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Modelling the dynamic response of cattle heart rate during loading for transport

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Abstract

Researchers in animal welfare and transport use heart rate (HR) as an important parameter to describe animal response to emotional and physical stresses. This study examined the dynamic HR response in cows to stress-inducing factors during loading for transport. The simulation model was developed using Powersim software via application of exponential function to describe the pattern of HR signals during loading. The model was tested on HR data of 18 cattle (11 heifers aged 14-16 months and 7 cows aged 2-3 years) and it described the HR profile well. The mean coefficient of determination, R^2, was found to be 0.89 $\pm$ 0.06. The HR rose exponentially from its mean resting value to a peak value (about 1.9 times the value at resting level) and then declined during a recovery period (about 1.15 times the value at resting level). The mean HR at resting condition, peak, and after recovery was 80$\pm$6 bpm, 136$\pm$35 bpm and 91$\pm$19 bpm for heifers and 47$\pm$4 bpm, 102$\pm$27 bpm, and 55$\pm$12 bpm for cows, respectively. The rate of increase in HR (during rising period) was greater than the rate of decrease during the recovery period. In all HR data sets, it was noticed that HR reduced immediately after it attained the peak value.

Keywords: Heart rate, cattle, loading, simulation model, Powersim, exponential function.
Abbreviations: t_time in s; HR_ heart rate in bpm (beat per minute); HR_{rest}_heart rate at resting condition; HR_{max}_peak heart rate value; HR_{rec}_recovered heart rate; A_1_amplitude of the rising heart rate in bpm; A_2_amplitude of the decreasing heart rate in bpm; T_1_time of rising period in s; T_2_time of recovery period in s; r_1_parameter describing growth rate of heart rate in s^{-1} ; r_2_parameter describing the recovery rate of heart rate in s^{-1}; R_2_coeficient of determination; DDE_dynamic data exchange.

Introduction

Animals are transported for different purposes, such as slaughter, fattening and breeding (Gebresenbet et al., 2011). Cattle transport has been increasing steadily in recent decades, both on national and international level, as a result of structural adjustments and increasing market globalisation (Gebresenbet and Ericsson, 1998). During transport and handling, animals are subjected to a series of stress-inducing factors. Loading and unloading have been identified, using animal heart rate (HR) measurements, as the main stress moments for animals (Kenny and Tarrant, 1987; Gebresenbet and Ericsson, 1998; Scientific Committee, 2002). The alterations in HR due to loading processes are the result of: (1) physical activities as animals mount ramps with a steep slope, and (2) emotional stress as animals are forced to leave their familiar surroundings and enter the vehicle (Stewart et al., 2003; Zakynthinaki and Stirling, 2006; Gebresenbet et al., 2010). In relation to physical activities, by measuring HR and oxygen consumption simultaneously, previous studies confirmed that the increase in HR is proportional to the energy requirement. Rometsch and Becker (1993) and O'Neil and Kemp (1989) studied the HR response of oxen to draught work and concluded that it correlated well with draught force (R=0.80) and draught power (R= 0.67). Doherty et al. (1997) studied HR and energy expenditure by ponies during transport and found that the physical exertion on the animals could be quantified by directly measuring their oxygen expenditure. They also found a strong correlation between HR measurements and energy expenditure. Ruiz-de-La-Torre et al. (2001) found that transport of sheep by vehicle on rough secondary roads was more stressful for the animals than journeys on smooth roads, resulting in a HR increase with greater energy expenditure. There was also evidence that this greater energy expenditure, during a rough journey to the slaughterhouse, had a harmful effect on meat quality of the sheep. Unlike the case of physical activities, it is difficult to determine the functional relationship between HR and emotional stress. In previous studies (Gebresenbet et al., 2006), it was found that when animals adapted to their new conditions, their elevated HR decreased back to the resting level, but when no such adaptation took place the animal remained under stressful conditions. Figure 1 shows the HR profiles of three cattle before loading, during loading and transport. After loading, the HR of the two animals resumed the same level as before loading, while the HR of the third animal remained higher than the resting level. Thus, the HR of the third animal did not fully recover, and this indicated that either the animal was under stress condition or exposed to more physical activities during loading. Heart rate profiles are dynamic, non-linear or even chaotic (Haque et al., 2001). In the case of signals such as HR measurements, the amplitude and rate of oscillation of the component parts of a signal vary with time (Marchant, 2003), rendering such signals complicated to analyse. Based on the assumption that non-linear model structures provide a more complete description, various non-linear techniques have been devised to analyse HR variability under different experimental

Table1. Parameter values noted from recorded data*

Subject**	HR_{rest}	HR_{max}	HR_{rec}	T_1	T_2
1	77	125	77	158	342
2	80	123	93	114	84
3	89	125	90	31	124
4	74	113	74	111	237
5	83	180	125	107	59
6	87	180	129	98	41
7	77	110	77	24	199
8	78	110	77	47	104
9	73	101	77	71	69
10	73	124	82	85	185
11	90	203	95	205	765
12	57	155	80	310	540
13	47	107	53	99	301
14	46	114	58	117	123
15	44	85	44	204	176
16	45	81	51	48	122
17	46	97	52	60	217
18	47	76	48	19	116
All subjects Mean	67	123	77	106	211
±SD	17	35	24	75	184
11 heifer	80	136	91	96	201
Mean ±SD	6	35	19	54	208
7 cows	47	102	55	122	228
Mean ±SD	4	27	12	102	153

*All parameters are as indicated under description of Abbreviations on the first page. ** Subject 1- Subject 11 are heifers while subject 12- Subject 18 are cows.

conditions. For example, in recent years changes in animal heart rate have been studied using time-frequency analysis modelling techniques such as Fourier Transform (FT), Auto-regressive (AR), Auto-regressive moving average (ARMA) and neural network (NN) (Haque et al., 2001; Marchant, 2003; Pichon et al., 2006). Aerts et al. (2008) used a single-input single-output linear discrete transfer function model to describe the dynamic response of horses' heart rate to speed during training. Some researchers used logistic and exponential functions to describe the pattern of human heart rate response during physical exercise (Christenfeld et al., 2000; Nijsen et al., 2006; Riley et al., 2006). Zakynthinaki et al. (2011) used stochastic optimization method to calculate the parameter values that optimally fit a dynamical systems model to the recorded heart rate data. In investigating such a dynamic, non-linear heart rate response, computer based simulation analysis can be used effectively. Van Elmpt et al. (2006) used Matlab software package to simulate the pattern of decaying HR from stress level to post- stress baseline by implementing a curve-fitting algorithm based on exponential decaying function. In the present study, an exponential function was used to develop a simulation model using Powersim simulation software which utilizes system dynamics method to model the system and simulate its behaviour over the required time window (Powersim Corporation, 1997). Previous researchers mainly used basic descriptors of animal HR, such as mean values of HR at resting, peak level and post-stress baseline, to assess the welfare of animals. However, little emphasis has been placed on the dynamic aspect of HR response, i.e. the rate of increase or decrease in HR when animals are subjected to stress conditions such as loading and unloading on to vehicles.

The aim of this study was to investigate the dynamic HR responses of heifers and cows during loading for transport, and to describe the HR time series using a dynamic simulation model. Such simulation analysis is useful to understand the dynamic nature of the increasing and declining rate of HR during loading the cattle on to vehicle. It provides a clearer explanation than relying only on mean values of HR signals.

Materials and methods

Animals

A field experiment was carried out using 18 cattle (11 heifers and 7 cows). The cattle were transported from two farms to the abattoir. The age of heifers varied from 14 to 16 months, and the age of cows varied from 2 to 3 years. All animals were Swedish red breed.

Heart rate measurements

The instrument package manufactured by Polar Electro Oy, in Finland, was used for the HR instrumentations (Gebresenbet et al., 2010). It consisted of two main components, a sensor/transmitter and a wrist receiver. The sensor was mounted as illustrated in Figure 2(A). The sensor transmits the heart rate of animals to the receiver wirelessly and was attached to an adjustable strap and fitted on the animals (see Figure 2(B)). To ensure contact between the skin and the sensor and avoid signal interruptions, the band was moistened and a gel (Lectro Derm) was used on the belt and skin of the animals before fitting. The data stored in the

Table 2. Parameter values determined during simulation experiment*

Subject**	A_1	A_2	A_3	r_1	r_2	R^2
1	48	48	0	0.014	0.010	0.89
2	43	30	13	0.016	0.049	0.91
3	36	35	1	0.079	0.024	0.81
4	39	39	0	0.050	0.009	0.72
5	97	55	42	0.021	0.044	0.96
6	93	51	42	0.020	0.032	0.92
7	33	33	0	0.083	0.013	0.91
8	32	32	0	0.096	0.026	0.89
9	28	24	4	0.035	0.029	0.90
10	51	42	9	0.022	0.014	0.93
11	113	108	5	0.014	0.003	0.94
12	100	75	25	0.008	0.005	0.94
13	60	54	6	0.033	0.007	0.88
14	68	56	12	0.016	0.025	0.88
15	41	41	0	0.008	0.012	0.85
16	36	30	6	0.087	0.042	0.90
17	51	45	6	0.049	0.011	0.93
18	29	28	1	0.115	0.038	0.93
All subjects	55	46	10	0.043	0.022	0.89
Mean						
±SD	27	20	13	0.034	0.015	0.06
11 heifer	56	45	11	0.041	0.023	0.89
Mean	30	23	16	0.031	0.015	0.07
±SD						
7 cows	55	47	8	0.045	0.020	0.90
Mean	23	16	8	0.042	0.015	0.03
±SD						

* All parameters are as indicated under description of Abbreviations on the first page.
** Subject 1- Subject 11 are heifers while Subject 12- Subject 18 are cows.

receiver were uploaded with a PC interface unit. Measurement of HR started before loading to obtain data on HR at resting conditions and continued until the end of loading activities. The HR data were recorded on a beat-to-beat basis. It was noticed that fitting the strap influenced the HR at the beginning, so the animals were allowed to rest after the sensor was fitted, before the loading started. The loading condition was similar for all subjects.

Building a Model

Mathematical function

The profile of time series of heart rate of heifers and cows during loading was observed to increase to peak value and decreased during recovery period (Gebresenbet, 2006). HR is the function of time and stress level. Since the rate of change of HR is a function of time (t), it could be written as:

$$\frac{d}{dt} HR = r * HR(t)$$
(1)

where r is the change in heart rate in a unit time (i.e. rate of increase or decrease). The solution to this could be:

$$HR(t) = A * e^{rt}$$
(2)

where A denotes the amplitude of HR in the rising or decreasing period and *e* is the base of natural logarithm (Barnes and Fulford, 2009). Using figure 3 and the above equation the following mathematical expression could be formulated to describe the pattern of HR signals during loading.

$$HR(t) = \begin{cases} HRrest + A_1 * e^{r_1(t-T_1)} \ldots\ldots\ldots\ldots\ldots\ldots t \le T_1 \\ HRrec + A_2 * e^{-r_2(t-T_1)} \ldots\ldots\ldots\ldots\ldots\ldots t \ge T_1 \end{cases}$$
(3)

Where HR(t) is a dependent variable, heart rate at time t (time t is independent variable) (see Abbreviations and Figure 3).
A_1 and A_2, can be determined as:

$$A_1 = HR_{\max} - HR_{rest}$$
(4)

$$A_2 = HR_{\max} - HR_{rec}$$
(5)

$$A_3 = HR_{rec} - HR_{rest}$$
(6)

Where HR_{max} is the recorded peak HR value (refer to Abbreviations).

Powersim Software

The Powersim software package was used to build the simulation model, using the aforementioned mathematical functions. It is windows-based software for creating system

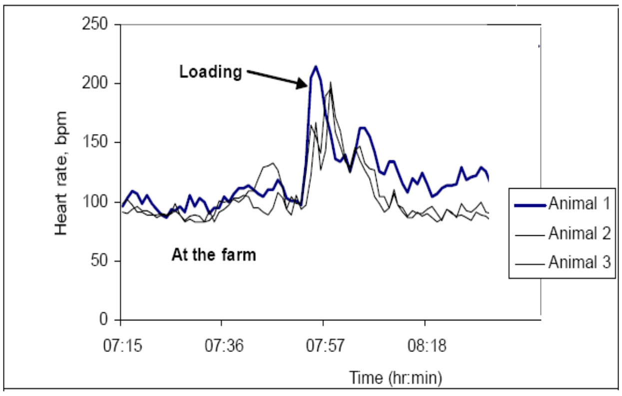
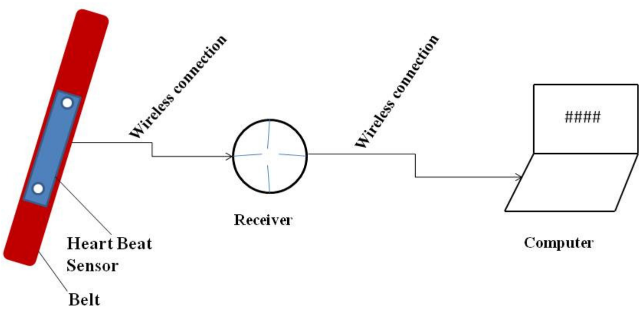


Fig 1. Animal heart rate profiles of three bulls during loading: Animal 1 remained relatively under stress after loading while animals 2 and 3 adapted 100% to the stressful conditions induced due to loading and related activities. Adopted from Gebresenbet (2006)

A. Heart rate sensors and receivers mounted on cows



B. Schematic illustration of heart beat recording process

Fig2. Illustration of heart beat recording process. (A) illustrates how the instrument is mounted on a cow . (B) illustrates how heart rate data is recorded and transferred to computer for analysis

dynamics models. It is a product of Powersim Corporation based in Norway and an object-oriented package that is used for hierarchical modeling with an unlimited depth of sub models. Its packages allow for the on-screen construction of a flow-chart style representation of a simulation model (Powersim Corporation, 1997). The intractable model was developed using dynamic data exchange (DDE) tool of Powersim enabling successful transfer of recorded heart rate from spreadsheet to Powersim.

Model verification and validation

In order to verify and validate the model, 18 data sets were used (see Tables 1 and Table 2). The HR data set of subject-1 was used to test the model and make adjustments as part of model verification. After verifying that the simulation model was able to provide realistic output that describes the general pattern of cow HR response to loading activity, the model was evaluated using the remaining 17 data sets. In this process, HR-related model parameters such as HR_{rest}, HR_{rec} and HR_{max} were first obtained from recorded data. A simulation experiment was then conducted, and the simulated signals over the entire time window were compared with the profile of the recorded data. In this validation process, the coefficient of determination, R^2, was determined and used to measure the accuracy of fitness of the simulated values to the measured HR data (see Table 1). Moreover, the capacity of Powersim software to present the simulation results in graphs was used to visualise the fitness of the model during each simulation trial. Before verifying the model, the raw data was edited by excluding such occasional errant data points from the data series. This can be done by omitting points with values greater than 6 to 10 (for example) times standard deviations from the local mean value (Zakynthinaki and Stirling , 2007). In this study, the raw data was smoothed using moving average data filtering technique with interval of 5 data points.

Estimating Parameters

The curve described by the simulated HR values is considered to be the best fit to the recorded data curve if the sum of residuals is minimum (Stirling et al., 2008). This is an optimization problem where the values of model parameters can be determined using least square technique. For this purpose, PowerOpt, a package that works interactively with Powersim software, was extensively used for determining the model parameter values during model fitting. PowerOpt could search parameter values that result in best fit based on appropriate estimate of the initial values. The task was to achieve a best fit via minimizing the sum of residuals and modifying the shape of the curve provided by the model i.e. by changing the values of variables, r_1 and r_2. The charts of heart rate data and simulated value of heart rate were used to make possible the visualization of model fitting during each simulation. Other model parameters, HR_{rest}, HR_{max}, HR_{rec}, T_1, and T_2 were determined from the recorded heart rate data. A_1, A_2 and A_3 were determined using equations 2, 3 and 4. The performance of the model was quantified by calculating the coefficient of determination, R^2, between the recorded and simulated heart rate data sets and it was determined for each data set of the 18 subjects (see Table 1).

Results

Recorded data

From the recorded HR data, HR_{rest}, HR_{max} and HR_{rec} were noted from all data sets. In Table 1 it is presented that, for the 11 heifers (subject1-subject11), the value of HR_{rest} varied

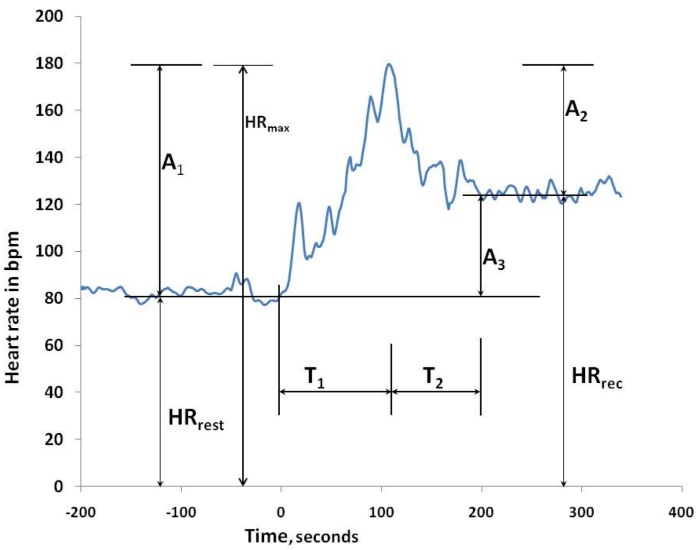


Fig3. Graphical illustration of parameters. $HR_{rest\_}$ heart rate at resting condition in ; $HR_{max\_}$ peak heart rate value; $HR_{rec\_}$ recovered heart rate in; $A_{1\_}$ amplitude of the rising heart rate in; $A_{2\_}$ amplitude of the decreasing heart rate in; A3_the difference between HR_{rec} and HR_{rest}; $T_{1_}$time of rising period; $T_{2\_}$ time of recovery period

from 73bpm - 90 bpm with a mean (±SD) value of 80±6 bpm. The HR_{rec} value was 91 ± 19 bpm (ranging from 77-129 bpm) while HR_{max} was 136 ± 35 bpm (ranging from 101-203 bpm). For the 7 cows (subject12-subject18), HR_{rest} varied from 44-57 bpm with mean value of 47±4 bpm. HR_{rec} was 55±12 bpm (ranging from 44-80 bpm) while HR_{max} was 102±27 bpm (ranging from 76-155 bpm). The values of the two time parameters, T_1 and T_2 were also noted from the recorded data sets of the 18 subjects. The value of T_1 was 106 ± 75 seconds (ranging from 24 - 310 seconds) and T_2 was 211±184 seconds (ranging from 41 to 540 seconds).

Simulated data

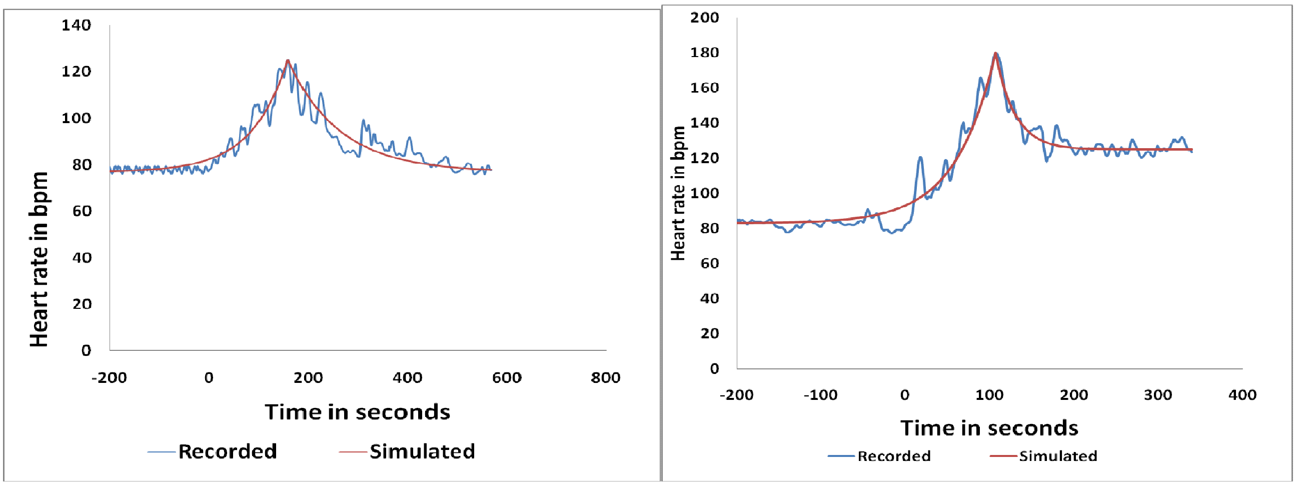
Table 2 presents the values of the parameters determined for each subject during the simulation experiment. Parameters A_1, A_2 and A_3 were determined using equations (4), (5) and (6). Considering all together, for the heifers and cows, the amplitude A_1 was 55 ± 27 bpm and A_2 was 46 ± 20 bpm. A_3 indicates the difference between the rising and falling amplitudes. Its value varied from 0-42 bpm. The relationship between A_1 and A_3 was investigated and it was noticed that A_3 increases with an increase of A_1 (see Figure 3). High A_3 value suggests that the animal was under more stress condition and HR did not fully recover to the resting level. The two parameters describing the rising rate (r_1) and recovery rate (r_2) of HR were determined with PowerOpt (see section 2.3). For the 18 subjects, the mean value of r_1 was 0.043 ± 0.034 (ranging from 0.008 to 0.115) while the value of r_2 was 0.022 ± 0.015 (ranging from 0.003 to 0.049) (see Table 2). The R^2 value was determined in order to compare the simulated signals to the measured values and its value was 0.89 ± 0.06 (see Table 2).

Some remarks on recorded and simulated parameters

The model could simulate the pattern of the heart rate response. During simulation it was noticed that the simulated values of HR_{rest}, HR_{max} and HR_{rec} were almost the same to the recorded values for each subject. It was also observed that, although the values of HR_{rest}, HR_{max} and HR_{rec} varied for different subjects, the general pattern of the heart rate response was the same for the heifers and cows. Typical graphical presentations of the measured and predicted HR signals are shown in Figure 4a and 4b. There is no significant difference between the mean values of R^2 for data of heifers and cows. For some animals, A_3 value was zero, indicating that the heart rate of the animal was fully recovered. In general, during stress, the HR was raised from its mean value at resting to about 1.9 times the value at resting level. During the recovery period, HR declined and maintained steady state at HR_{rec} value, which was 1.15 times the resting value, on average. The relationships between r_1 and T_1, and between r_2 and T_2 were also assessed and noted to be nonlinear. The values of r_1 and r_2 decreased as T_1 and T_2 increased (Figure 5). In general, it was noticed that the mean r_1 value was nearly twice the r_2 value for both heifers and cows. This indicated that the heart rate rose more rapidly and recovered slowly.

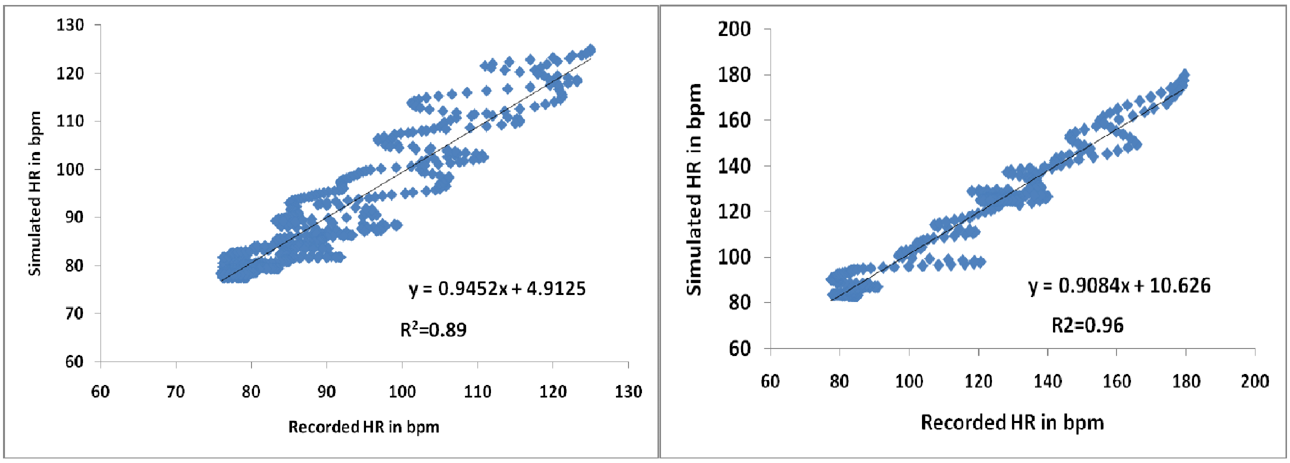
Discussion

The HR simulation model, developed in this study, could describe the dynamic heart rate response of cows during loading. The model simulates the heart rate of individual subject at any time within the time window of loading activity. The coefficient of determination (R^2) was determined for all the 18 individuals. For one of the animals the R^2 value was 0.72. For the remaining 17 animals, it was greater than 0.80, indicating that the model could describe well the dynamic HR response (see Figure 4c and 4d). Loading is one of the most stressful components of transportation for animals (Trunkfield and Broom, 1990; Waran and Cuddeford, 1995) and HR in animals tended to peak during loading (Stewart et al., 2003; Stirling et al., 2008). The result of this study confirmed this as the HR of cattle increased exponentially from resting value to peak value. Although the values of HR_{rest}, HR_{max} and HR_{rec} were higher for heifers than cows (see Table 1), the amplitude of the rising part of HR response (A1) was not significantly different for heifers and cows. Similarly the amplitude of the decaying part of HR response for heifers and cows was almost the same on average (see Table 1). In all cases it was observed that the HR value did not stayed at peak value. Once the peak value was attained it started decaying during the recovery period. It was observed that quick response of the cattle to stress could be assessed using this dynamic simulation model. Static measures may not be enough for capturing inherently dynamic processes. Mathematical models describing the transition from resting level to stress level (during heart rate increase) and from stress level to post-stress baseline (during recovery) appear to capture this dynamic process reliably (Christenfeld et al., 2000). HR_{max}, the highest heart rate value recorded during loading, does not necessarily indicate the maximum possible HR of the animal, but only the level to which HR rose due to the stress induced by loading. The maximum possible HR value in each data set would be greater than the HR_{max} value recorded during the experiment. After the peak value was attained, the HR started decaying without delay. However, the total recovery process took more time as could be observed from the value of T_2 which varied from 41 to 765 seconds and in some cases, the HR could not be recovered to the level of resting value (see Figure 4b). The value of A_3 (see equation 4) for each subject indicates the degree of adaptation of the animal to the



A. Recorded and simulated curves for Subject 1. The negative times indicate the time before loading.

B. Recorded and simulated curves for Subject 5. The negative Times indicate the time before loading



C. Regresion line and model for the entire data range of Subject 1

D. Regresion line and model for the entire data range of Subject 5

Fig 4. Curves of recorded and simulated heart rate values. (a) example of curves when the HR fully recovered: HR_{rest}=80, HR_{max}=125, HR_{rec}=77, A_1=48, A_2=48, A_3=0, T_1=158, T_2=342, r_1=0.014, r_2= 0.01; (b) example of curves when HR recovered partialy: HR_{rest}=83, HR_{max}=180, HR_{rec}=125, A_1=97, A_2=55, A_3=42, T_1=107, T_2=59, r_1=0.021, r_2=0.044. (c) and (d) examples of regresion lines between experiment and simulated data

stressful conditions. The smaller the A_3 value, the more the animal adapted to the new conditions. Seven of the 18 cows showed good adaptation, with 100% recovery in HR from the stress level to the resting level, whereas five animals did not adapt well in comparison to the remaining cows (see Table 1). Considering animals for which the HR recovered 100%, the recovery period (T_2) was about 197 seconds on average. This indicated that if there is no continuous stressor or physical activities in the vehicle, the animal could adapt to the loading condition within about 200 seconds of recovery period. The behavioural condition of the animal should be noted at resting condition before starting to load. Animals with experience of ill treatment might be more stressed during human handling and loading (Scientific Committee, 2002). Animal welfare is usually defined in reference to the adaptation ability of animals to cope with changes in environmental conditions (Gebresenbet et al., 2010). Accordingly, animals with smaller values of A_3 and T_2 adapted well, with nearly 100% recovery in HR from stress level to resting level. In contrast to this, subjects with greater values of A_3, T_1 and T_2 adapted less and stayed under stressful conditions for relatively long period of time. In general, during loading, the HR of animals responds to the physical activities and emotional stress. However, since there was no intensive physical exercise during the loading operations studied here, the increase in HR might be mainly related to emotional stress such as fear. Gebresenbet and Ericsson (1998) found that HR signals increase during loading and unloading, indicating the occurrence of strong stressors, and that these stressors might occur due to inexperienced animal handlers (time taken for loading) and the prior loading experience of the animal itself. Christenfeld et al. (2000) used logistic function to describe the dynamic nature of human HR recovery from stress level during physical task and indicated that using mathematical models in curve-fitting procedure could capture the dynamic nature of the process and analyse the entire range of data. The simulation model (based on non-linear systems) developed in

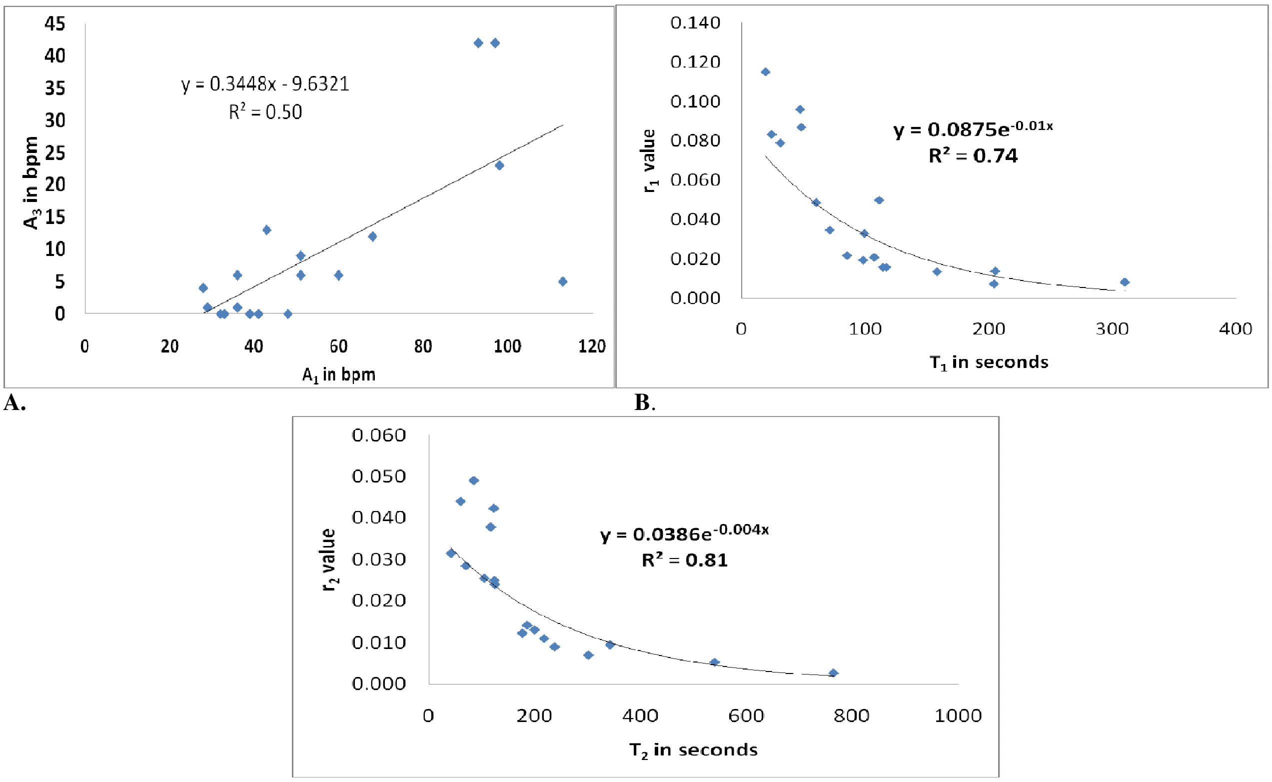


Fig 5. Relationship between parameters. (a) the A_3 increases as A_1 increases; (b) r_1 decreases as T_1 increases and (c) r_2 decreases as T_2 increases

this study, has potential advantages. It describes mathematically the dynamic nature of animal heart rate response during loading. It simulates and presents the curve that fits best to the entire data range (starting from resting period up to end of recovery period). It describes more reliably the transition from resting level to peak value and from stress level to post-stress baseline. Such a simulation model can also be useful for studying the relationship between the model parameters and stress parameters in the case of loading and lay foundation for further investigations. This may generate useful information for developing methods for loading and handling. Similar approach might be used to investigate the HR response of cattle during unloading from trucks as unloading is also one of most stressful procedure for cattle during animal transport (Trunkfield and Broom, 1990). In this study, the number of individuals was limited and further study on dynamic heart rate response of cattle to loading and unloading parts of transport can be conducted with more number of subjects.

Conclusions

A dynamic simulation model was developed using an exponential function and Powersim software package to study the dynamic heart rate (HR) response of cattle during loading. The model was able to simulate the trajectory of HR signals over the entire time window of loading process. The simulated data was correlated well to the recorded data with the coefficient of determination (R^2) of 0.89±0.06. The results showed that the HR of the animals increase exponentially from resting value to peak value and decreases exponentially from the HRmax to HR_{rec}. However the rate of rising was nearly twice the rate of decaying. The mean values of HR_{rest}, HR_{max} and HR_{rec} were 80±6 bpm, 136±35 bpm and 91±19 bpm for heifers and 47±4 bpm, 102±27 bpm, and 55±12 bpm for cows, respectively. In all cases, it was noticed that the HR value did not stay at its peak value during loading. Once the peak value was attained, it immediately started decaying.

References

Aerts J-M, Gebruers F, Van Camp E, Berckmans D (2008) Controlling horse heart rate as a basis for training improvement. Computers and electronics in agriculture 64:78-84.

Barnes B, Fulford GR (2009) Mathematical modelling with case studies: A Differential Equations Approach using Maple™ and MATLAB®, Second Edition, New York.

Christenfeld N, Glynn LM , Gerin W (2000) On the reliable assessment of cardiovascular recovery: An application of curve-fitting techniques. Psychophysiology 37:543-550.

Doherty O, Booth M, Waran N, Salthouse C, Cuddeford D (1997) Study of the heart rate and energy expenditure of ponies during transport. Veterinary Record 141:589-592.

Gebresenbet G, Ericson B (1998) Effects of transport and handling on animal welfare, meat quality and environment with special emphasis on tied cows. Swedish university of Agricultural Sciences, Project Report 33:1998.

Gebresenbet G, Kaumbutho PG, Simpkin P (2006) Work Performance and Physiological response of camels: Project

Report; Swedish University of Agricultural Sciences, Uppsala.

Gebresenbet G, Aradom S, Bulitta FS, Adam M (2010) Effect of Transport Time of up to 12 Hours on Animal Welfare. Project Report, Swedish University of Agricultural Sciences, Uppsala.

Gebresenbet G, Bosona TG, Ljungberg D, Aradom S (2011) Optimisation analysis of large and small-scale abattoirs in relation to animal transport and meat distribution. Australian Journal of Agricultural Engineering 2(2):31-39.

Haque MA, Hasan MK, Tazawa H (2001) Investigation of nonlinearity in the heart rate dynamics. Medical Engineering & Physics 23:111-115.

Kenny FJ, Tarrant PV (1987) The Reaction of Young Bulls to Short-Haul road Transport. Applied Animal Behaviour Science 17:209-227.

Marchant BP (2003) Time-frequency analysis for biosystems engineering. Biosystems Engineering 85(3):261-281.

Nijsen TME, Van Elmpt WJC, Griep PAM, Arends JBAM (2006) A model of heart rate changes to detect seizures in severe epilepsy. Seizure 15:366-375

Oneill DH, Kemp DC (1989) A comparison of work outputs of draught oxen. Journal of Agricultural Engineering Research 43:33-44.

Pichon A, Roulaud M, Antoine-Jonville S, Bisschop C, Denjean A (2006) Spectral analysis of heart rate variability: interchange ability between autoregressive analysis and fast Fourier transform. Journal of Electrocardiology 39: 31-37.

Powersim Corporation (1997). User Guide of Powersim Constructor 2.5, version 2.5(d), Norway.

Riley MS, Po´rsza´sz J, Engelen MPKJ, Shapiro SM, Brundage BH, Wasserman K (2006) Responses to constant work rate bicycle ergometry exercise in primary pulmonary hypertension: The Effect of Inhaled Nitric Oxide. Journal of the American College of Cardiology 36 (2): 547-556

Rometsch M, Becker K (1993) Determination of the reaction of heart rate of oxen to draught work with a portable data-acquisition system. Journal of Agricultural Engineering Research 54:29-36.

Ruiz-De-La-Torre JL, Velarde A, Diestre A, Gispert M, Hall SJG, Broom D M, Manteca X (2001) Effects of vehicle movements during transport on the stress responses and meat quality of sheep. Veterinary Record 148: 227-229.

Scientific Committee (2002) The Welfare of Animals During Rransport. Report of the Scientific Committee on Animal Health and Animal Welfare, adopted by European Commission: 24-36.

Stewart M, Foster TM, Waas JR (2003) The effects of air transport on the behaviour and heart rate of horses. Applied Animal Behaviour Science 80:143- 160.

Stirling JR, Zakynthinaki M, Refoyo I, Sampedro J (2008) A model of heart rate kinetics in response to exercise. Journal of Nonlinear Mathematical Physics 3: 426-436.

Trunkfield HR, Broom DM (1990) The welfare of calves during handling and transport. Applied Animal Behaviour Science 28:135-152.

Van Elmpt WJC, Nijsen TME, Griep PAM, Arends JBAM (2006) A model of heart rate changes to detect seizures in severe epilepsy. Seizure 15: 366-375.

Waran NK, Cuddeford D (1995) Effects of loading and transport on the heart rate and behavior of horses. Applied Animal Behaviour Science 43:71-81.

Zakynthinaki MS, Stirling JR (2006) Stochastic Optimization for modeling physiological time series: application to the heart rate response to exercise. Computer Physics Communications 176: 98-108.

Zakynthinaki MS, Barakat RO, Martínez CAC, Molinuevo JS (2011) Stochastic optimization for the detection of changes in maternal heart rate kinetics during pregnancy. Computer Physics Communications 182:683-691.