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Behaviour-time budget and functional habitat use of a free-ranging European badger (*Meles meles*)

David W McClune[1], Nikki J Marks[1*], Richard J Delahay[2], W Ian Montgomery[1] and David M Scantlebury[1*]

Abstract

Background: The European badger (*Meles meles*) is involved in the maintenance of bovine tuberculosis infection and onward spread to cattle. However, little is known about how transmission occurs. One possible route could be through direct contact between infected badgers and cattle. It is also possible that indirect contact between cattle and infected badger excretory products such as faeces or urine may occur either on pasture or within and around farm buildings. A better understanding of behaviour patterns in wild badgers may help to develop biosecurity measures to minimise direct and indirect contact between badgers and cattle. However, monitoring the behaviour of free-ranging badgers can be logistically challenging and labour intensive due to their nocturnal and semi-fossorial nature. We trialled a GPS and tri-axial accelerometer-equipped collar on a free-ranging badger to assess its potential value to elucidate behaviour-time budgets and functional habitat use.

Results: During the recording period between 16:00 and 08:00 on a single night, resting was the most commonly identified behaviour (67.4%) followed by walking (20.9%), snuffling (9.5%) and trotting (2.3%). When examining accelerometer data associated with each GPS fix and habitat type (occurring 2 min 30 s before and after), walking was the most common behaviour in woodland (40.3%) and arable habitats (53.8%), while snuffling was the most common behaviour in pasture (61.9%). Several nocturnal resting periods were also observed. The total distance travelled was 2.28 km.

Conclusions: In the present report, we demonstrate proof of principle in the application of a combined GPS and accelerometer device to collect detailed quantitative data on wild badger behaviour. Behaviour-time budgets allow us to investigate how badgers allocate energy to different activities and how this might change with disease status. Such information could be useful in the development of measures to reduce opportunities for onward transmission of bovine tuberculosis from badgers to cattle.

Keywords: Accelerometry, GPS, Badger, *Meles meles*, Mustelid, Behaviour, Biosecurity

Background

There is substantial interest in badger behaviour owing to their involvement in the transmission of *Mycobacterium bovis* (the causative agent of bovine tuberculosis (bTB)) to cattle [1]. Control of bTB in cattle is a major animal health issue in the UK with a cost of over £100 million in Great Britain during 2011 to 2012 and almost £23 million in Northern Ireland during 2010 to 2011 [2,3]. Although badgers rarely interact directly with cattle on pasture, indirect interactions - such as cattle investigating pasture contaminated with badger excrement - are thought to occur more frequently [4-8]. Badgers are also known to visit farm buildings and use cattle troughs [9,10]. Infected badgers may display behavioural differences, as disease status has been shown to correlate with both ranging and denning behaviour with infected individuals having larger home ranges [11] and spending a greater proportion of their time occupying outlier sets [12]. There are also accounts of chronically infected badgers becoming solitary and taking up residence in farm buildings [13].

*Correspondence: n.marks@qub.ac.uk; m.scantlebury@qub.ac.uk
[1] School of Biological Sciences, Institute for Global Food Security, Queen's University Belfast, University Road, Belfast BT7 1NN, UK
Full list of author information is available at the end of the article

Therefore, a greater understanding of the behaviour of free-ranging badgers, particularly within areas of potential direct or indirect overlap with cattle, would be important when devising biosecurity measures to reduce opportunities for disease transmission. The present study reports the use of GPS and tri-axial accelerometer devices on a free-ranging European badger. Our study provides proof of principle for the utility of this technology in the construction of detailed behaviour-time budgets for this nocturnal, semi-fossorial wild carnivore.

Methods

A population of wild badgers has been the subject of an intensive long-term ecological and epidemiological study at Woodchester Park, Gloucestershire, South-West England. The study area consists of a mosaic of largely deciduous woodland and pasture (see [14] for detailed composition). During routine capture-mark-recapture exercises [15] in January 2012, an adult female European badger (*Meles meles*) with a body mass of 9.0 kg was captured in a steel mesh live-trap and transferred to an examination facility where it was anaesthetised by intramuscular administration of two parts butorphanol tartrate (Torbugesic®, Wyeth, Ontario, Canada), two parts ketamine hydrochloride (Ketaset®, Wyeth, Ontario, Canada) and one part medetomidine (Domitor®, Orion Corporation, Espoo, Finland) [16]. Samples of faeces, urine, and tracheal and oesophageal aspirate were collected for mycobacterial culture [17], and a sample of jugular blood was taken for gamma interferon (IFNγ) [18] testing and STAT-PAK serological assay (BrockTB STAT-PAK®; Chembio Diagnostic Systems, New York, USA) [19]. A leather collar was fitted to the badger with a GPS (i-gotU GT-120; Mobile Action Technology, Inc., Taiwan) configured to record a fix once every 5 min and a tri-axial accelerometer (X8M-3; Gulf Coast Data Concepts, LLC, Waveland, USA; recording range: ± 2 *g*) set to record acceleration (and therefore behaviour) at 50 Hz. In addition, the system temperature of the accelerometer was recorded once every 15 min. Both devices were scheduled to record daily between 16:00 and 08:00 in order to target out-of-sett activity. The devices were attached securely to a leather collar using tesa® tape (No. 4651; tesa AG, Hamburg, Germany). The *y*-axis of the accelerometer corresponded with 'surge' motion (front-back acceleration), the *x*-axis with 'sway' (left-right acceleration) and the *z*-axis with 'heave' (up-down acceleration). Following recovery from anaesthesia, the animal was released at the point of capture. After a period of approximately 1 week, traps were baited and reset to recapture the animal, after which the collar was removed and data were downloaded. Data from the first night post-release were disregarded as they are likely to have been most influenced by the trapping event. The battery of the accelerometer depleted during the third night. Thus, data described are of the complete second night starting approximately 25 h after release. Accelerometer data were processed using the software and decision tree from a previous validation study on a captive badger [20]. In brief, static acceleration was derived by taking a 2-s running mean of the raw acceleration data. Dynamic acceleration was obtained by subtracting the static acceleration from the raw acceleration [21]. Vectorial dynamic body acceleration (VeDBA) was calculated as the vectorial sum of dynamic acceleration in the three axes [22]. The mean absolute dynamic acceleration, mean static acceleration, and normalised maximum amplitude by discrete Fourier transform were then extracted within a 2-s sliding window. Behaviour was classified as: resting if there was low mean absolute dynamic acceleration in each axis (less than or equal to 0.03 *g*); snuffling (the primary mode of foraging) if there was an increase in mean static acceleration in the surge axis indicating that the badger had its nose pointing towards the ground (greater than or equal to 0.345 *g*); and, depending on amplitude in the heave axis, walking (less than 0.664 *g*) or trotting (greater than or equal to 0.664 *g*) [20]. Classification values are reported as percentage (by dividing the number of data points classified as a given behaviour by the total number of points) and time engaged (by dividing the number of data points by the sampling frequency) in each behaviour. GPS traces were visualised using R version 3.1.3 [23]. Capture and examination of badgers at Woodchester Park is carried out under licence from Natural England and the UK Home Office and with the approval of the APHA Animal Welfare Ethical Review Body.

Results

The collared badger was negative on *M. bovis* culture, IFNγ and STAT-PAK tests at all captures up to and including the date of collar attachment. Thus, the subject was considered to be bTB negative. The mean (± SD) ambient temperature during the recording period was 4.0°C ± 1.0°C (obtained from a local weather station situated approximately 4.7 km from the study area). There were occasional bouts of activity from 16:00 until approximately 18:00, but resting was the most common behaviour (92.6%; collar temperature (mean ± SD): 37.2°C ± 1.7°C). The badger then became more active and briefly exited the sett at about 19:00 as trotting behaviour was observed (activity between 18:55 and 19:05: 6 min 1 s (60.9%) walking, 1 min 2 s (10.6%) trotting, 2 min 34 s (26.0%) snuffling, and 14 s (2.5%) resting) and the collar temperature dropped to 14.0°C, although no GPS fix was obtained at this point. Shortly thereafter, the badger returned to the sett and again resting was the most common behaviour with brief periods of activity (behavioural classification between 19:20 and 22:55: 26 min 18 s (13.1%) walking, 2 s

(0.0%) trotting, 5 min 28 s (2.7%) snuffling, and 2 h 49 min 18 s (84.2%) resting; collar temperature: 34.9°C ± 3.1°C). At approximately 23:00, activity levels increased and the first GPS fix was obtained at 23:21:08. During the recording period, three distinct trips were made from setts (blue, orange, and purple tracks in Figure 1 and Additional file 1). For a detailed account of the out-of-sett behaviours associated with each GPS fix and nocturnal resting periods between each trip, see Table 1. The final GPS fix was obtained at 02:10:27. From 03:00 until the remainder of the recording period at 08:00, the badger appeared to settle and resting was the most classified behaviour (83.4%). The total distance travelled, calculated from all GPS fixes, was 2.28 km. After linking the habitat types associated with each GPS fix, walking was the most common locomotory gait in all habitats (woodland: 40.3%, pasture: 19.8%, and arable: 53.8%). Snuffling was the most common behaviour in pasture (61.9%) suggesting that it was an important foraging habitat (Table 2). Out of the total recording period, resting was the most classified behaviour (67.4%), followed by walking (20.9%), snuffling (9.5%) and trotting (2.3%). Although trotting was the least classified behaviour, it accounted for a substantial proportion (17.5%) of the overall instantaneous VeDBA (Table 3). This VeDBA value may be a slight underestimate as particularly vigorous activity occasionally exceeded the maximum recording range of the accelerometer.

Discussion

Methods previously used to study the behaviour and movement patterns of wild badgers include direct observation and radio telemetry [24,25], camera surveillance [9], the spool-and-line technique [26,27] and magnetic localisation [28,29]. GPS and proximity logger devices have also previously been deployed on free-ranging European badgers [5,7,30]. Recently, badgers have been used in captive scenarios to validate the use of accelerometers in the classification of animal

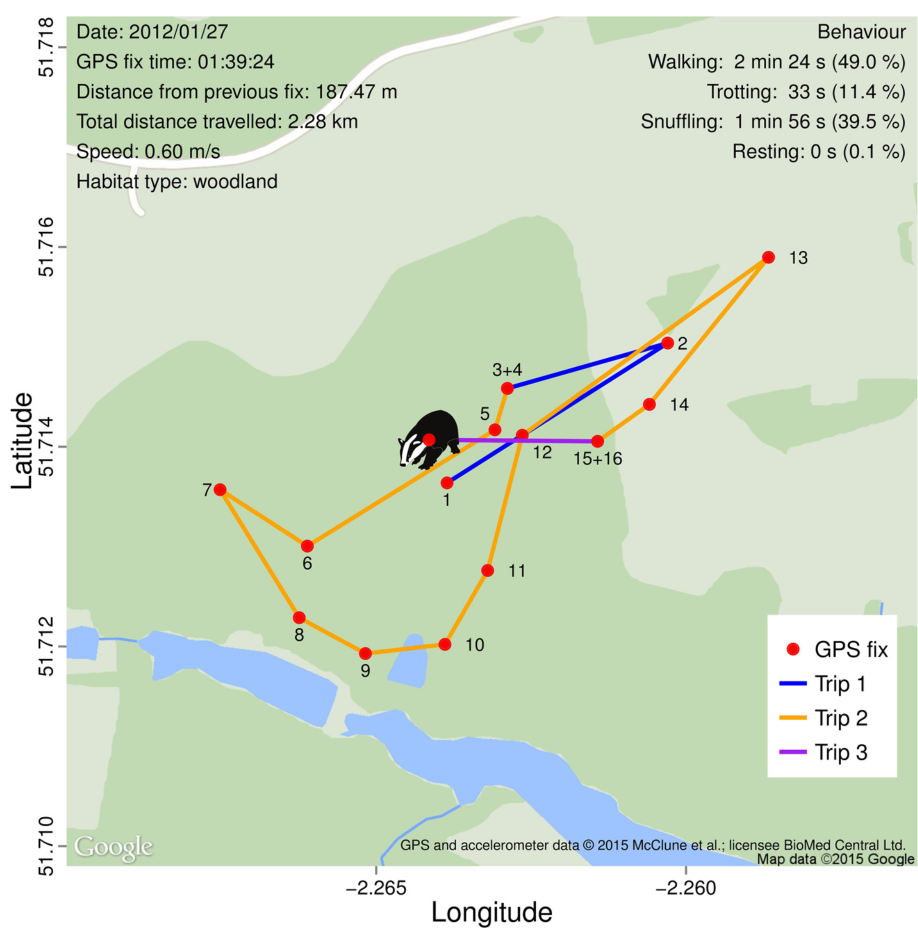

Figure 1 GPS tracks and behaviour of a free-ranging adult female European badger (*Meles meles*). GPS traces of three distinct trips from setts by the badger. Accelerometer derived behavioural information is also displayed (classified 2 min 30 s before and after the GPS fix time). The badger was considered to be inside a sett if: resting behaviour was classified, there were no GPS fixes, and there was an increase in collar temperature. See Additional file 1 for an animated version with location and associated behavioural information for each GPS fix in turn.

Table 1 Behavioural classifications associated with GPS fixes and nocturnal resting periods

Time	Fix number	Habitat type	Walking	Trotting	Snuffling	Resting	Notes
23:21:08	1	woodland	3 min 30 s (72.4%)	36 s (12.5%)	43 s (15.1%)	0 s (0.0%)	Left sett. 'Trip 1'
23:32:06	2	pasture	1 min 41 s (34.7%)	1 min 44 s (35.6%)	1 min 27 s (29.7%)	0 s (0.0%)	Moved into pasture
23:37:00	3	woodland	1 min 25 s (29.9%)	28 s (10.1%)	2 min 51 s (60.1%)	0 s (0.0%)	Returned to woodland. Trip 1 distance travelled: 475.80 m, collar temperature (mean ± SD): 9.5°C ± 6.4°C
23:37:00 to 00:05:47			9 min 25 s (35.2%)	15 s (1.0%)	4 min 23 s (16.4%)	12 min 43 s (47.5%)	Re-entered sett. Nocturnal resting period. Collar temperature: 16.3°C ± 9.9°C
00:05:47, 00:11:29, 00:16:15, 00:21:07, 00:26:08, 00:30:55, 00:35:47, 00:41:22, 00:50:07	4, 5, 6, 7, 8, 9, 10, 11, 12,	woodland	19 min 11 s (44.9%)	6 min 5 s (14.2%)	14 min 16 s (33.4%)	3 min 13 s (7.5%)	Left sett. Tracked down and up the valley through woodland. 'Trip 2'
01:02:04	13	arable	2 min 27 s (53.8%)	1 min 45 s (38.4%)	21 s (7.8%)	0 s (0.0%)	Moved across pasture to arable land
01:13:35	14	pasture	15 s (5.2%)	3 s (1.2%)	4 min 39 s (93.6%)	0 s (0.0%)	Re-visited pasture. High classification of snuffling
01:18:35	15	woodland	55 s (19.1%)	44 s (15.1%)	3 min 11 s (65.8%)	0 s (0.0%)	Returned to woodland. Trip 2 distance travelled: 1.62 km, Collar temperature: 9.8°C ± 7.6°C
01:18:35 to 01:34:11			4 min 58 s (31.6%)	31 s (3.3%)	5 min 35 s (35.5%)	4 min 40 s (29.6%)	Entered a sett, possibly an outlier. Nocturnal resting period. Collar temperature: 13.5°C ± 13.4°C
01:34:11, 01:39:24	16, 17	woodland	3 min 16 s (33.7%)	33 s (5.8%)	2 min 12 s (22.8%)	3 min 40 s (37.8%)	Left sett. Moved back to the original point of emergence. 'Trip 3', distance travelled: 187.47 m, Collar temperature: 23.0°C
01:39:24 to 02:10:27			9 min 6 s (30.5%)	2 s (0.1%)	3 min 47 s (12.7%)	16 min 54 s (56.7%)	Re-entered a sett. Nocturnal resting period. Collar temperature: 25.7°C ± 2.5°C
02:10:27	18	woodland	17 s (7.4%)	0 s (0.0%)	25 s (10.4%)	3 min 19 s (82.2%)	Briefly emerged, before returning to the sett.

Classified 2 min 30 s before and after each GPS fix.

Table 2 Summary of functional habitat use for a free-ranging European badger (*Meles meles*)

Behaviour	Woodland	Pasture	Arable
Walking	28 min 37 s (40.3%)	1 min 57 s (19.8%)	2 min 27 s (53.8%)
Trotting	8 min 28 s (11.9%)	1 min 48 s (18.3%)	1 min 45 s (38.4%)
Snuffling	23 min 41 s (33.4%)	6 min 6 s (61.9%)	21 s (7.8%)
Resting	10 min 12 s (14.4%)	0 s (0.0%)	0 s (0.0%)

Derived from tri-axial accelerometer data 2 min 30 s before and after each GPS fix ($n = 18$).

behaviour [20,31-33]. The use of tri-axial accelerometers has also been reported on free-ranging badgers, although they were used to either gain a coarser measurement of overall activity (smoothed with a 10-min running mean) [34] or to identify basic postural changes during rest [35] rather than the classification of discrete behaviours. Future work to calibrate VeDBA with rate of oxygen consumption ($\dot{V}O_2$) by respirometry would allow specific energetic costs to be assigned to behaviours in high resolution. VeDBA (for example, Table 3) can be

Table 3 Overall behaviour-time budget and VeDBA of four behaviours in a free-ranging European badger (*Meles meles*)

Behaviour	Time (%)	Total Inst. VeDBA (*g*) (%)	Median VeDBA (IQR) (*g*)
Walking	3 h 11 min (20.9%)	172,118 (46.5%)	0.231 (0.121 to 0.388)
Trotting	20 min 49 s (2.3%)	64,761 (17.5%)	1.055 (0.704 to 1.275)
Snuffling	1 h 26 min 21 s (9.5%)	109,553 (29.6%)	0.318 (0.179 to 0.528)
Resting	10 h 15 min 12 s (67.4%)	23,338 (6.3%)	0.011 (0.008 to 0.015)
Overall	15 h 13 min 24 s	369,770	0.015 (0.010 to 0.137)

Inst., Instantaneous.

used as a proxy for energy expenditure owing to the linear relationship of dynamic body acceleration with $\dot{V}O_2$ [22,36,37].

When examining functional habitat use in the present study, GPS fixes were designated to a habitat type and the associated accelerometer classified behaviours were collated (similar to [38], although our implementation differs). An improvement on this method would be to incorporate dead reckoning (see [39]) to recreate the exact travel path so that all accelerometer data could be associated with a habitat type, not just those temporally linked with GPS fixes which may be sporadic under certain conditions such as tree cover or dense vegetation. We must emphasise that the present study relied on the classification thresholds defined in McClune *et al.* (2014) [20], which were derived from a single individual with an accuracy of 99.4% for resting, 78.7% for trotting, 77.5% for snuffling and 77.4% for walking. Parallel direct tracking (and observation as far as possible) or video footage recorded using camera traps could be used to expand upon training data sets and further assess the accuracy of these methods with respect to inter-individual variation and terrain. Classification improvements may be made by experimenting with additional algorithms such as hidden Markov models (for example, [40]). Even on the second night post-release, it is possible that the badger's behaviour was influenced by the trapping event due to lost foraging time. Nevertheless, the present study demonstrates proof of principle in the application of combined GPS and accelerometer devices to collect detailed data on the behaviour of free-ranging European badgers, and results agree with previous work, suggesting that woodland is a preferred habitat but pasture is also an important foraging area [41]. Additional behaviours that may be identifiable in badgers by accelerometry include squat-marking and defecation during latrine use from static, postural changes [42,43]. Specific foraging events could also be investigated in more detail (for example, [44,45]) as badgers are known to display a pronounced upward flick of the head when predating earthworms [46].

Conclusions

In the present study, we demonstrate the utility of a combined GPS and accelerometer device to collect detailed quantitative data on wild badger behaviour. The badger spent the largest proportion of time resting, followed by walking, snuffling and trotting. Behaviour also appeared to vary depending on habitat type, with walking the most common behaviour associated with GPS fixes in both woodland and arable areas, compared to snuffling on pasture. Over extended deployments, such behaviour-time and habitat use information may be of value to quantify putative bTB-induced behavioural alterations in badgers. A greater understanding of badger behaviour on and around farms, particularly in areas of potential direct or indirect overlap with livestock, could be important in the development of biosecurity measures to reduce opportunities for disease transmission.

Additional file

Additional file 1: Functional habitat use of a free-ranging European badger (*Meles meles*). An animation showing the time and location of each GPS fix. Information on distance travelled, speed, habitat type, and approximate points of sett entry are displayed. The corresponding accelerometer derived behaviours (2 min 30 s before and after each GPS fix time) are also shown.

Abbreviations

g: Gravitational acceleration (1 g = 9.80665 m/s^2); bTB: bovine tuberculosis; IFNγ: Gamma interferon; VeDBA: Vectorial dynamic body acceleration; $\dot{V}O_2$: Rate of oxygen consumption.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

DWM performed the experiments and analysed the data. DWM, NJM, RJD, WIM, and DMS wrote the paper. All authors read and approved the final manuscript.

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Author details

[1] School of Biological Sciences, Institute for Global Food Security, Queen's University Belfast, University Road, Belfast BT7 1NN, UK. [2] National Wildlife Management Centre, Animal and Plant Health Agency, Woodchester Park, Gloucestershire GL10 3UJ, UK.

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