concerning the consequences of acute and chronic stress on reward sensitivity. Because these lines of research often involve animal models, evidence for this stress–reward interaction is available also for animals (eg Morgan & Einon 1975; Bertierre *et al* 1984; Jones *et al* 1990; Hall 1998).

On the basis of this information, we hypothesised that animals with different previous experiences would show different levels of reward sensitivity as measured by their anticipatory behaviour. In other words, more stress will

result in a higher level of anticipation for a reward; or, conversely, more positive experiences will result in a lower level of reward anticipation. To test this, we investigated the level of anticipatory behaviour for a food reward (sucrose solution) in groups of laboratory rats with different previous experiences (Van der Harst *et al* 2003a; see also Table 1 part I). One group was housed under ‘standard’ laboratory housing conditions, which are rather stimulus-poor (social housing in cages containing only sawdust). The other group was housed in enriched cages that were based on the standard cages but with several additions (a shelter/partition object, gnawing-sticks and a heightened lid) to provide the opportunity to display a more extensive repertoire of species-specific behaviour (eg hiding, climbing, gnawing, rearing). Anticipatory behaviour was evoked using a classical conditioning paradigm in which an initially neutral stimulus (sound and light) was repeatedly paired with the presentation of bottles of sucrose solution (5%). The interval between the announcement and the reward was gradually lengthened from 30 s to 10 min over a period of 10 days, with several training sessions per day (this is a form of delay-conditioning in which the experimenter is present in the room and is therefore part of the cue). The animals were trained in their home cage and were tested on several occasions during the conditioning period in an observation cage, where behaviour during the delay was recorded on videotape.

This study revealed that the standard-housed rats showed a greater level of anticipatory behaviour than the enriched-housed animals; ie the former group of animals was more sensitive to rewards than the latter. This confirms our hypothesis that previous experiences influence reward sensitivity and thereby the level of anticipatory behaviour. Furthermore, from these results it can be concluded that the

welfare of standard-housed rats is poorer than that of enriched-housed rats, probably because they are unable to satisfy their behavioural needs in these impoverished housing conditions. Further evidence of the relationship between previous experiences and reward sensitivity is provided by other studies of our group (eg Van den Berg *et al* 1999; Von Frijtag *et al* 2000).

Evidence in support of use II

Second, we argued that reward expectancy may serve to counteract stress and, thus, to improve welfare. Stress is part of everyday life and may result in depression when it becomes chronic and attempts to cope repeatedly fail; in terms of the 'bank account', this situation reflects 'bankruptcy'. Depression is an affective disorder, the symptoms of which, such as insensitivity to rewards, can be observed also in animals after chronic stress (the relationship between [in]sensitivity to rewards and welfare will be discussed in the last part of this paper). Insensitivity to rewards in animals resembles anhedonia (loss of the ability to experience pleasure), which is considered to be a major symptom of human depression (American Psychiatric Association 1994). Several lines of evidence exist for the role of dopamine in the mechanism of action of antidepressant treatments concerning their therapeutic effect on anhedonia and loss of motivation (Zacharko & Anisman 1991; Cabib & Puglisi-Allegra 1996; D'Aquila *et al* 2000).

On the basis of the fact that reward announcement, thus inducing reward expectancy, causes activation of mesolimbic reward systems and subsequent increased dopamine release (Schultz *et al* 1997; O'Doherty *et al* 2002), we hypothesised that regular activation of the reward system could counteract the effect of chronic stress on reward sensitivity. We therefore investigated whether a treatment of regular reward announcements could counteract the development of symptoms of depression (Van der Harst *et al* 2005, unpublished data 2007; see also Table 1 part II). (Reward announcements were always followed by presentation of the reward after the conditioned stimulus–unconditioned stimulus [CS–US] interval.) In order to elicit depressive-like symptoms in rats, we used a social stress paradigm — a validated model of depression (Von Frijtag 2001; Von Frijtag *et al* 2000, 2001, 2002).

The first study (Van der Harst *et al* 2005) focussed on preventing the development of anhedonia in socially stressed rats by means of regular announcements and subsequent presentations of a food reward during the long-term social isolation period after defeat, which is an important part of the social stress paradigm. This study confirmed the hypothesised therapeutic efficacy of regular activation of the reward system: the group that received regular reward announcements and subsequent reward presentations did not develop anhedonic symptoms. Interestingly, a subsequent test using an enriched cage as reward induced a reversal of the depressive-like symptoms in the non-treated social stress group (Van der Harst *et al* 2005). Therefore, a second study was conducted (Van der Harst *et al* unpublished data 2007) to investigate whether this reversal of symptoms was caused by the repeated short-term (30 min) visits to the enriched cage,

in which the rats were able to display a larger repertoire of species-specific behaviour, increasing the possibility for rewarding activities; or, whether the announcement thereof had an additional effect, by prolonging the activation of the reward system as compared to merely providing the reward. In other words, we investigated whether it was solely the *presentation* of the reward that caused the reversal of the depressive-like symptoms, or whether the *announcement* of the reward contributed to this effect through the increase in duration of reward-system activation attributable to the anticipatory time-delay. In this study, as well as reward sensitivity, an additional parameter was measured: synaptic plasticity of the hippocampus (electrophysiological measurements in slices of the CA1 area), a brain area known to be affected by stress and depression (McEwen & Magarinos 2001; Pavlides *et al* 2002; Shakesby *et al* 2002). Socially stressed rats show a severe attenuation of this parameter, which can be restored by treatment with an antidepressant (Von Frijtag *et al* 2001), indicating the relevance of both the animal model and the parameter to depression.

The results showed that both unexpected enriched housing (ie control group transferred to the enriched cage without a prior announcement) and announced enriched housing restored reward sensitivity (and thus reversed the anhedonic state) in socially stressed rats. Furthermore, we found that both unexpected and announced enriched housing caused recovery of synaptic plasticity in the hippocampus ($116 \pm 2.65\%$ and $203.27 \pm 23.03\%$, respectively; baseline is 100% and indicates impaired synaptic plasticity which is the case for the non-treated group [ie the socially stressed rats that were not transferred to an enriched cage]). Importantly, in support of our hypothesis, it was found that the announcement had an additional effect, as indicated by a significantly higher level of recovery of synaptic plasticity ($203.27 \pm 23.03\%$ versus $116 \pm 2.65\%$: Mann-Whitney $U = 1$, $P = 0.006$).

In conclusion, announced short-term enriched housing has a high and long-lasting counteracting efficacy on stress-induced alterations of both reward sensitivity and hippocampal synaptic plasticity. This information is important for counteracting the consequences of chronic stress in captive animals and may therefore have therapeutic value in cases of welfare problems. Further evidence in support of this behavioural therapy is provided by a study conducted in pigs (Dudink *et al* 2006), which showed that announcing the arrival of enrichment increases play behaviour and reduces weaning-stress-induced behaviours of piglets directly after weaning.

Evidence in support of use III

Third, we argued that anticipatory behaviour is influenced by the (rewarding) properties of a forthcoming stimulus/event and, thus, may serve as a tool to assess animals' perception of this stimulus/event. The behavioural response of animals to a certain stimulus (or event) is likely to be representative of the perception of this stimulus, as the neural substrates of behavioural activation and the perception of reward are remarkably similar (mesolimbic dopamine system) (Kalivas & Nakamura 1999). In line with this, we have argued (Spruijt *et al* 2001)

that behavioural activation in anticipation of the arrival of a reward represents the activation of reward centres in the brain. The level of activation depends on the incentive value of the reward (eg Koob 1996; Richardson & Gratton 1996). Therefore, a behavioural parameter based on this response could be very useful for the assessment of the perception (ie appraisal) of stimuli and events.

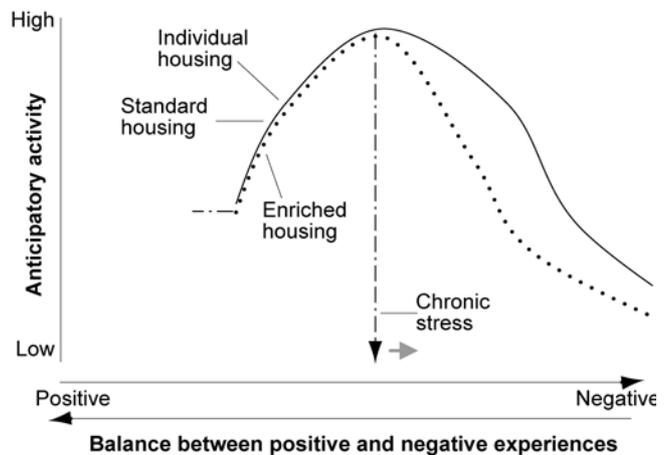
On the basis of this information, we hypothesised that the level of anticipatory behaviour is influenced by the type and rewarding properties of a stimulus. To test this, the intensity of the behavioural activation occurring in the time-delay between the announcement and the arrival of a reward or other event was investigated in rats that expected different types of stimuli (Van der Harst *et al* 2003b; see also Table 1 part III). The animals all had the same history in terms of housing and management, to prevent interference of different previous experiences on their anticipatory response. A secondary aim of this study was to investigate whether rats would perceive a (relatively simple) enriched cage as rewarding. Therefore, transfer to an enriched cage was used as one of the stimuli. Sexual contact was used as a stimulus for the positive control group, as sexual behaviour belongs to a class of naturally occurring behaviours that are generally considered to be highly rewarding (eg Agmo & Berenfeld 1990; Van Furth *et al* 1995; Pfaus *et al* 2001). The other groups were transferred either to a standard cage (neutral stimulus) or to a cylinder that was filled with water (negative stimulus). The results showed different levels of anticipatory behaviour for the different expected events (see Van der Harst *et al* 2003b), thereby confirming the hypothesis.

It is important to note that we used several control groups that received types of stimuli that are known to be either rewarding or stressful to validate that the level of anticipatory activity is related to the rewarding properties of the stimulus (as was hypothesised on the basis of literature about activation of reward centres in the brain) and to exclude the possibility that an increase in activity is also related to the anticipation of a negative event. Furthermore, the strong increase in activity during anticipation of both an enriched cage and sexual contact, and the similar response concerning the separate behavioural elements, indicate that the appraisal of access to an enriched cage shares a common denominator with the perception of sexual contact. Since the latter is generally accepted to have highly rewarding properties for rats it is concluded that the enriched cage is highly rewarding also. The anticipatory response for sexual contact or an enriched cage was obviously different from the anticipation for access to a standard cage or for a forced swim, indicating that this response is related to the positive (ie rewarding) nature of the stimulus. Further evidence for the use of anticipatory behaviour as a tool to assess animal perception is provided by a recent study of Badihi and Buchanan-Smith (2007; see p xxx, this issue), who used anticipatory behaviour to investigate the significance of positive and negative events to laboratory-housed common marmosets (*Callithrix jacchus*).

Conclusions and animal welfare implications

To conclude, the above-described studies provide support for the three proposed uses of reward-related behaviour. First, it

Figure 1



Hypothetical relationship between reward sensitivity, as reflected by anticipatory activity after announcement of a reward (y-axis), and welfare, as reflected by the balance between positive and negative experiences (x-axis).

was shown that previous experiences influence anticipatory behaviour to rewards in rats. This indicates that this natural behavioural response may serve as a welfare indicator. Second, it became apparent that regular reward announcements could both prevent and reverse the consequences of (chronic) stress, and the announcement appeared to have an additional effect over and above that of the presentation of the stimulus. Interestingly, enrichment of housing conditions appeared to have a high therapeutic effectiveness, which illustrates the importance of environmental enrichment for captive animals. Third, it was confirmed that anticipatory behaviour is influenced by the type of stimulus (positive/neutral/negative), indicating its usefulness for assessing animal perception. The same study also provided further evidence for the importance of environmental enrichment, as the anticipatory response of rats expecting to be transferred to an enriched cage indicated that it was perceived as highly rewarding. It is likely that this is due to the fact that an enriched cage provides the opportunity to engage in rewarding activities (species-specific behaviours that satisfy ethological needs). Again, this stresses the importance of reward and reward-related behaviours for animal welfare.

It is important to explain the relationship between stress/negative experiences and reward sensitivity in some detail. We hypothesised that there is a positive correlation between reward sensitivity (as measured by anticipatory activity) and negative experiences and we provided some evidence for this. Furthermore, we also explained that chronic stress resulted in anhedonia (insensitivity to rewards). Therefore, we hypothesise a relationship between welfare and reward sensitivity as represented in Figure 1: an increasing level of negative experiences that are not compensated for by positive experiences will result in an increased sensitivity to rewards until a 'cut-off' point is reached when the stress becomes chronic. The exact shape of the curve is currently being determined through further research.

On the basis of these results, we state that announcement and presentation of rewards provide a useful tool to both measure and improve the welfare of animals. Importantly, this tool is based on the natural behavioural response of animals and is therefore a non-invasive method for assessment of welfare. Additionally, our research has shown that use of information from animal studies that are conducted to improve human welfare (eg addiction and depression research) can be very useful for the benefit of animal welfare. The biological background of our concept of welfare can be generalised to all (vertebrate) species, and anticipatory behaviour can be evoked in a wide range of other species. Therefore, this tool to measure and improve the welfare of captive animals has great potential and is currently being further developed and validated.

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References

- Agmo A and Berenfeld R** 1990 Reinforcing properties of ejaculation in the male rat: role of opioids and dopamine. *Behavioural Neuroscience* 104: 177-189
- American Psychiatric Association** 1994 *DSM-IV: Diagnostic and Statistical Manual of Mental Disorders (4th Edition)*. American Psychiatric Association: Washington DC, USA
- Badihi I and Buchanan-Smith HM** 2007 Anticipatory behaviour — a means of determining the significance of positive and negative events? Poster presentation. *Animal Welfare* 16(S): xxx-xxx
- Berridge KC** 1996 Food reward: brain substrates of wanting and liking. *Neuroscience and Biobehavioral Reviews* 20: 1-25
- Bertiè MC, Sy TM, Baigts F, Mandenoff A and Apfelbaum M** 1984 Stress and sucrose hyperphagia: role of endogenous opiates. *Pharmacology Biochemistry and Behavior* 20: 675-679
- Blackburn JR, Phillips AG, Jakubovic A and Fibiger HC** 1989 Dopamine and preparatory behavior. II: A neurochemical analysis. *Behavioural Neuroscience* 103: 15-23
- Cabanac M** 1971 Physiological role of pleasure. *Science* 173: 1103-1107
- Cabanac M** 1992 Pleasure: the common currency. *Journal of Theoretical Biology* 155: 173-200
- Cabib S and Puglisi-Allegra S** 1996 Stress, depression and the mesolimbic dopamine system. *Psychopharmacology* 128: 331-342
- Cohen JD and Blum KI** 2002 Reward and decision. *Neuron* 36: 193-198
- Craig W** 1918 Appetites and aversions as constituents of instincts. *Biological Bulletin* 34: 91-107
- D'Aquila PS, Collu M, Gessa GL and Serra G** 2000 The role of dopamine in the mechanism of action of antidepressant drugs. *European Journal of Pharmacology* 405: 365-373
- Dudink S, Simonse H, Marks I, de Jonge FH and Spruijt BM** 2006 Announcing the arrival of enrichment increases play behaviour and reduces weaning-stress-induced behaviours of piglets directly after weaning. *Applied Animal Behavioural Science* 101: 86-101
- Hall FS** 1998 Social deprivation of neonatal, adolescent, and adult rats has distinct neurochemical and behavioral consequences. *Critical Reviews in Neurobiology* 12: 129-162
- Jones GH, Marsden CA and Robbins TW** 1990 Increased sensitivity to amphetamine and reward-related stimuli following social isolation in rats: possible disruption of dopamine-dependent mechanisms. *Psychopharmacology* 102: 364-372
- Kalivas PW and Nakamura M** 1999 Neural systems for behavioral activation and reward. *Current Opinion in Neurobiology* 9: 223-227
- Koob GF** 1996 Hedonic valence, dopamine and motivation. *Molecular Psychiatry* 1: 186-189
- Matthews K, Wilkinson LS and Robbins TW** 1996 Repeated maternal separation of preweanling rats attenuates behavioral responses to primary and conditioned incentives in adulthood. *Physiology & Behavior* 59: 99-107
- McEwen BS and Magarinos A** 2001 Stress and hippocampal plasticity: implications for the pathophysiology of affective disorders. *Human Psychopharmacology: Clinical and Experimental* 16: 7-19
- Moe RO, Bakken M, Kittilsen S, Kingsley-Smith H and Spruijt BM** 2006 A note on reward-related behaviour and emotional expressions in farmed silver foxes (*Vulpes vulpes*): basis for a novel tool to study animal welfare. *Applied Animal Behavioural Science* 101: 362-368
- Morgan MJ and Einon D** 1975 Incentive motivation and behavioural inhibition in socially isolated rats. *Physiology & Behavior* 15: 405-409
- O'Doherty JP, Deichmann R, Critchley HD and Dolan RJ** 2002 Neural responses during anticipation of a primary taste reward. *Neuron* 33: 815-826
- Pavlidis C, Nivon LG and McEwen BS** 2002 Effects of chronic stress on hippocampal long-term potentiation. *Hippocampus* 12: 245-257
- Pfaus JG and Phillips AG** 1991 Role of dopamine in anticipatory and consummatory aspects of sexual behaviour in the male rat. *Behavioural Neuroscience* 105: 727-743
- Pfaus JG, Kippin TE and Centeno S** 2001 Conditioning and sexual behavior: a review. *Hormones and Behavior* 40: 291-321
- Piazza PV, Deminière JM, Le Moal M and Simon H** 1990 Stress- and pharmacologically-induced behavioural sensitization increases vulnerability to acquisition of amphetamine self-administration. *Brain Research* 514: 22-26
- Poole T** 1992 The nature and evolution of behavioural needs in mammals. *Animal Welfare* 1: 203-220
- Richardson NR and Gratton A** 1996 Behavior-relevant changes in nucleus accumbens dopamine transmission elicited by food-reinforcement: an electrochemical study in rat. *Journal of Neuroscience* 16: 8160-8169
- Schultz W, Dayan P and Montague PR** 1997 A neural substrate of prediction and reward. *Science* 275: 1593-1599
- Shakesby AC, Anwyl R and Rowan MJ** 2002 Overcoming the effects of stress on synaptic plasticity in the intact hippocampus: rapid actions of serotonergic and antidepressant agents. *Journal of Neuroscience* 22: 3638-3644
- Spruijt BM** 2001 How the hierarchical organization of the brain and increasing cognitive abilities may result in consciousness. *Animal Welfare* 10: S77-S87
- Spruijt BM, van den Bos R and Pijlman FT** 2001 A concept of welfare based on reward evaluating mechanisms in the brain: anticipatory behaviour as an indicator for the state of reward systems. *Applied Animal Behavioural Science* 72: 145-171
- Van den Berg CL, Pijlman FT, Koning HA, Diergaarde L, Van Ree JM and Spruijt BM** 1999 Isolation changes the incentive value of sucrose and social behaviour in juvenile and adult rats. *Behavioural Brain Research* 106: 133-142

- Van den Bos R, Meijer MK, Van Renselaar JP, Van der Harst JE and Spruijt BM** 2003 Anticipation is differentially expressed in rats (*Rattus Norvegicus*) and domestic cats (*Felis silvestris catus*) in the same classic conditioning paradigm. *Behavioural Brain Research* 141: 83-98
- Van der Harst JE** 2003 *Tools to measure and improve welfare of laboratory rats: reward-related behaviour and environmental enrichment*. PhD thesis, Utrecht University, The Netherlands
- Van der Harst JE, Baars JM and Spruijt BM** 2003a Standard housed rats are more sensitive to rewards than enriched housed rats as reflected by their anticipatory behaviour. *Behavioural Brain Research* 142: 151-156
- Van der Harst JE, Fermont PCJ, Bilstra AE and Spruijt BM** 2003b Access to enriched housing is rewarding to rats as reflected by their anticipatory behaviour. *Animal Behaviour* 66: 493-504
- Van der Harst JE, Baars JM and Spruijt BM** 2005 Announced rewards counteract the impairment of anticipatory behaviour in socially stressed rats. *Behavioural Brain Research* 161: 183-189
- Van Dierendonck MC** 2006 *The importance of social relationships in horses*. PhD thesis, Utrecht University, The Netherlands
- Van Furth WR, Wolterink G and Van Ree JM** 1995 Regulation of masculine sexual behavior: involvement of brain opioids and dopamine. *Brain Research, Brain Research Reviews* 21: 162-184
- Vinke CM, Van den Bos R and Spruijt BM** 2004 Anticipatory activity and stereotypical behaviour in American mink (*Mustela vison*) in three housing systems differing in the amount of enrichments. *Applied Animal Behavioural Science* 89: 145-161
- Von Frijtag JC** 2001 *Long-term effects of social stress in rats: the assessment of animal welfare using a model of human depression*. PhD thesis, Utrecht University, The Netherlands
- Von Frijtag JC, Kamal A, Reijmers LG, Schrama LH, van den Bos R and Spruijt BM** 2001 Chronic imipramine treatment partially reverses the long-term changes of hippocampal synaptic plasticity in socially stressed rats. *Neuroscience Letters* 309: 153-156
- Von Frijtag JC, Reijmers LGJE, Van der Harst JE, Leus IE, Van den Bos R and Spruijt BM** 2000 Defeat followed by individual housing results in long-term impaired reward- and cognition-related behaviours in rats. *Behavioural Brain Research* 117: 137-146
- Von Frijtag JC, van den Bos R and Spruijt BM** 2002 Imipramine restores the long-term impairment of appetitive behavior in socially stressed rats. *Psychopharmacology* 162: 232-238
- Zacharko RM and Anisman H** 1991 Stressor-induced anhedonia in the mesocorticolimbic system. *Neuroscience and Biobehavioral Reviews* 15: 391-405