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Emotional reactions to learning in cattle

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Abstract

It has been suggested that during instrumental learning, animals are likely to react emotionally to the reinforcer. They may in addition react emotionally to their own achievements. These reactions are of interest with regard to the animals' capacity for self-awareness. Therefore, we devised a yoked control experiment involving the acquisition of an operant task. We aimed to identify the emotional reactions of young cattle to their own learning and to separate these from reactions to a food reward. Twelve Holstein–Friesian heifers aged 7–12 months were divided into two groups. Heifers in the experimental group were conditioned over a 14-day period to press a panel in order to open a gate for access to a food reward. For heifers in the control group, the gate opened after a delay equal to their matched partner's latency to open it. To allow for observation of the heifers' movements during locomotion after the gate had opened, there was a 15m distance in the form of a race from the gate to the food trough. The heart rate of the heifers, and their behaviour when moving along the race towards the food reward were measured. When experimental heifers made clear improvements in learning, they were more likely than on other occasions to have higher heart rates and tended to move more vigorously along the race in comparison with their controls. This experiment found some, albeit inconclusive, indication that cattle may react emotionally to their own learning improvement.

Introduction

Emotional responses to stress exposure are greater when the stressful stimuli are not controllable, than when the subject can learn to control them (Drugan et al., 1997). In the absence of fear or pain, is it possible that the ability to control something might in itself be rewarding? Dogs that are trained to assist people with severe disabilities in everyday tasks, have been noticed to perform at high levels of excitement, reliability and versatility when they have learned to experience task solving as intrinsically rewarding (N. Bondarenko, personal communication). During a previously conducted learning experiment with cattle we remarked increased excitement and possible signs of pleasure during the learning process (Hagen and Broom, 2003).

Thus, animals might not only get excited about, for instance, the expectation of a reward, but also about realising that they themselves to some extent control the delivery of a reward. In other words, if they develop an understanding of a causal relationship in which they are the agents, this might be exciting to them. If this were the case, their emotional reactions in a situation where they learned a causal relationship should be different from their reactions in a situation where they just learned to expect something. The difference might occur either specifically during the process of understanding, or it might be retained after a task has been acquired. To investigate the occurrences of such differences, we designed a yoked control learning experiment.

2. Methods

2.1. Animals and apparatus

Twelve Holstein–Friesian yearling heifers were kept together in a 0.5 ha paddock from about 3 months prior to the experiment. In addition to grazing, they were fed a total of 80 kg of hay and 1–2 kg each per day of concentrates (rolled barley and nuts).

The heifers were assigned to six matched pairs on the basis of weight, age, and sire (when known). One heifer from each pair was randomly assigned to the experimental or control group. One of the heifers became difficult to handle, resulting in the exclusion of both her and the heifer matched to her from the experiment, reducing the sample size to five pairs. The experimental heifer had to learn a task, whereas her matched control was yoked, that is, the control heifers obtained the same conditions as their respective matched partners, irrespective of what they themselves did.

An experimental apparatus was built within the paddock and consisted of a start area and a race, partly covered with tarpaulin to visually isolate the heifers from the experimenter and from the other heifers (Fig. 1). The start area had an entrance gate, through which the heifers were let in, and an exit gate, which was opened to let them go down the race. A small panel, mounted on a wooden plate in the start area, 50 cm away from the exit gate and at a height of 1 m, was used as an operant for experimental heifers. The race to which the exit gate gave access was 15 m long, and at the end of it there was a food trough into which the reward was delivered. A control panel for the experimenter was located just outside the entrance to the start area. It had two light emission diodes (LEDs) that signalled when an operant was manipulated, or when latencies had passed. In addition, it had a switch with which the onset and offset of a trial could be recorded.

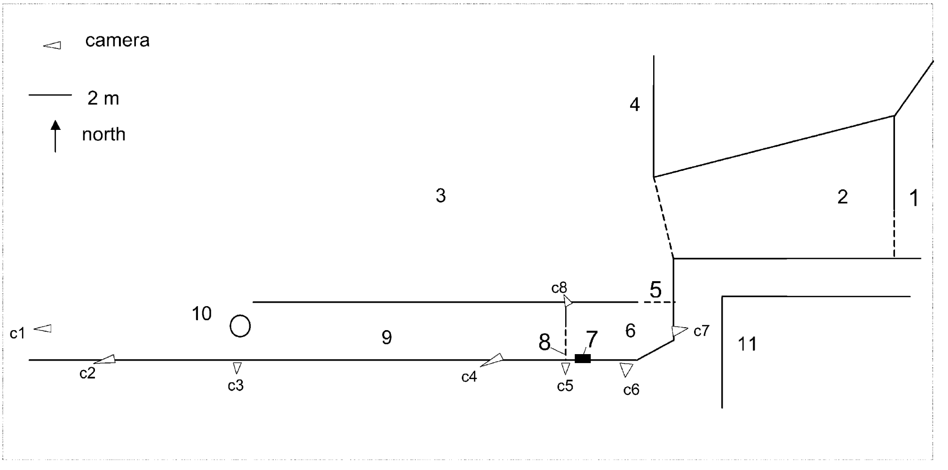

Fig. 1. Map of apparatus: 1, corner of grazing area; 2, holding area; 3, experimental and feeding area; 4, place for putting heart rate equipment on; 5, entrance gate to 6, start area; 7, operant; 8, exit gate; 9, race; 10, food trough; 11, building with computer and video equipment. Cameras, c1–c8.

2.2. Structure of the experiment and learning procedure

One session was carried out per day on consecutive days. All heifers had one trial per session. Trials were carried out with an experimental animal first, followed by its control.

At the start of each trial, a heifer was taken out of the holding pen, led to the experimental area, and fed some concentrates while being fitted with the heart rate measurement device. She was then led into the start area of the maze and the entrance gate was closed behind her. If the heifer was in the experimental group, an LED on the control panel, visible only to the experimenter, would light up as soon as the heifer had pressed the panel once. The exit gate would then immediately be opened, allowing access to the race and the food reward. A computer recorded the time at which the panel was pressed. If the panel was not pressed within 3 min, some concentrate was fed to the heifer near the panel and the gate was opened. For control heifers, the computer recorded their panel presses, but gave the light signal for the experimenter to open the door independently of presses, matched to the latency of the experimental heifer previously recorded.

Once the gate had opened, the heifer was free to go down the race to the trough and eat the food. Having eaten, the heifer could exit the race or move back into it. However, it was not possible for the heifer to get into the start area. Three minutes after she had finished eating, the heifer was rejoined with the group outside the experimental area.

2.3. Data collection and analysis

Latencies from when a heifer's head was inside the start area until she made the exit gate open were categorised into four groups with equal counts. The latency categorisation and the proportion of behaviour that the heifer in the start area directed towards the operant were used to assign a performance index (Table 1) to the experimental heifers for each trial.

Table 1
Scheme used to assign a performance index

Panel pressed?	Latency before gate opens	Proportion of time directed towards operant	Performance index value
No	–	–	0
Yes	>60 s	<half	2
		>half	3
	21–60 s	<half	3
		<half	4
	9–20 s	–	5
	<9 s	–	6

For further analysis, the difference between the performance index of an animal on the trial in question and its index on the day before was calculated. This change was categorised into a binary variable where 0 denotes no change from previous day or lower performance (difference values from −5 to 1) and 1 denotes that performance is clearly better than on the day before (difference values >1). This binary performance change index was used for further analysis and is referred to as ‘learning index’. Notes were also kept on behaviours such as repeated butting of the operant panel after the exit gate had opened. In addition, whether the heifers chose to go back into the race after they had eaten their reward, and whether they tried to get back into the start area or tried to reach the panel was recorded.

The heifers’ behaviour from the time that they entered the experimental area and had the heart rate monitor fitted until they were led out, was recorded on video with eight cameras (Fig. 1). The time taken to go from the exit gate to the food trough and behaviours during this locomotion (Table 2) were coded from the video records by two observers. Before coding, all video clips were edited out of context and compiled on new tapes in random order. Inter- and intra-observer agreement was ensured by randomly interspersed re-observation of clips. For further analysis, an index for the gait was derived from a combination of the ‘main gait’ and ‘other gait’ classification as outlined in Table 3.

Polar Sport Testers storing 5 s interval averages (Polar Electro Oy, Finland) were used to record heart rate. For each heifer, the mode of her heart rate across all measurements

Table 2
Behaviour during locomotion

Variable	Levels	Description
Main gait	Walk, trot, gallop/canter	The gait that dominates the clip
Other gait	None, walk, trot, gallop/canter	Additional gait that occurs during the clip (if several additional gaits occur, the one that appears most)
Jump	Yes, no	The front legs are lifted together, top line descends sharply from back to front and all feet are then in the air simultaneously
Buck	Yes, no	Both hind legs are lifted simultaneously and the top line ascends sharply from front to back
Kick	Yes, no	One of the hind legs is extended back- and sideward in a sharp movement

Table 3
Derivation of gait index from raw scores of 'main gait' and 'other gait'

Possible combinations		Gait index
Main gait	Other gait	
Walk	None	1
	Trot	2
	Gallop	3
Trot	Walk	3
	None	4
	Gallop	5
Gallop	Walk	5
	Trot	6
	None	7

was calculated as an individual baseline. For further analysis, the mean deviation from an individual's mode was calculated for functional phases of the experiment: before a heifer entered the start area (a); during the last 15 s before the exit gate was opened (b); during the first 10 s after gate has been opened (c); 10–20 s after gate had been opened (d); from 20 s after gate had been opened until the heifer stopped eating (e); after the heifer had stopped eating (f). The deviation of the heart rate in each phase from an individual's mode was expressed as a percentage higher or lower than the mode, i.e. deviation $= ((\text{mean}/\text{mode}) - 1) \times 100$.

As a consequence of the experimental design, pairwise differences between experimental subjects and their matched controls were of particular interest as dependent variables. Pairwise differences were always calculated as experimental-control, i.e. the pairwise heart rate differences were the differences, in each functional phase of each trial, between an experimental heifer's heart rate deviation from mode, and her matched control's heart rate deviation from mode. Only cases where both were available were included in the analysis.

Prior to non-parametric tests following Siegel and Castellan (1988), proportions and numerical values were averaged to one value per subject per treatment level to ensure independence of the data. Effects on heart rate were investigated with a general linear mixed model calculated in R (Ihaka and Gentleman, 1996). The repeated measures design and individual differences were taken into account by including the individual pairs as a random factor. Normality of the residuals' distributions was tested with the Kolmogorov–Smirnov test and homogeneity of variances was tested with the Bartlett test.

3. Results

The latency to press the panel varied from up to 3 min (at the beginning of the experiment) to 3 s when the heifers had learned the task well. Fig. 2 shows the performance index and the derived learning index for the experimental heifers. The figure also shows the occurrence of panel investigation or panel-directed play behaviour after the gate has opened, and of

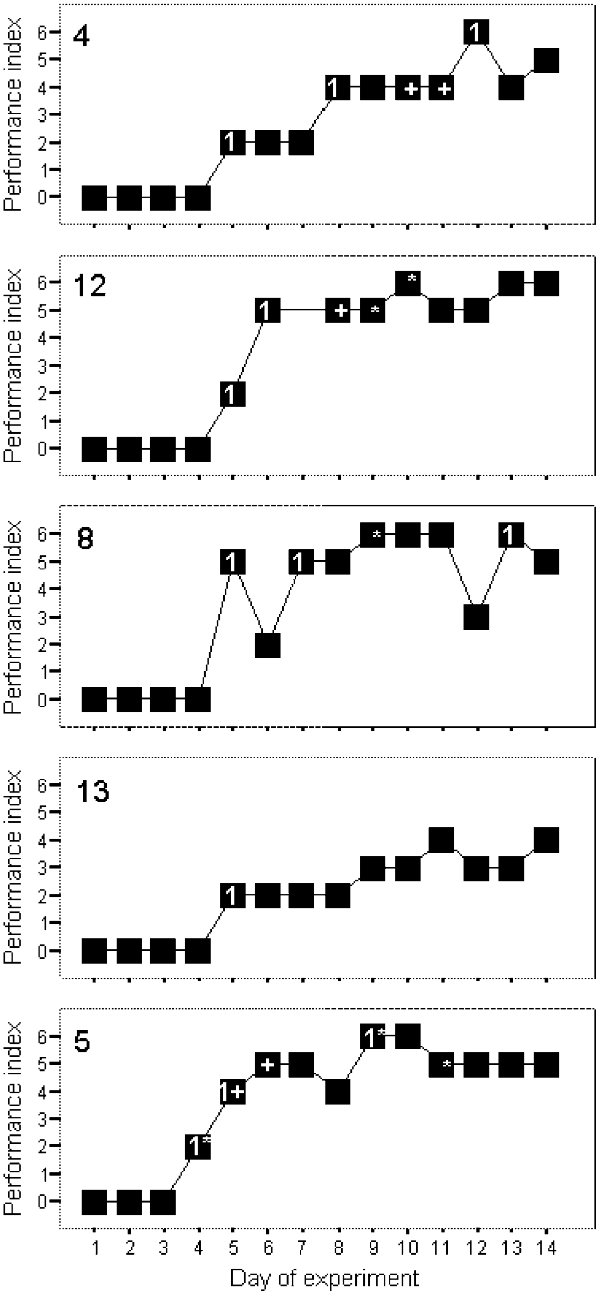

Fig. 2. Performance index on each day for each of the heifers. Numbers within squares indicate where the resulting learning index is 1. Asterices indicate that the heifer showed investigative or play-like behaviour towards the panel after the gate had opened. Plus signs indicate that the heifer went back into the race and investigated the gate after eating.

gate investigation after the heifer has eaten the food. Only one of the control group heifers showed such behaviour on one occasion.

The time taken to move down the race, from when a heifer's head was through the exit gate until it was in the food trough, ranged from 4 to 71 s. After a decrease from the first day, the values remained close to a median of 8 s. There was no difference between experimental and control animals (Wilcoxon signed-ranks test: $T = 9$, $N = 5$, $P = 0.81$), and the differences in speed between experimental and control heifers within matched pairs were not influenced by the binary learning index ($T = 12$, $N = 5$, $P = 0.32$).

The main gait when moving down the race was walk in 88 cases (74%), trot in 26 cases (22%), and gallop in 5 cases (4%). The distribution of the gait index was thus strongly skewed towards lower values. It was not correlated with the speed when moving down the race (Spearman rank correlation: $r_s = -0.05$, $N = 112$, $P = 0.59$). Gait scores increased over the experiment (Page test: $L = 1232$, $k = 7$, $N = 10$, $P < 0.001$), but they did not differ between experimental and control groups (Wilcoxon signed-ranks test: $T = 10$, $N = 5$, $P = 0.63$). There was a trend for a relationship ($T = 15$, $N = 5$, $P = 0.062$) between the binary learning index and the pairwise differences in gait scores between the experimental and control heifers: when the learning index was 1, the experimental heifers tended to be more likely to score higher than their matched controls, than when it was 0. Jumping occurred in five cases: heifer 4 on day 13, heifer 12 on days 6 and 12, heifer 8 on day 2 and heifer 5 on day 5; bucking in three cases: heifers 12 and 5 on the same occasions as when they jumped; and kicking in one case: heifer 4 on day 6 (see Fig. 2 for comparison with their learning curves). In the control group, neither jumping, bucking or kicking occurred on any occasion.

Individuals' median heart rate values differed but were not correlated with body weight or age. There were no overall treatment group differences (Wilcoxon signed-ranks test: $T = 8$, $N = 5$, $P = 0.89$). Heart rate varied across functional phases (Friedman two-way

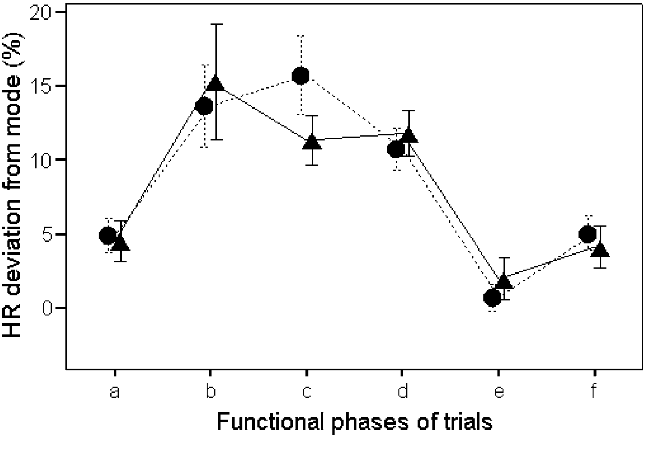

Fig. 3. Deviation of heart rate from mode (mean percentage ± S.E.) pooled over days for experimental (▲, solid line) and control (●, dashed line) groups, in the functional phases of the experiment: a, up to 15 s before gate opens; b, last 15 s before gate opens; c, first 10 s after gate has opened; d, 10–20 s after gate has opened; e, while eating reward; f, after eating.

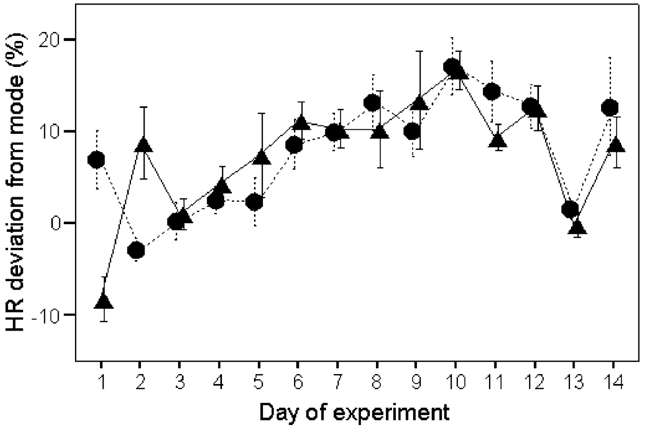

Fig. 4. Deviation of heart rate from mode (mean percentage ± S.E.) pooled over functional phases for experimental (▲, solid line) and control (●, dashed line) groups, on each day of the experiment.

analysis of variance: $F_r = 33.7$, d.f. $= 5$, $N = 10$, $P < 0.001$; Fig. 3) and increased with time (days of the experiment) in the control group (Spearman rank correlation: $r_s = 0.48$, $N = 60$, $P < 0.001$), with a trend for increase in the experimental group ($r_s = 0.25$, $N = 60$, $P = 0.055$). Inspection of Fig. 4 shows that the groups only differed on the first 2 days, and that the relationship between heart rate and time was relatively linear from day 3 to day 11.

Heart rate while, and shortly after, going down the race was not correlated with the number of seconds taken to go down the race (Spearman rank correlation: $r_s = 0.10$, $N = 54$, $P = 0.46$ for control group in phase c; $r_s = 0.04$, $N = 48$, $P = 0.80$ for experimental group in phase c; $r_s = 0.22$, $N = 55$, $P = 0.12$ for control group in phase d;

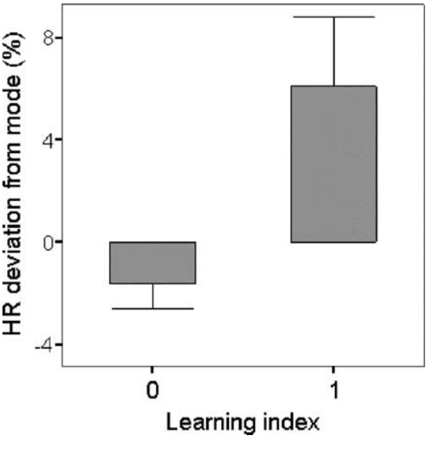

Fig. 5. Pairwise differences in deviation of heart rate from mode (mean percentage ± S.E.) in relation to the learning index for experimental heifers.

$r_s = -0.08$, $N = 49$, $P = 0.59$ for experimental group in phase d). It did correlate weakly with the gait index in the control group ($r_s = 0.31$, $N = 52$, $P = 0.026$ for control group in phase c; $r_s = 0.07$, $N = 52$, $P = 0.23$ for experimental group in phase c; $r_s = 0.36$, $N = 52$, $P = 0.019$ for control group in phase d; $r_s = 0.17$, $N = 53$, $P = 0.23$ for experimental group in phase d). A stronger correlation was found between gait index and heart rate for both groups in phase b, i.e. just before the gait opened ($r_s = 0.46$, $N = 52$, $P = 0.001$ for control group; $r_s = 0.31$, $N = 52$, $P = 0.024$ for experimental group).

Nine extreme values (heart rate deviation of more than 50%) were excluded to achieve a normal distribution of residuals in the general mixed model for effects on the differences in heart rate deviation between experimental group and control group. The only significant factor in the fitted model was the learning index (ANOVA: $F_{1,286} = 6.98$, $P = 0.0087$, Fig. 5).

4. Discussion

Five of the six experimental heifers acquired the operant tasks and reached levels of reliable and quick performance within 12 trials. This ease of training cattle to operant tasks, provided that they are not scared, is in line with previous findings (Kiley-Worthington and Randle, 1998).

As the heifers had no prior experience of the start box and maze, it is not surprising that on their first trials they took longer to go down the race than on subsequent trials. In the later course of the experiment, speed remained stable and was not correlated with the gait index, which increased in both treatment groups. On days when learning performance increased, heifers tended to have higher gait scores than their matched controls. Jumps, bucks and kicks only occurred in the experimental group. Taken together, the behaviours while moving down the race indicate more agitation in the experimental group when the learning curve was steep.

Heart rate dropped in the two groups on days 1 and 2, respectively, and then rose in both groups until day 11. This may reflect the stress of habituation to the learning apparatus, in similar way as has been observed in the context of visual discrimination learning in dwarf goats (Langbein et al., 2003), although in their case, a similar tendency was observed not during learning itself, but in periods of rest between learning sessions. In our study, heart rate also varied with functional phases, with peaks around the time of the main locomotor activity and a low during eating, reflecting the amount of movement. However, heart rate was only weakly correlated with the gait index. Metabolic activity could therefore not explain the variation in heart rate. Pairwise differences between experimental heifers and their matched controls with regard to heart rate deviation from individual mode were greater when the learning index was 1, than when it was 0. This indicates that there was a treatment effect on heart rate which corresponds to the effect on movement.

The experimental animals got more excited than the control animals, not generally, but in a temporal relation to the only difference between the groups: that the experimental heifers experienced an operant learning process whereas the control heifers did not. There are two possible explanations for this result. Firstly, in line with the hypothesis that we addressed, the experimental heifers were reacting to their own learning process and thus in a sense to their own achievement. Secondly, it could also be argued that increased arousal or motivational levels occurred randomly, but led to better performance. We speculate that the arousal leading to improved performance may well be the result of a process of understanding after the previous trial, rather than occurring randomly.

The investigation of non-verbal 'self' and of consciousness in animals and in infants have been focused on cognitive abilities and self-recognition in mirrors (Marten and Psarakos, 1995; Mitchell, 1997; De Veer and Van den Bos, 1999; Shillito et al., 1999; Swartz et al., 1999). In the light of theories of self-consciousness that make attempts at explaining its evolution and ontogeny in terms of emotional and bodily responses rather than cognition only (Neisser, 1991, 1997; Bermúdez et al., 1995; Bermúdez, 1998; Damasio, 2000), there is a challenge to devise alternative empirical approaches (Rochat and Hespos, 1997; Rochat and Goubet, 2000). The present study represents an attempt at establishing such an approach to investigating ways in which there may be non-verbal self-referral, as there would be in the emotional response to one's own understanding.

One assumption underlying the experimental design was that the operant acquisition task involved such a process of understanding. However, the yoked control design is not in itself sufficient to demonstrate instrumental learning (Church, 1988; Church et al., 1989). The idea of a process agency, and of understanding the causal connection between a response and a reward, can be accommodated in theories of goal-directed action and incentive learning (Dickinson and Balleine, 1994). Further investigation of emotional reactions to learning would involve validation of the instrumental nature of the learning process.

To our knowledge, our experimental approach to investigate whether animals might respond emotionally to a process of understanding, has not been used before. The yoked control design was first used to show that rats with control over the termination of electric shocks developed fewer stomach ulcers than their yoked controls (reviewed by Drugan et al., 1997). In the present experiment, the purpose was to control for all variables that might influence emotional responses other than the learning process.

In conclusion, the yoked control design was effective to some extent in separating the effects of the operant learning process from other variables like habituation and expectation of reward. The study indicated that cattle might be more agitated when they are just about to acquire a task, i.e. understand, and thus that they may have an emotional perspective on their own agency. However, because of the novelty of the approach and the small number of animals, this study should be seen as a first step towards further investigation of the topic.

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