Costantini, David, Sebastiano, Manrico, Goossens, Benoit and Stark, Danica 2017. Jumping in the night: an investigation of leaping activity of western tarsier (cephalopachus bancanus borneanus) using accelerometers. Folia Primatologica 88 (1) , pp. 46-56. 10.1159/000477540

Publishers page: http://dx.doi.org/10.1159/000477540

Jumping in the night: an investigation of leaping activity of western tarsier (*Cephalopachus bancanus borneanus*) using accelerometers

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number of words in the manuscript: 4,512

Abstract

Accelerometers enable scientists to quantify activity of free-living animals whose direct observation is difficult or demanding due to their elusive nature or nocturnal habits. However, the deployment of accelerometers to small-bodied animals and, in particular, to primates has been little explored. Here we show the first application of accelerometers on the Western tarsier (*Cephalopachus bancanus borneanus*), a nocturnal small-bodied primate endemic to the forests of Borneo. The fieldwork was carried out in the Lower Kinabatangan Wildlife Sanctuary, Sabah, Malaysian Borneo. We provide guidelines for the deployment of accelerometers on tarsiers that might also be applied to other primate species. Our data collected on two females show levels of leaping activity comparable to those previously described using direct observation of wild or captive individuals. The two females showed different patterns of leaping activity, which calls for work to explore individual differences further. Our work demonstrates that accelerometers can be deployed on small primates to collect body motion data that otherwise would be demanding to collect using classic field observations. Future work will be focused on using accelerometer data to discriminate in more detail the different behaviours tarsiers can do and to address the causes and consequences of individual variation in activity.

Key Words

Body acceleration · Movement ecology · Primates · Tarsier

Running head: Accelerometers and tarsiers

Introduction

Activity patterns can provide important information about the ways animals interact with their environment. Historically, however, this type of data has been not only time-consuming but also logistically challenging to collect, particularly for elusive or nocturnal species. In recent years, monitoring activity with accelerometer loggers is increasingly being used as accelerometers can remotely record the body motions of free-living animals [e.g., Sullivan et al., 2006; Byrnes et al., 2011; Nathan et al., 2012; Wunderlich et al., 2014; Hammond et al., 2016]. Accelerometer loggers are small devices that can be attached to an animal's body (e.g., on a collar or backpack) and take recordings of either bi- or tri-axial body acceleration. Gravitational acceleration produces a signal referred to as static acceleration, which depends on the posture of the tagged individual (when the accelerometer is fixed to the subject). The signal derived from the subject's motion is referred to as dynamic acceleration.Data on dynamic acceleration can be used to calculate the vector sum of dynamic body acceleration (VeDBA) or the overall dynamic body acceleration (ODBA), which indicate body motion when g-values are higher than 0. Both VeDBA and ODBA values may also provide information about energy expenditure [e.g., Qasem et al., 2012; Jeanniard-de-Dot et al., 2017]. Accelerometer data can be used to derive daily activity budgets [e.g., when an animal moves; Yoda et al., 1999; Lagarde et al., 2008; Grünewälder et al., 2012; Williams et al., 2014] and, if accelerometer and viewer-observed behavioural data are collected simultaneously, accelerometer data can also be used to characterise behaviours (e.g., walking, running, leaping [Sakamoto et al., 2009; Nathan et al., 2012; Graf et al., 2015] and to estimate energy expenditure associated with different behaviours [Wilson et al., 2006; Qasem et al., 2012; Jeanniard-du-Dot et al., 2016].

Until now, accelerometers have primarily been deployed on large-bodied species [Fig. 1 in Hammond et al., 2016], but with the development of micro-accelerometers, the deployment of accelerometers on small-bodied animals is increasing rapidly[Hammond et al., 2016].

In recent times, there has been growing interest of primatologists in accelerometers, but the number of studies carried out on free-living animals is still limited [Sellers and Crompton, 1994, 2004; Mann et al., 2005; Sullivan et al., 2006; Papailiou et al., 2008; Ravignani et al., 2013; Wunderlich et al., 2014]. Prior work on primates found that accelerometers can enable investigators to collect valuable information about the behaviour and ecology of a given species. For example, Sullivan et al. [2006] found that the level of physical activity quantified using accelerometers is a particularly important factor contributing to weight change in adulthood and that there are large, but stable, differences in physical activity among individuals in female rhesus monkeys (*Macaca mulatta*). Wunderlich et al. [2014] showed that data collected with accelerometers can enable the identification of specific movement patterns of Verreaux's sifakas (*Propithecus verreauxi*) in the absence of direct observation. Moreover, accelerometers might offer primatologists and conservation biologists a tool to investigate how environmental changes or even captive care techniques can affect individual activity.

Western tarsiers are small primates endemic to the tropical forests of Borneo and are currently listed as Vulnerable by IUCN. Their nocturnal behavioural patterns and small size makes direct visual observation of them demanding. Previous work on both captive and wild tarsiers showed that they have a bimodal nocturnal activity (mostly due to leaping), with peaks of activity occurring shortly after sunset and slightly before sunrise (Niemitz, 1984; Crompton and Andau, 1986, 1987). In this study, we deployed accelerometers on the Western tarsier (*Cephalopachus bancanus borneanus*) for the first time and used this earlier work on tarsiers as a reference to compare our accelerometer data. Here we provide guidelines for the deployment of accelerometers on tarsiers and assess whether the data gathered by accelerometers can deliver valuable information on leaping activity, which is the main locomotor mode of tarsiers (more than 60% in Crompton and Andau, 1986), that would otherwise be demanding to collect using traditional field observations (Crompton and Andau, 1986, 1987).

Materials and Methods

The fieldwork was carried out from the 1st to the 21st of April 2016 in the Lower Kinabatangan Wildlife Sanctuary, East Sabah, Malaysian Borneo. The entire sanctuary spans 26,100 ha along both sides of the Kinabatangan River. Data were collected within the areas surrounding the Danau Girang Field Centre (Lot 6, N5° 24’ 49.4” E118° 02’ 14.9”), a collaborative research and training facility managed by the Sabah Wildlife Department and Cardiff University.

Body acceleration was measured using small (size of the whole unit: 0.8×10×19 mm; weight of the whole unit plus shrinkable plastic tube: 1.2 g, ≤ 1% of a tarsier body mass), ultra-low power, 3-axis acceleration data loggers (AXY-3, Technosmart Europe srl, Roma, Italy). The AXY Manager software (Technosmart Europe srl, Roma, Italy) was used to configure the accelerometers and download the data. Each device was connected to a laptop using a USB cable and configured to record continuously at a frequency of 10 Hz (i.e., 10 readings taken per second) with a 10-bit sampling resolution and a g-range of ± 4. We chose a frequency of 10 Hz because at this sampling rate our accelerometers can record continuously the body motion for over one month. Prior work on other species used a sampling rate of 100 Hz [Byrnes et al., 2011; Wunderlich et al., 2014], but this required the application of heavier accelerometers for shorter periods than ours. However, a sampling rate of 10 Hz is low and might not capture all leaps, hence we configured the accelerometers in order to have a sampling resolution of 10 bits. Accelerometers were deployed on two adult females (herein F1 and F2, both with a body mass of 135 g) that had previously been radio-collared. At the time of accelerometer deployment, each female had a three-month old infant. The animals were located in the forest during the day using radio telemetry; once spotted, they were captured by hand and put in a cotton bag to keep them calm. Once a tarsier was caught, the radio collar (Biotrack Ltd PIP3 Tag with coated brass collar; 3.55g) was removed to attach the accelerometer with electrical tape, then was covered with a transparent shrinkable plastic tube to provide abrasion resistance and environmental protection (fig. 1). Using a lighter, the plastic tube was slightly melted to make it adhere to the accelerometer. When doing so, the lighter had to be moved continuously along the plastic tube to avoid a concentration of heat in a given spot because, while accelerometers are resistant to heat, cables (that connect the battery to the accelerometer) and the battery could be damaged. The accelerometer was attached on the radio-collar in such a way that made it stay on the dorsal side of the head during the study period. We opted to attach the accelerometer to the radio-collar because accelerometers had to be recollected in order to download the data onto a computer, and radio-collars allowed us to easily locate the tarsiers again. Moreover, the radio-collar provided a support where to attach the accelerometer without the need to use other techniques, which helped to keep the overall extra-weight low. Before releasing the animal, the accelerometer was turned on by passing a magnet over the magnetic switch near the connector area of the device. Successful activation of the accelerometers was signalled by the blinking blue light indicator, which then switched off after 29 flashes. We recorded the time at which the accelerometer was turned on, which is needed in order to link accelerometer data to the time of day they were recorded. When tarsiers were re-caught, the accelerometers were turned off by using the same magnet as that used to turn them on, and then removed from the collar. When back to the field station, accelerometers were connected to a laptop using a USB cable and the AXY Manager software was used to download the data recorded by the accelerometers.

The Framework4 software (http://framework4.co.uk/index.php) was used to visualise and analyse the accelerometer data that had been downloaded with the AXY Manager software. The raw values of acceleration for each X, Y and Z axis were the result of the combination of static acceleration (due to gravity) and dynamic acceleration (due to movement), and were derived using the software. Raw accelerometer data were converted to dynamic body acceleration by first using a moving average to smooth each channel in order to derive the static acceleration and then subtracting this static acceleration from the raw data. The gravitational component (which sums to one) is therefore already subtracted before the calculation of VeDBA. Using the same software, the vector sum of dynamic body acceleration in three dimensions [VeDBA = $\sqrt{}(A_x^2 + A_y^2 + A_z^2)$] was calculated and used as an index of body motion [Qasem et al., 2012]. Although accelerometers were well attached on the radio-collar, VeDBA instead of ODBA was used because, conversely to the ODBA, the VeDBA values are less affected by any inconsistent orientation of the devices among individuals.

Results

Performance of accelerometers

Data on free-ranging animals were collected for 78 and 311 hours for F1 and F2, respectively. Shortly after deployment, the accelerometer of F1 unexpectedly stopped recording, probably due to battery failure. A possible reason may be due to insufficient waterproofing during deployment, resulting in damage to the battery during a heavy rainstorm three days after deployment. The battery of F2 was substantially more than half full when we re-caught the tarsier. Thus, with our configuration, body acceleration data may be collected for around 35-40 days. Fig. 2A shows the overall acceleration profile of F1, while fig. 2B shows how the number of peaks of the acceleration profile increases during the transition from dormancy to arousal for F1.

Identification of leaps

Fig. 3 shows the acceleration signals of F2 during the recapture session; the tarsier jumped away repeatedly before successfully re-capturing her. Our recording with a video camera of F2 enabled us to ascertain that only leaps generated VeDBA values at least ≥ 1 g (fig. 3). Using the Framework4 software, we could link accelerometer data to the time of the day at which a given accelerometer value was recorded. Thus we could link the accelerometer values to the video recording by matching the video to the time at which a leap was made. During our video recording, we also observed tarsiers to climb and to turn their head in different directions. We also observed the two tarsiers climbing and turning their head after being released after accelerometer deployment. In all these observations, these behaviours did not generate VeDBA values higher than 1. However, VeDBA values below 1 g might also indicate small leaps. To be conservative, a cut-off VeDBA value of 1 was deemed appropriate to estimate the number of leaps made by each tarsier and to describe leaping activity in this study. However, given the limited duration of our direct observations (less than one hour), we recommend that future protocols would include longer recordings of the animals to make sure that all behaviours are observed and the accelerometer response to them tested.

Comparison of leaping activity

To make data of F1 and F2 comparable, we only took the first 78 hours of recording for F2 into account. Our data show that F1 shows less leaping activity (i.e., number of leaps made) than F2 during the night (fig. 4). The main period of leaping activity for the two tarsiers began between 17:00 and 18:00 and ended between 05:00 and 06:00. For both tarsiers, there was a peak of leaping activity between 18:00 and 19:00 (black arrow in fig. 4), but for F2 there were additional peaks of leaping activity between 21:00 and 22:00 and between 04:00 and 05:00 (black arrow in fig. 4). For F1, we found low nocturnal leaping activity between 20:00 and 06:00, whereas the period of low nocturnal leaping activity was only between 00:00 and 02:00 for F2 (fig. 4). As expected, both tarsiers were most active in terms of leaps made during the night, however, there were also values of VeDBA higher than 1 (mainly above 3) during the day, mainly between 10:00 and 11:00 and between 12:00 and 13:00 for F1 (grey arrow in fig. 4); between 12:00 and 14:00 for F2 (grey arrow in fig. 4). The leaping activity of F2 recorded over the selected period of 78 hours was very similar to that recorded over the entire period, i.e. 311 hours (fig. 5). The number of leaps made by F2 per night is similar to that estimated by previous work on tarsiers, while that of F1 was much smaller (fig. 6).

Discussion

Our results show that accelerometers can be used successfully to collect data on body motion that can be used to quantify the leaping activity of tarsiers. It is, however, very important to protect the devices to avoid any damage caused by the animal or environment. This might be particularly relevant if accelerometers are deployed on primates that live in groups, where engaging in social grooming can lead to removal or destruction of the unit. Building upon previous studies on primates in captivity [Sellers and Crompton, 1994, 2004; Mann et al., 2005; Sullivan et al., 2006; Papailiou et al., 2008; Ravignani et al., 2013; Wunderlich et al., 2014], our study shows that accelerometers can also be deployed on free-living primates as small as a tarsier for several weeks.

Our data on leaping activity of tarsiers are generally in agreement with previous work on the activity of tarsiers. A previous study using a continuous all-night following of free-living tarsiers concluded that the Western tarsier is entirely nocturnal [Crompton and Andau, 1986, 1987]. Tarsiers began to move from their sleeping sites between 18:05 and 19:10 but most often between 18:30 and 18:45, and would stop traveling between 05:55 and 06:15 [Crompton and Andau, 1987]. Previous work also showed that the nocturnal leaping activity of tarsiers appeared to be bimodal, with peaks of activity shortly after sunset and slightly before sunrise. Niemitz [1984] found a peak in leaping activity in captive tarsiers around 19:00 and then a second peak between 05:00 and 06:00. Crompton and Andau [1987] found similar results in wild tarsiers. A study on captive individuals found that tarsiers were almost completely sedentary during the photoperiod (inactive period), with changes in location recorded on only 5% of 1,576 position checks during the day on 408 randomly selected days [Roberts and Kohn, 1993]. Tarsiers generally awoke within 15 minutes of the onset of the night, and virtually all activity occurred during the night [Roberts and Kohn, 1993]. Our estimates of leaping activity may be considered conservative because we do not know if VeDBA values lower than 1 indicate small leaps (a g-value of 2 g is equivalent to a leap of approximately 1 m in the red ruffed lemur (*Varecia rubra*); Sellers and Crompton, 2004) and our low sampling rate (10 Hz) might have not captured all the leaps made. However, the estimated number of leaps made by F2 per night is similar to that estimated by previous studies on both captive and wild tarsiers using direct observations of the animals (fig. 5). The number of leaps made by F1 was lower, reasons of which need further exploration. Our data show that tarsiers may occasionally leap during the daytime, the reasons of which need to be further explored. Previous work on primates found that factors, such as human disturbance, personality or availability of food [e.g., Krebs and Davies, 1993; Peres, 1993; Passamani, 1998; Uher et al., 2008], may influence individual activity budgets. Studies on other species, such as the Malayan colugos (*Galeopterus variegatus*), also showed that sexes may differ in activity budgets and performance of different locomotor behaviours [Byrnes et al., 2011]. Furthermore, we cannot exclude the possibility that the two tarsiers responded differently to the deployment of accelerometers. More research is necessary to address this issue (e.g., testing longer lasting deployments, assessing metrics of physiological stress).

In conclusion, accelerometers enabled data collection on leaping activity without the need of doing continuous all-night follows. However, this study did not enable us to determine specific behaviours, such as if leaping indicated foraging or fleeing from a threat. To do so, controlled observations of tarsiers in the wild or in captivity are required to link acceleration data to specific behaviours. Future work will be needed to assess the extent to which accelerometer data can be used to determine specific behaviours of tarsiers. In doing so, it will be important to test whether recording at frequencies higher than that used in this study (i.e., 10 Hz) would improve differentiation between behaviours and estimate of the number of leaps. Understanding more about the behaviour of tarsiers can have important implications for their conservation. For example, data on daily activity may give information on the impact of human disturbance or quality of the environment (e.g., tarsiers might move more for foraging in forest patches near plantations) has on tarsiers. Moreover, validation of VeDBA [or of ODBA; Jeanniard-de-Dot et al., 2017] as a metric of energy expenditure might provide a tool to investigate the metabolic costs incurred due to the rapid land-use changes that are occurring in the tropics.

Conflict of interest statement

The authors certify that they have no any conflicts of interest.

Acknowledgments

We thank the Sabah Wildlife Department and the Sabah Biodiversity Council for permitting this study. Thanks also to the local staff and K. Hedger for helping with fieldwork; to the editor Christophe Soligo, Robin Crompton and anonymous reviewers for providing comments that helped us to improve the presentation of our work; the Framework4 software developers for advice. We are grateful to the staff of Technosmart for kindly providing the accelerometers and technical assistance. We are also grateful for the financial support provided by the Research Foundation of Flanders to DC, La Vallée des Singes and Le Conservatoire pour la Protection des Primates to MS, and Columbus Zoo and Aquarium, Cleveland Zoological Society, Houston Zoo and Phoenix Zoo to BG and DJS. This study adhered to animal handling and observing protocols of the American Society of Mammalogists.

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Figure captions

Figure 1. Example of how the tri-axial accelerometer was attached on the radio-collar deployed on a Western tarsier (*Cephalopachus bancanus borneanus*).

Figure 2. The accelerometer profile of Western tarsier (*Cephalopachus bancanus borneanus*) F1 (Panel A) and the accelerometer profile of F1 during the transition from dormancy to arousal (Panel B).

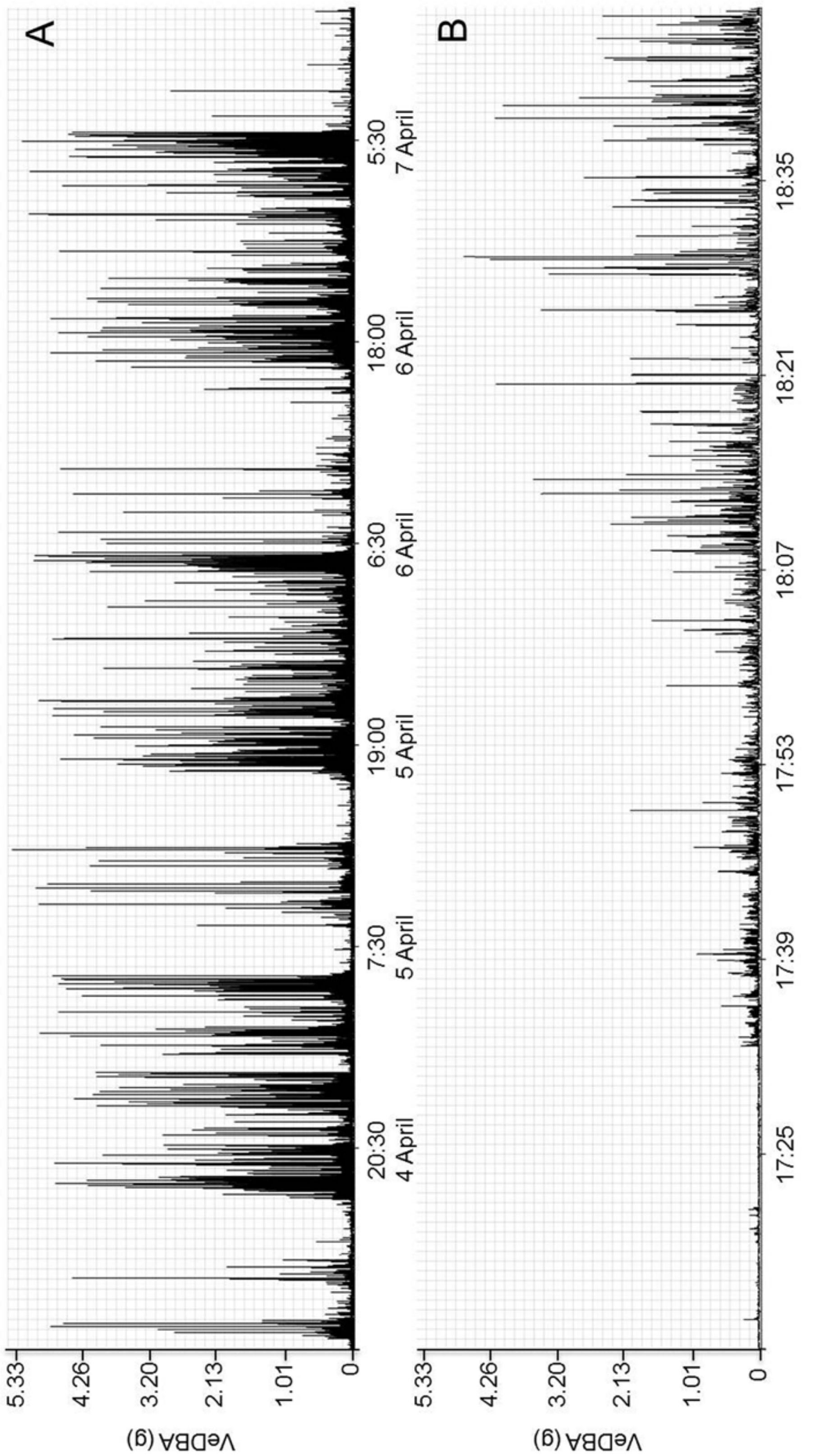
Figure 3. Accelerometer profile of the Western tarsier (*Cephalopachus bancanus borneanus*) F2 that was video-recorded while leaping away during an attempted re-capture. The VeDBA peaks shown in the graph refer only to when the tarsier was seen leaping. Acc. X = acceleration along the X axis; Acc. Y = acceleration along the Y axis; Acc. Z = acceleration along the Z axis; VeDBA = vector sum of dynamic body acceleration in the three dimensions.

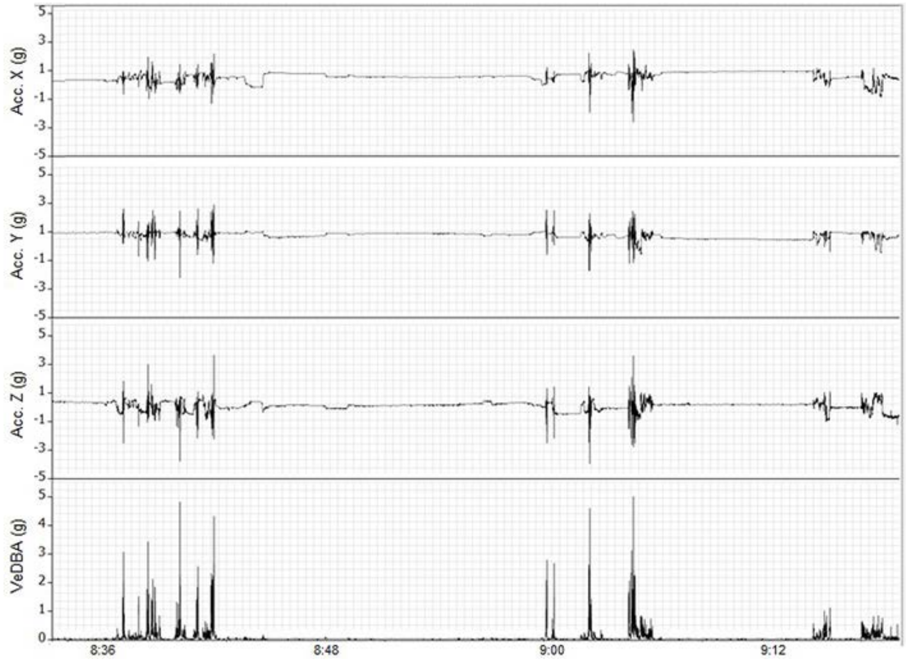
Figure 4. Leaping activity of the two female Wester tarsiers (*Cephalopachus bancanus borneanus*) over a period of 78 hours. Note that only VeDBA-values ≥ 1, which indicate leaping behaviour, were used for this description; thus data are not representative of the whole activity budgets. Note also that we are using counts, which refer to the peaks of the VeDBA profile. Our accelerometers recorded ten times per second, meaning that a single leap included several g-values, which increased as soon as the animal jumped and then decreased as soon as the animal started landing. Values are shown as mean and standard deviation per hour. Grey dots refer to F1, while black dots refer to F2. Note that in order to avoid overlap of the boxplots of the two tarsiers,

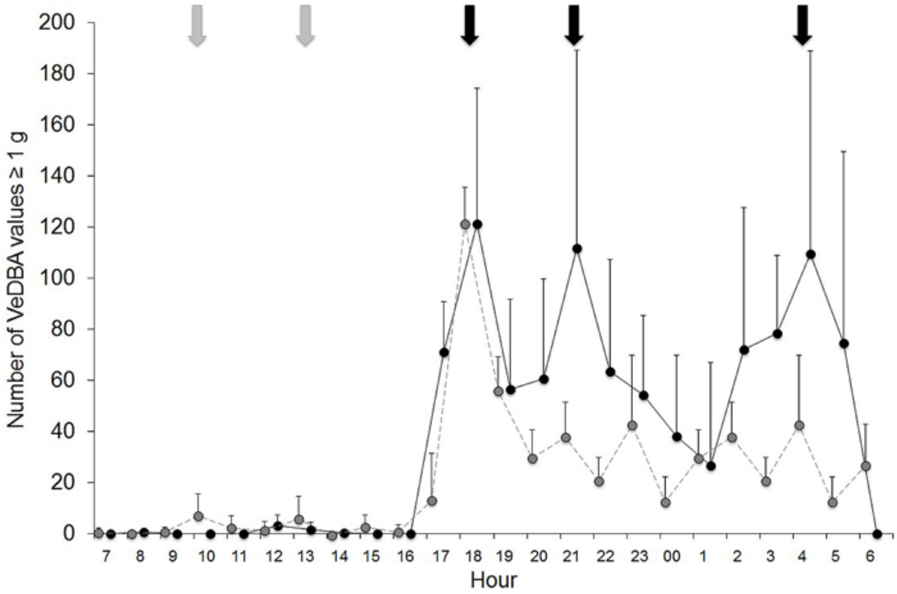
boxplots of F2 were slightly moved to the right of those of F1. Grey arrows indicate leaping activity during the daylight, while black arrows indicate peaks of leaping activity during the night.

Figure 5. Leaping activity of one female Wester tarsier (*Cephalopachus bancanus borneanus*) recorded over a period of 311 hours.

Figure 6. Comparisons of estimated average number of leaps made per night by tarsiers recorded in our and previous studies.


A
B
VeDBA (g)
5.33
4.26
3.20
2.13
1.01
0
20:30
4 April
7:30
5 April
19:00
5 April
6:30
6 April
18:00
6 April
5:30
7 April
VeDBA (g)
5.33
4.26
3.20
2.13
1.01
0
17:25
17:39
17:53
18:07
18:21
18:35


Acc. X (g)
5
3
1
-1
-3
-5
Acc. Y (g)
5
3
1
-1
-3
-5
Acc. Z (g)
5
3
1
-1
-3
-5
VeDBA (g)
5
4
3
2
1
0
8:36
8:48
9:00
9:12


Number of VeDBA values ≥ 1 g
200
180
160
140
120
100
80
60
40
20
0
7
8
9
10
11
12
13
14
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17
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22
23
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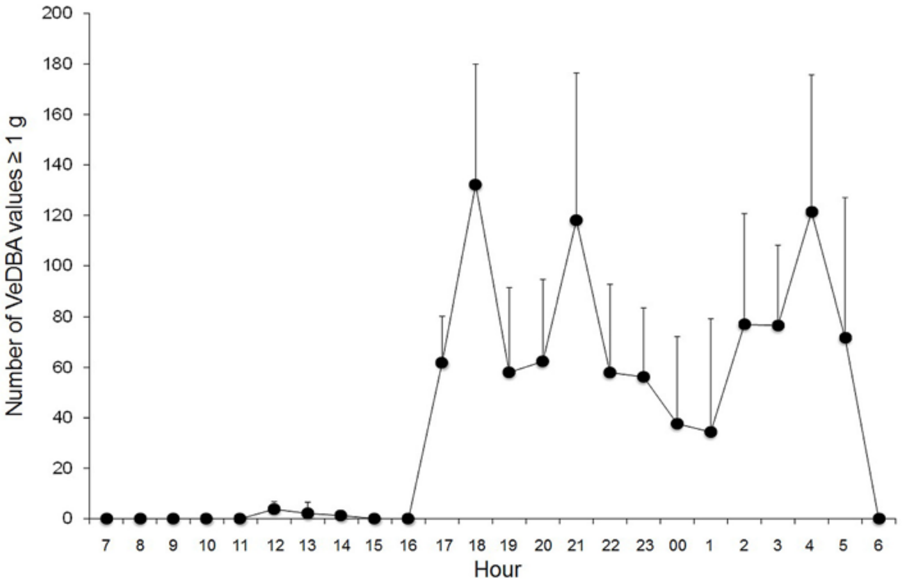
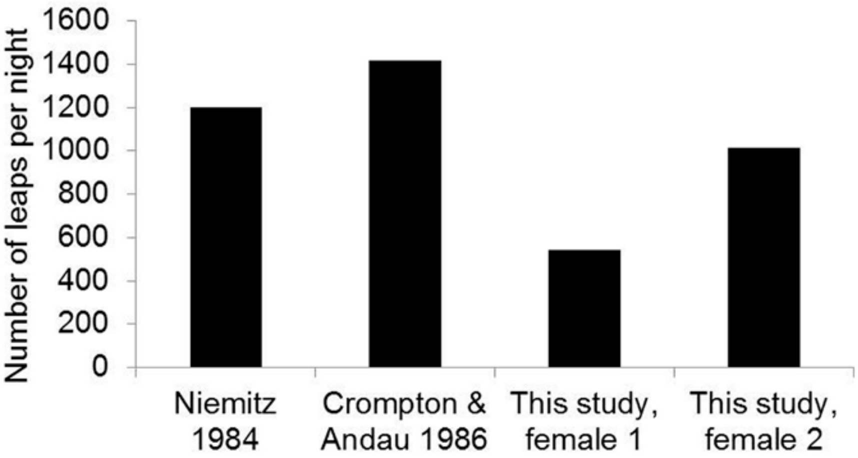
1
2
3
4
5
6
Hour


Number of VeDBA values ≥ 1 g
0
20
40
60
80
100
120
140
160
180
200
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
00
1
2
3
4
5
6
Hour


Number of leaps per night
1600
1400
1200
1000
800
600
400
200
0
Niemitz 1984
Crompton & Andau 1986
This study, female 1
This study, female 2