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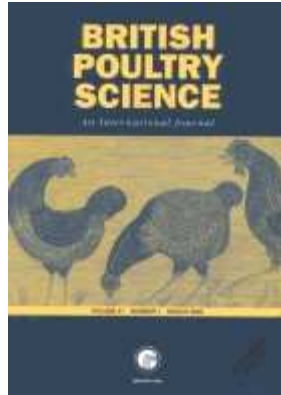
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Circadian variation in heart rate, blood pressure, body temperature and EEG of immature broiler breeder chickens in restricted-fed and *ad libitum*-fed states

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4 **Abstract** 1. Heart rate, intra-aortic blood pressure, deep body temperature and telencephalic EEG
5 were monitored by radiotelemetry in 6 freely moving immature broiler breeders (3 in each of two
6 years), during routine food restriction and then *ad libitum* feeding, over two 24-h periods in each
7 feeding state.
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10 2. Heart rate, blood pressure and body temperature were all higher during *ad libitum* than restricted
11 feeding, and heart rate and body temperature were higher by day (12 h) than at night (12 h). The
12 decreases in heart rate and body temperature at night were greater during restricted than *ad libitum*
13 feeding. Blood pressure tended to be higher at night, except in year 2 during restricted feeding.
14 Body temperature and ambient temperature were higher in year 2 than year 1.
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17 3. During restricted feeding, marked peaks in heart rate, blood pressure and body temperature in the
18 15 min after provision of the daily food ration at 09:00 h, when birds were eating, were equivalent
19 to corresponding values seen during *ad libitum* feeding.
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22 4. Relative powers in delta (1-4 Hz) and theta (4-8 Hz) frequency bands of the EEG power
23 spectrum were higher at night in year 2 only, while power in the alpha (8-12 Hz) band was higher at
24 night in both years.
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27 5. It is concluded that most of the variation in heart rate, blood pressure and body temperature
28 between feeding states and times of day/night can be accounted for in terms of variation in food
29 intake and energy expenditure. The greater slow wave (delta, theta) EEG activity seen after lights-
30 off in year 2 may reflect non-paradoxical sleep at that time.
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32 INTRODUCTION

33
34 In commercial conditions, all growing broiler breeder chickens are fed on quantitatively restricted
35 rations in order to limit their body weight at sexual maturity and thereby improve health and
36 reproductive performance (Hocking *et al.*, 1989). Female birds fed on such recommended rations,
37 which are usually provided once a day and eaten in <10 min, typically eat only a third as much as
38 they would with free access to food, and are highly motivated to feed at all times (Savory *et al.*,
39 1993). They are much more active than unrestricted birds, and (unlike the latter) show increased
40 pacing and oral behaviours that are characteristic of frustration of feeding motivation (Duncan and
41 Wood-Gush, 1972; Kostal *et al.*, 1992; Savory and Maros, 1993).
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44 Evidence suggests that such apparently abnormal behaviours may be associated with de-
45 arousal and perhaps serve a coping function (Delius, 1967; Hutt and Hutt, 1970; Dantzer and
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Mormede, 1983; Soussignan and Koch, 1985). To address this possibility, which is potentially important in animal welfare terms, a commercially available radiotelemetry system (Data Sciences International, USA) was applied successfully in the (freely moving) chicken for chronic measurement of heart rate, intra-aortic blood pressure, deep body temperature and telencephalic EEG as putative physiological indices of arousal (Savory and Kostal, 1997). By combining this technology with simultaneous videorecording, these parameters were related to ongoing behaviour in 6 restricted-fed immature female broiler breeders. Results obtained were consistent with the idea that apparently abnormal behaviour is related to arousal state in a homeostatic way, being both stimulated by it and reducing it (Savory and Kostal, in press).

An additional purpose of this same study was to compare heart rate, blood pressure, body temperature and EEG between daytime and night-time, and between restricted-fed and *ad libitum*-fed states. This was done by switching the 6 birds onto *ad libitum* feeding immediately after they were monitored during food restriction, and then monitoring them again two weeks later. The results of these further comparisons are presented here. A similar approach was taken in another recent study, where heart rate and body temperature were measured over periods of 36 h in restricted-fed and *ad libitum*-fed broiler breeders (de Jong *et al.*, 2002). However, in that work, blood pressure and EEG were not measured, heart rate and body temperature were regarded as stress parameters rather than as indices of arousal, no attention was given to the influence of feeding time during food restriction and there was uncertainty regarding interpretation of results. Here, we conclude that variations in heart rate, blood pressure and body temperature, between feeding states and times of day/night, are associated more closely with variation in food intake and energy expenditure than with either physiological stress or arousal.

MATERIALS AND METHODS

Subjects and husbandry

In each of two successive years, 3 female broiler breeders (Ross 308, Aviagen Limited, UK) were reared in larger groups (of 32 and 13 birds) in floor pens according to a recommended restricted feeding programme (Ross Breeders, 1995). They were fed on a standard layer “starter” diet (201 g/kg crude protein and 11.7 MJ/kg metabolisable energy) for the first 6 weeks of life (in mash form first, then as pellets), and layer “grower” pellets (164 g/kg crude protein and 11.8 MJ/kg

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3 metabolisable energy) thereafter. Lights were on from 07:00 to 19:00 h, the daily ration was
4 provided at 09:00 h and water was available *ad libitum*.
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7 At 11 weeks of age, they were housed individually in 3 adjacent cages measuring 36 cm x 46 cm
8 x 52 cm (w x d x h), in a room where lights were on from 07:00 to 19:00 h and ambient temperature
9 was maintained at about 22 °C. Hardboard panels between the cages prevented birds seeing each
10 other except when they had their heads out of the fronts. Each cage had a food container, water
11 container and radiotelemetry receiver. The 3 receivers were linked to a computer with installed data
12 acquisition card and Dataquest LabPRO software (version 3.0, Data Sciences International, USA)
13 for acquisition and analysis of data (see Savory and Kostal (1997) for details). The daily ration of
14 grower pellets (60 g per bird, all eaten in <10 min) was provided at 09:00 h, when water containers
15 (1 litre) were also filled.
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23 **Radiotelemetry implantation**

24 At 13 (year 1) and 12 (year 2) weeks of age, when mean body weights were $1.27 \pm \text{SE } 0.04$ and 1.32
25 ± 0.03 kg respectively, each bird had a radiotelemetry transmitter (type TL11M2-C50-PXT, Data
26 Sciences International, USA) implanted surgically under halothane anaesthesia (Savory and Kostal,
27 1997), to allow monitoring of heart rate, intra-aortic blood pressure, deep body temperature and
28 telencephalic EEG. The tip of the device's pressure sensing catheter was introduced into the
29 descending aorta *via* a leg (ischiodic) artery and, although the catheter was tied in place, circulation
30 in the leg was maintained through collateral arteries and leg function was not impaired. EEG was
31 recorded from the device's paired sensing electrodes positioned on the surface of the telencephalon
32 (using stereotaxic apparatus), the electrode leads being passed under the skin and held in place on
33 the posterior skull with dental acrylic.
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43 **Data recording**

44 All birds recovered well and ate all their food ration rapidly on the day after surgery. At 15 (year 1)
45 and 13 (year 2) weeks of age, when they weighed 1.71 ± 0.02 and 1.45 ± 0.04 kg, the physiological
46 parameters and behaviour of the 3 birds were monitored over two 24-h periods (midnight to
47 midnight), separated by two days. Immediately after the second period, food restriction ceased and
48 birds were fed *ad libitum* thereafter. At 17 (year 1) and 15 (year 2) weeks, when they weighed 2.29
49 ± 0.04 and 2.22 ± 0.12 kg, they were monitored again, in the *ad libitum*-fed state, over two 24-h
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3 periods separated by two days. In all 4 monitoring periods, each physiological parameter was
4 recorded from a 5-s sample in every minute.
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7 **Data analysis**

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9 The data obtained were analysed in two ways. Firstly, overall mean values for heart rate, blood
10 pressure, body temperature, and relative powers in delta (1-4 Hz), theta (4-8 Hz), alpha (8-12 Hz)
11 and beta (12-30 Hz) frequency bands of the EEG power spectrum were calculated for every 12 h of
12 light (day) and darkness (night), and every bird and monitoring period. These were analysed by a
13 nested analysis of variance which tested the significance of effects of feeding state (restricted, *ad*
14 *libitum*), time (day, night), year (1, 2), and their interactions. Secondly, overall mean values from
15 all birds and both monitoring periods were calculated for every 15 min over 24 h, to show circadian
16 variation in restricted-fed and *ad libitum*-fed states.
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24 When the 5-s EEG signal waveforms were viewed (on computer screen print-outs), there were
25 sometimes obvious artefacts or other anomalies, due to the presence of one or more very large
26 peaks, major deviations in the baseline, or either partial or total absence of a signal. Many of these
27 would presumably have been movement artefacts, sometimes apparent during feeding, and in at
28 least one bird there may occasionally have been tension on the sensing electrode contacts when its
29 neck was extended due to insufficient slack in the electrode leads. (All birds were examined after
30 being killed by lethal injection at the end of experimentation, and the dental acrylic holding
31 electrodes in place was still firmly attached to the skulls of all of them.) The problem of artefact
32 rejection is a common feature of EEG research (*e.g.* Grasing and Szeto, 1992; Berger and Phillips,
33 1994), and here all waveforms with one or more obviously anomalous peak, or major deviation in
34 baseline, or less than 3 s of signal were excluded from the analyses. Out of 34560 (6 birds x 4 d x
35 24 h x 60 min) EEG waveforms that were inspected visually, 2006 (5.8%) were rejected
36 (subjectively) on the basis of any of these criteria. Proportions rejected in individual birds were
37 14.1, 6.0, 5.0, 4.7, 2.7 and 2.4%. Apart from 3 very low heart rate values (<60 bpm), which were
38 rejected, there were no such anomalies in the heart rate, blood pressure and body temperature data.
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51 **RESULTS**

52 Significant ($P<0.05$) effects on the physiological variables of feeding state, time of day/night, year,
53 and their interactions are shown in the Table. Thus, heart rate, blood pressure and body temperature
54 were all higher during *ad libitum* feeding than restricted feeding (F). Heart rate and body
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3 temperature were also higher by day than at night (T). The differences in heart rate and body
4 temperature between day and night were greater during restricted than *ad libitum* feeding (FxT).
5 The decrease in overall mean heart rate at night was greater in year 2 than year 1 (TxY). Blood
6 pressure tended to increase from day to night, except in year 2 during restricted feeding (FxTxY).
7 Overall mean body temperature was higher in year 2 (41.11 °C) than year 1 (40.69 °C) (Year),
8 possibly because ambient temperature during monitoring periods was also higher (P=0.007, by t-
9 test) in year 2 (23.4±0.2 °C) than year 1 (21.5±0.4 °C). The decrease in body temperature at night
10 during restricted feeding was greater in year 1 than year 2 (TxY, FxTxY).
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Table near here

18 Relative powers in delta (1-4 Hz) and theta (4-8 Hz) frequency bands of the EEG power
19 spectrum were higher at night than by day, but only in year 2, when they were also higher (by day
20 and at night) than in year 1 (T, Y, TxY). Power in the alpha (8-12 Hz) band was higher at night
21 than by day in both years (T). There were no other significant effects.
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25 During restricted feeding, there were marked peaks in heart rate (Figure 1a), blood pressure
26 (Figure 1b) and body temperature (Figure 1c) in the 15 min after provision of the daily ration at
27 09:00 h, when birds were feeding (all food was eaten in <10 min). After feeding, there was a
28 gradual decline in heart rate that continued until after lights-off (19:00 h). There was no such
29 consistent change in either blood pressure or body temperature; indeed the latter took 2-3 h to fall to
30 the night-time level after lights-off, and started rising toward the day-time level about 1 h before
31 lights-on (07:00 h). Circadian variations in heart rate, blood pressure and body temperature during
32 *ad libitum* feeding were associated only with lights-on and lights-off.
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40 There were no obvious changes in relative powers in delta (Figure 2a), theta (Figure 2b), alpha
41 (Figure 2c) or beta (Figure 2d) frequency bands of the EEG power spectrum around feeding time
42 during restricted feeding. In that feeding state, however, powers in theta and alpha bands did appear
43 to be reduced between lights-on and shortly after the daily meal. Powers in delta and theta bands
44 peaked about an hour after lights-off and then declined gradually, in year 2 only (significant TxY
45 interactions, Table). These peaks, and also one in alpha power then, were more marked during
46 restricted feeding, but there was no significant FxT interaction with any EEG band in the Table.
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DISCUSSION

The increase in energy expenditure above resting metabolic rate that occurs after eating a meal has been referred to as “diet-induced thermogenesis” (Rothwell and Stock, 1979) or “the thermic effect of food” (Hill *et al.*, 1985). Presumably it explains why heart rate, blood pressure and body temperature of the broiler breeders here were all increased significantly during *ad libitum* feeding monitoring periods, when their mean daily food intake (208 ± 7 g in year 1 and 178 ± 11 g in year 2) was about 3 times higher than the 60 g daily ration provided during restricted feeding monitoring periods. It should also explain why heart rate, blood pressure and body temperature were all as high in the 15 min after provision of the daily meal during restricted feeding as they were during *ad libitum* feeding (Figures 1a, 1b, 1c).

Total removal of food has been found to cause progressive reduction in heart rate in young broiler and layer fowls (Yamamoto and Mimura, 1976; Shimada and Koide, 1978). Chronic food restriction caused reductions in fasting and resting rates of heat production in adult laying hens (Macleod and Shannon, 1978), broilers and broiler breeders (Macleod *et al.*, 1993; Koh and Macleod, 1999) and pigeons (Phillips *et al.*, 1991), and it also caused reductions in rectal and foot-surface temperatures in broiler breeders (Macleod *et al.*, 1993). The peaks in heart rate and blood pressure found in the present study in association with the single daily meal during food restriction are like those found to occur during a 1-h feeding period in restricted-fed rats (van den Buuse, 1999). It appears that no previous study has examined blood pressure or EEG in relation to either food restriction or time of day/night in domestic fowls, and here there was no effect of feeding state on EEG (Table).

Reductions in heart rate, heat production and body temperature at night have been reported previously for fowls (Yamamoto and Mimura, 1976; Shimada and Koide, 1978; Macleod *et al.*, 1980; Macleod and Jewitt, 1984; de Jong *et al.*, 2002), Japanese quail (Hohtola *et al.*, 1991; Underwood *et al.*, 1999) and pigeons (Graf *et al.*, 1989; Ostheim, 1992; Phillips *et al.*, 1991, 1993). Just as in the present study, these reported nocturnal declines were greater during food restriction or total food withdrawal than during *ad libitum* feeding. It has been proposed that the more marked nocturnal hypothermia observed during restricted feeding enhances energy savings already being achieved through lowered thermal conductance (Phillips *et al.*, 1991). From an earlier comparison of heat production of restricted- and *ad libitum*-fed broiler breeders (Macleod *et al.*, 1993), using the

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3 same restricted feeding programme as in the present study, it can be calculated that mean thermal
4 conductances across 24 h (*i.e.* day and night) were 38 and 71 kJ/°C, respectively.
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7 In a pilot radiotelemetry trial with one restricted-fed chicken (Savory and Kostal, 1997), heart
8 rate and blood pressure were correlated negatively, the former being higher and the latter lower by
9 day than at night. Although similar opposite trends were observed in the present study, the
10 difference in blood pressure between day and night was not consistent in year 2 during food
11 restriction. Such a tendency for heart rate and blood pressure to be correlated negatively in the fowl
12 appears to differ from the rat, in which heart rate and blood pressure changed in parallel between
13 day and night (van den Buuse, 1999). It may also differ from the turkey, in which mean arterial
14 blood pressure has been found to be slightly lower at night than by day (Krista *et al.*, 1981). With
15 humans, it was concluded that the 24-h profile of blood pressure, as observed under normal
16 circumstances, is the sole result of environmental and behavioural factors such as the occurrence of
17 sleep, and has no endogenous circadian component (van Dongen *et al.*, 2001).
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27 Regardless of feeding state, relative powers in the slower wave (delta (1-4 Hz), theta (4-8 Hz))
28 frequency bands of the EEG power spectrum were higher at night than by day in the present study in
29 year 2 only, while power in the alpha (8-12 Hz) band was higher at night in both years. There was
30 no such difference between day and night in fast wave (beta (12-30 Hz)) power. Slow wave (delta
31 band) activity has also been shown to reach high levels at night in the pigeon (Berger and Phillips,
32 1994). With the rat, the trend in relative delta power over the daytime, inactive period (when
33 nocturnal rodents sleep) resembles that seen in human subjects during sleep, with peak levels
34 occurring at the onset, followed by a steady decline during remaining hours of the daytime rest
35 period (Grasing and Szeto, 1992). This is like the marked peaks in delta, theta and alpha powers
36 shown by broiler breeders after lights-off during restricted feeding in the present study. There was a
37 smaller peak in delta power after lights-off during ad libitum feeding. In a previous study with
38 domestic hens, it was reported that delta activity decreases across the night, reflecting a transition
39 from (mainly slow wave) non-paradoxical to (less slow wave) paradoxical sleep (van Luijtelaaar *et*
40 *al.*, 1987).
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52 Overall mean body temperature was significantly higher in year 2 than year 1, possibly
53 because ambient temperature during monitoring periods was also higher in year 2 than year 1
54 (see Results). This may explain why the decline in body temperature at night during restricted
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3 feeding was greater in year 1 (4.5%) than year 2 (3.1%) (significant FxTxY interaction, which
4 also accounts for the significant TxY interaction). It might also explain why the increase in
5 (overall mean) heart rate by day was greater in year 2 (22%) than year 1 (14%), why delta and
6 theta (slower wave) EEG powers were (36% and 39%) greater in year 2 than year 1, and why
7 the increases in delta and theta powers at night were much greater in year 2 (19% and 12%)
8 than year 1 (0% and 2%). The significant interactions may also be due partly to the small
9 sample size used (3 birds in each of two years), which was a consequence of the high cost and
10 labour intensity of this type of work.

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18 Another purpose of this study, reported elsewhere (Savory and Kostal, in press), was to test
19 a hypothesis that some behaviours observed during food restriction are associated with de-
20 arousal (see Introduction). For this, it was assumed that arousal is associated with increased
21 heart rate, blood pressure, body temperature and beta (fast wave) EEG power, and reduced delta
22 and theta (slow wave) EEG powers, and that de-arousal is associated with opposite effects.
23 Based on powers in the different EEG frequency bands, there was no evidence here of any
24 consistent difference in arousal or de-arousal between restricted-fed and *ad libitum*-fed states.
25 Also, it can be concluded from the present results that variations in heart rate, blood pressure
26 and body temperature, between feeding states and times of day/night, are associated more
27 closely with variation in food intake and energy expenditure (see above) than with either
28 arousal state or physiological stress (cf. de Jong *et al.*, 2002).

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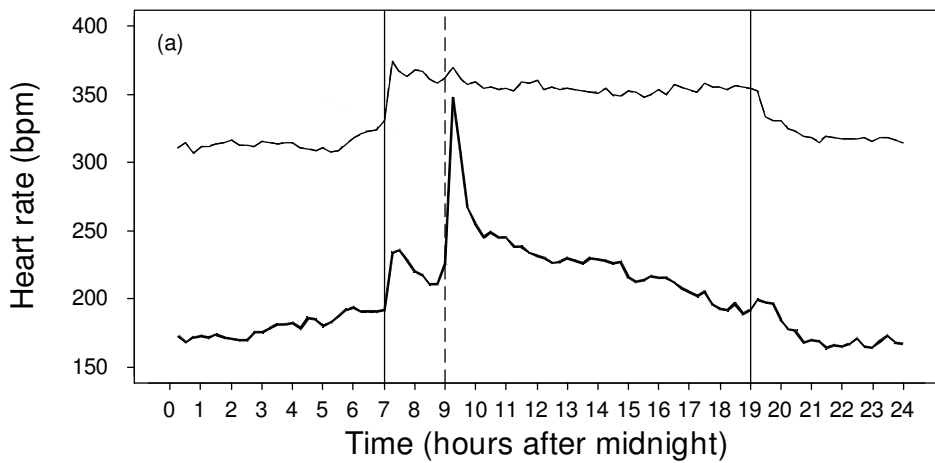
Table. Overall mean heart rate (HR), blood pressure (BP), body temperature (BT), and relative powers in different frequency bands (delta, theta, alpha, beta) of the EEG power spectrum, during the day (12 h) and night (12 h), in restricted-fed (R) and ad libitum-fed (AL) states; and significance of effects of feeding state (F), time of day/night (T), year (Y), and their interactions (P values, by ANOVA)

Feeding state Time	R		AL		Significance of effects						
	Day	Night	Day	Night	F	T	Y	FxT	FxY	TxY	FxTxY
HR (bpm)	226.0	176.7	356.9	317.5	<0.001	<0.001	0.376	0.007	0.939	<0.001	0.722
BP (mmHg)	109.3	111.6	117.8	122.2	0.007	0.104	0.774	0.603	0.393	0.090	0.046
BT (°C)	41.20	39.62	41.61	41.16	<0.001	<0.001	0.012	<0.001	0.393	<0.001	<0.001
EEG (mV ² /Hz)											
delta (1-4 Hz)	0.111	0.130	0.112	0.117	0.341	0.029	0.060	0.165	0.475	0.033	0.523
theta (4-8 Hz)	0.066	0.072	0.063	0.066	0.222	0.010	0.016	0.390	0.723	0.043	0.484
alpha (8-12 Hz)	0.037	0.040	0.036	0.038	0.304	0.001	0.290	0.291	0.501	0.492	0.109
beta (12-30 Hz)	0.019	0.020	0.019	0.020	0.724	0.297	0.417	0.602	0.398	0.768	0.497

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5 **Figure 1.** Circadian variation in overall mean heart rate (a), blood pressure (b) and
6 body temperature (c), in restricted-fed (bold line) and ad libitum-fed (fainter line) states.
7 Vertical lines indicate times of lights on (0700 h) and lights off (1900 h), and the vertical
8 dashed line indicates feeding time (0900 h).
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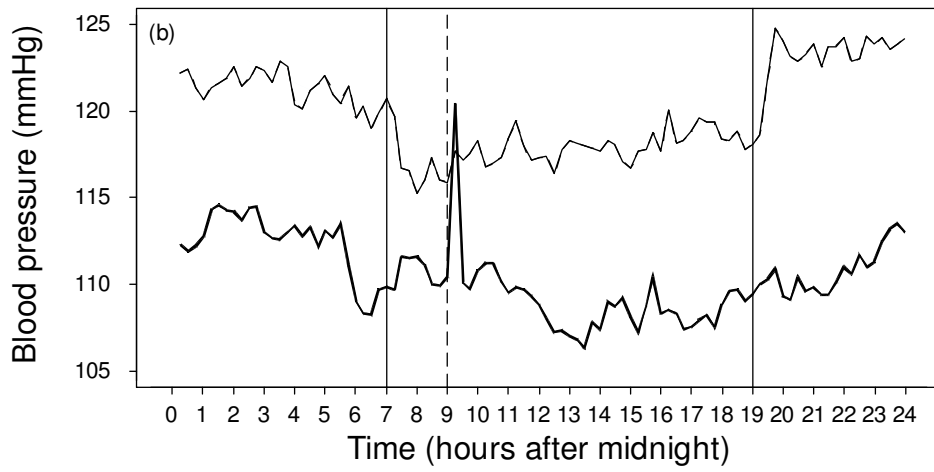
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15 **Figure 2.** Circadian variation in overall mean relative powers (mV^2/Hz) in the delta (a,
16 1-4 Hz), theta (b, 4-8 Hz), alpha (c, 8-12 Hz) and beta (d, 12-30 Hz) frequency bands of
17 the EEG power spectrum, in restricted-fed (bold line) and ad libitum-fed (fainter line)
18 states. Vertical lines indicate times of lights on (0700 h) and lights off (1900 h), and the
19 vertical dashed line indicates feeding time (0900 h).
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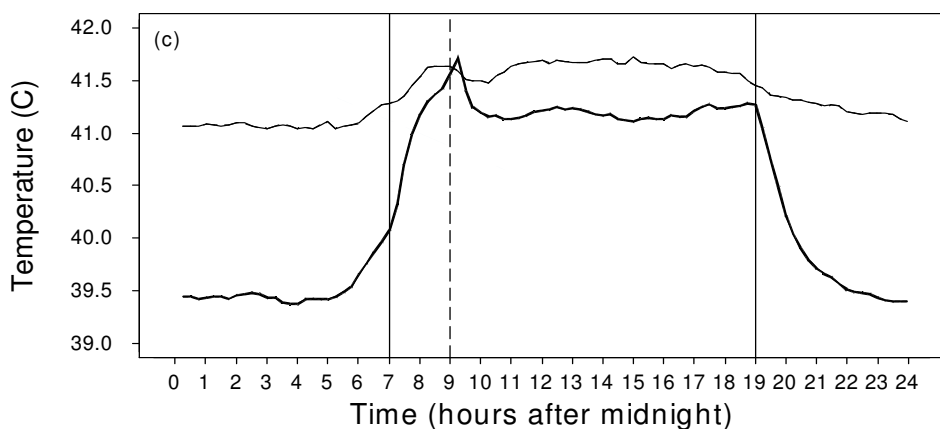


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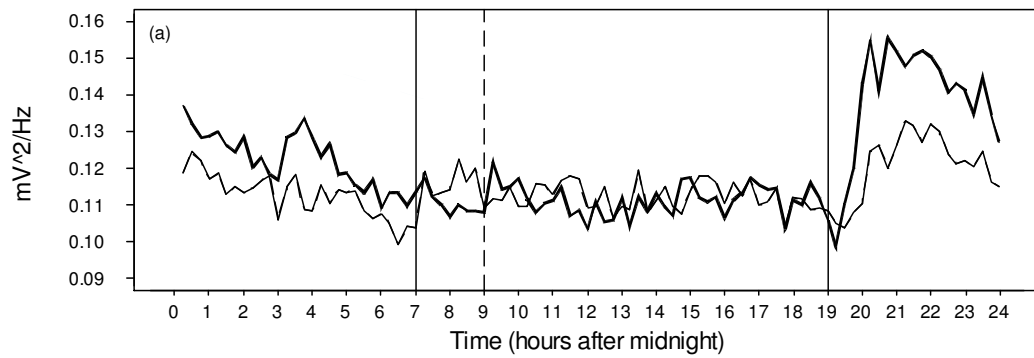


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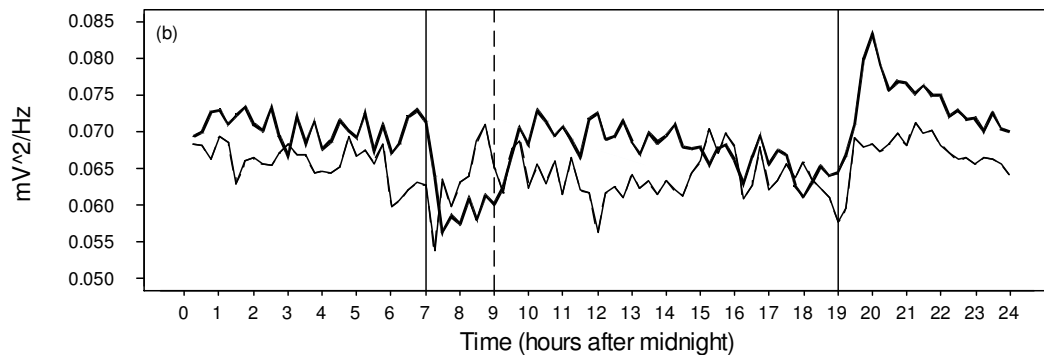
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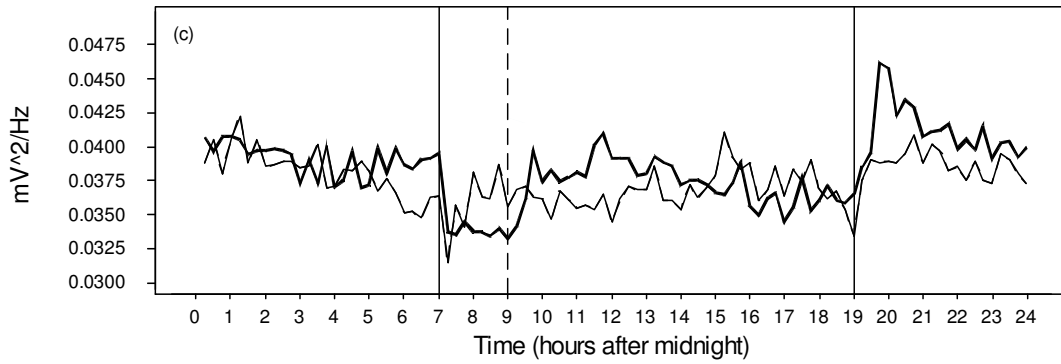
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