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Smartphone and a freely available application as a new tool to record locomotor activity rhythm in large mammals and humans

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ABSTRACT

Daily pattern of locomotor activity (LA), one of the most studied rhythms in humans and rodents, has not been widely investigated in large mammals. This is partly due to the high cost and breakability of used automatic devices. Since last decade, smartphones are becoming ubiquitous. Meanwhile, several applications detecting activity by using internal sensors were made available. In this study, we assumed that this device could be a cheaper and easier way to measure the LA rhythm in humans and large mammals, like camel and goat. A smartphone application (Nokia Mate Health), normally used to quantify physical activities in humans, was chosen for the study. To validate the rhythm data obtained from the smartphone, LA rhythm was simultaneously recorded using an automatic device, the Actiwatch-Mini[®]. Results showed that the smartphone provided a clear and significant daily rhythm of LA. The visual assessment of the superimposed LA rhythm's curves in all three species showed that the smartphone application displayed similar rhythms as those recorded by the Actiwatch-Mini. Highly significant positive correlation ($p \leq 0.0001$) exists between the two recording rhythms. The daily periods were both the same at 24.0 h. Acrophases were also significantly similar and occurring around mid-day: $11:40 \pm 0.35$ h vs $11:41 \pm 0.35$ h for the camel, $11:25 \pm 0.19$ h vs $11:37 \pm 0.25$ h for the goat and $13:04 \pm 0.11$ h vs $13:51 \pm 0.28$ h for humans using smartphone and Actiwatch, respectively. The related mesor and amplitude were also close between the two recording devices. Results indicate clearly that using smartphones constitutes a reliable cheap tool to study LA rhythm for chronobiology studies, especially in laboratories facing lack of funding.

KEYWORDS

Locomotor activity rhythm; smartphone; Actiwatch-Mini; camel; goat; large animals; humans

Introduction

Tracking animal movements is widely used in different many fields of research especially in ecology and chronobiology. Mammalian species display a clear daily temporal organization with alternating patterns of rest and activity (Halle and Stenseth 2000). Depending on time spent on active pattern, the temporal niche of several species ranges from diurnality to nocturnality. Furthermore, characterizing such pattern is fundamental when investigating the biotic and abiotic pressure exerted by an ecosystem on a species population. For example, the time and the amount of activity are known to be shaped by different pressures such as predation, competition and environmental constraints (Suselbeek et al. 2014). These relationships are critical to consider in behavioral ecology studies and wildlife management.

The locomotor activity (LA) rhythm has been studied in a large number of mammalian species, especially in rodents and laboratory animals (Aschoff 1960, 1979; Refinetti 1999, 2006; Refinetti and Kenagy 2018). In laboratory rodents, methods for measuring LA rhythm included the use of running wheels, infrared system, videobased tracking systems, ultrasonic system and radar systems (Hut et al. 1999; LeGates and Altimus 2011; Pasquali et al. 2006; Vatine et al. 1998). Whereas, in large animals, the most used technologies were, the piezo-accelerometer systems of actiwatch devices, radio tracking and telemetry (Davimes et al. 2017; Ensing et al. 2014; Gravett et al. 2017; Hetem et al. 2012; Piccione et al. 2008a, 2008b, 2010; Signer et al. 2010). However, the use of most of these techniques is limited to specific conditions. For example, recording activity in the field especially in wild and elusive species is usually difficult and requires more specific technologies. Beside of their high cost, most of devices used in large animals are easily damaged when subjected to repeated mechanical impacts leading to repetitive failure of data recording, especially in experiments lasting longer. This constraint may explain the paucity of studies concerning LA rhythm both in farm and wild large animals.

The lack of an inexpensive and robust system to record LA rhythm in large mammals impedes the progress of potential research in this field. This case is even more intricate for ecology and chronobiology research teams from low-income countries having several interesting and surely unstudied wild large animal populations. The search for new alternative technologies to overcome such difficulties is, henceforth, a major challenge. Nowadays, smartphones are provided with highly developed software applications which make them like small computers. Actually, both smartphones and their software applications users are increasing exponentially (Ericsson 2013; Teacher et al. 2013). Among freely available smartphone applications, those monitoring health state, calories consumption or measuring walking distance are recently widely used. These smartphone's fitness and workout applications are especially designed for humans use and are based on GPS systems and motion trackers or accelerometers (measuring acceleration), gyroscope (determining orientation in space) and magnetometer or compass (defining cardinal direction) (De Nazelle et al. 2013). Several of these applications have recorded up to 100 million downloads. These include applications like Endomondo, Jawbone UP, Garmin, Fitbit, Microsoft Band SDK, Google fit, Samsung Health.

In the present paper, we assumed that a smartphone combined to such applications could be used as a low cost and easily accessible tool to monitor LA rhythm and to promote ecological and circadian studies in domestic and wild animal models of desert, tropical and equatorial zones. This assumption has been verified in two large desert mammals, the camel, and the goat. Since in humans, devices devoted to record activity are also expensive that only specialized laboratories have access, the present study aimed also to ascertain the use of such tool in human subjects. To validate the smartphone's recorded LA rhythm data, a piezo-accelerometer system widely employed in research (i.e., Actiwatch-Mini[®] device) was simultaneously used for comparison purpose.

Materials and methods

Animals

All animal procedures comply with the ARRIVE (Animal Research: Reporting of In Vivo Experiments) guidelines. The study was in agreement with the Hassan II Agronomy and Veterinary Institute of Rabat and Moroccan Ministry of Agriculture recommendations which are in accordance with international ethical standards (European Union Directive 2010/63/EU) legislation.

All animal experiments were conducted at Hassan II Agronomy and Veterinary Institute of Rabat-Morocco (Latitude: 34°00'47" N; Longitude: 6°49'57" W). The study was performed at the same period of the year, on July corresponding to the summer season in Morocco. The natural LD cycle was 14.3L:9.7D and the daily variations of ambient temperature in shade varied between 17°C and 27°C. Six female camels (*Camelus dromedarius*) (7–12 years of age and 445 ± 73 kg of weight) and six male goats (*Capra hircus*) (3–4 years of age and 29 ± 3 kg of weight), originated from the South of Morocco have been used. The animals were individually housed in outdoor enclosures (10 m×8 m), moving freely under natural environmental conditions. They had free access to water and food was provided twice a day at 10h00 am and 05h00 pm.

Human study

Four members volunteers of our laboratory participated on a blinded way to record the LA in human subjects. All the participants were males and aged between 24 and 43 years. Prior to the trial, an informed consent form was signed by the candidates. The smart-phone and the Actiwatch-Mini were attached to a pelvic girdle, one on the left side and the other on the right side. During 10 successive days, the device recorded activity except during showering. Both in humans and animals experiments, no invasive manipulations were applied. Indeed, the recording tools (Actiwatch and Standard Smart-phone) were safely positioned without disturbing their daily normal life.

Smartphone and collecting data application

A basic smartphone (Samsung Galaxy S III) with 10 days charging time battery when disconnected from internet connection was used in this study (Figure 1). The smartphone was protected in a small box that allows protection and easy recovery of the device and then securely appended to the lateral side of the forearm both in the goat and the camel or placed in a belt around the pelvis in human subjects. In camel and goat, the smartphone was further protected in a small common stainless steel box (14.0 cm length, 8.0 cm width, and 2.0 cm thickness). The inside of the box was covered by a waterproof plastic bag and then by an antishock bubble plastic packaging. This allowed an effective protection and easy recovery of the device. The box containing the protected smartphone was then securely appended to the lateral side of the forearm. For human subjects, the smartphone was placed in a belt around the pelvis.

The smartphone acceleration sensors system that process mechanical and electrical information to detect movement is so-called micro-electromechanical systems (MEMS). Withings Health Mate, now known as Nokia Health Mate (NHM) application (Nokia Distribution LLC) available for free for the smart-phone to analyze the physical activity has been used. This application allows continual records of activity without needing internet connection. It can also provide an analysis of weight, blood pressure and quality of the sleep (when the application is coupled with Aura Sleep Sensor). The NHM records the number of steps of the subject every 30 min (i.e., minimal duration provided by the NHM). Data are automatically saved and are easily accessed through the application as histograms. The history of the recorded data was easily displayed on the touchscreen of the smartphone by sample touching of the histogram's bars which represent each a mean of 30 min of activity. Data were then manually transcribed to obtain the whole recording of the 10 days. Recovering of 24 h data last 2 to 3 min.

Actiwatch-Mini

To validate the results of the NHM application, the LA rhythm was jointly monitored using the Actiwatch-Mini® (Cambridge Neurotechnology Ltd. Cambridge. UK, Figure 1). The Actiwatch-Mini is a small (24 mm×7 mm) automatic device monitoring total activity of animals by using a piezo-electric accelerometer that records the intensity, amount and duration of activities. It is commonly used to record activity in large animals.

During the survey, the Actiwatch-Mini was protected in another box securely appended, both in the goat and the camel, on the lateral side of the forearm or placed in a belt around the pelvis in humans. During the survey, the Actiwatch-Mini was also protected, as for smartphone, in a round stainless steel

box (3.5 cm diameter) and placed in a waterproof plastic bag then covered in an antishock bubble plastic packaging. Thereafter, it was securely appended on the lateral side of the forearm in both camels and goats. In humans, it was placed in a belt around the pelvis.

For all three models recording, the Actiwatch-Mini was programmed to record LA every minute. Thereafter, the data were presented every 30 min to align them with the 30-min interval activity recording of NHM. Following the record of activities, the Actiwatch-Mini offers the possibility to convert data in AWD Files format that can be used to plot curves of daily activities.

Data analysis

Before starting the statistical analysis, a visual evaluation was performed to observe the degree of similarity of the curves of both methods to validate NHM results. The curves were plotted using the software SigmaPlot (v12.0, Systat Inc., San Jose, CA, USA).

The LA rhythm was analyzed by calculating the mesor, the amplitude, the acrophase, the period and the robustness for both the NHM and the Actiwatch-Mini. The different parameters were calculated using the Cosinor method with the programs Acro[®] and Cosinor[®] and also by using the Lomb-Scargle periodogram through the program LSP[®].

The robustness has been largely used in the circadian literature to describe how regular a circadian rhythm is (Refinetti 2004; Refinetti et al. 1994). In the present study, the robustness of the LA rhythm was calculated using Cosinor rhythmometry method as described by Nelson et al. (1979). The rhythm robustness is computed as the percentage of variance accounted for by the rhythm and automatically given by Cosinor software.

For each parameter (mesor, amplitude, acrophase, period, and robustness), a confidence interval of 95% probability is given. Similarly, the degree of significance of the regression is calculated.

The used programs, Acro, Cosinor, and LSP, are all developed by Roberto Refinetti and are freely available on the website of the Circadian Rhythm Laboratory. University of South Carolina, United States of America: <http://www.circadian.org/software.html>.

A two-way repeated measures ANOVA was used to evaluate the statistical differences between the period and the acrophase of Actiwatch and smartphone and also for both parameters across the three species, camel, goat, and human. To isolate which group(s) differ from the others, a multiple comparison post-hoc procedure (Holm-Sidak method) was used. The Spearman Rank Correlation was used to determine the strength of correlation by ranks between the distributions of NHM and the Actiwatch-Mini data. The correlation equal to 1 ($r_s = 1$) indicates a perfect association. A $p < .05$ was considered statistically significant in all statistical tests, which were performed using SigmaPlot software.

Results

The use of NHM smartphone application revealed an evident daily rhythm of LA in camel, goat, and human subjects (Figures 2, 3, and 4). As expected, the Actiwatch-Mini recorded also a clear LA rhythm in all species. Based on the recorded data during 10 days in each species, the regression equation of Cosinor method showed that the LA rhythm observed by using the smartphone application is significant in all the three model species ($p < .05$). Similar significance was also noticed for the LA rhythm recorded by the Actiwatch-Mini. The regularity of the LA rhythm defined as the robustness and calculated by the Cosinor regression was the same for both smartphone and Actiwatch-Mini observed rhythms. Robustness for NHM application versus Actiwatch was, respectively, $26.2 \pm 5.7\%$ and $27.7 \pm 3.6\%$ for camel, $17.6 \pm 1.82\%$ and $18.7 \pm 6.6\%$ for goat and finally $22.8 \pm 3.2\%$ and $23.7 \pm 2.1\%$ for human subjects. Compared to humans and goats, camels display a more regular rhythm showing the highest robustness.

The visual assessment of the superimposed LA rhythm's curves in all three species showed that the smartphone application displayed identical rhythms, with the same pattern, as those recorded by the Actiwatch-Mini device (Figures 2, 3, and 4). Furthermore, the observed two LA rhythms exhibit the same relationship with the LD-cycles transitions. The intense activity of the LA rhythm occurred during the day and the lowest activity was observed during the night (Figures 2, 3, and 4). In the camel and

goat, the onset and the offset of the LA are constantly matching respectively the light-dark and dark-light transitions; while, in human subjects, the photophase activity extends to the first hours of the night phase.

The Spearman Rank Correlation test demonstrates a very highly significant positive correlation ($P < .0001$) between the Smartphone recorded rhythm data and that obtained simultaneously by the Actiwatch-Mini (Table 1). Results also indicate that the coefficient of correlation r_s is very close to 1 with mean values of 0.913 ± 0.020 , 0.825 ± 0.026 and 0.903 ± 0.035 , respectively, for the camel, goat, and human subjects. These results highlight the fact that the LA rhythm recorded by the smartphone is very similar to that recorded by the Actiwatch-Mini device.

Both the periodogram LSP and the Cosinor method regression provided a precise and significant period of 24.0 h ($P < .05$) for both the smartphone and Actiwatch-Mini device (Tables 2 and 3). The two-way repeated measures ANOVA showed no significant differences in the period when comparing the two devices or the three species ($P \geq 0.05$) (Table 3). There was also no significant interaction between the two factors.

Moreover, the Cosinor regression test showed that the LA rhythm acrophase always occurred around midday for both the Actiwatch-Mini device and NHM application in all species subjects (Tables 2 and 3). The statistical analysis using the two-way repeated measures ANOVA showed no significant differences between rhythm acrophases recorded by using the smartphone application and the Actiwatch-Mini device. However, significant differences ($p < .001$) were observed between the three species (Table 3, Figure 5) with acrophase delayed ($p < .001$) by approximately 1.5 h in humans compared to camels and goats.

The Cosinor regressions revealed that the mesor and the amplitude of the LA rhythms recorded simultaneously by using the smartphone, and the Actiwatch-Mini device remained closer, although the Actiwatch-Mini exhibited generally higher values (Figures 2, 3, and 4; Table 2).

Discussion

In the present work, a successful recording of LA rhythm in humans and in two large animal models (the camel and the goat) has been achieved, by using a simple smartphone tool with freely accessible NHM application. Results indicate that the obtained LA rhythms were very similar to that recorded by a validated tool, the Actiwatch-Mini. The evident daily rhythm obtained in the present study is similar to that observed in previous related investigations conducted in the same species using other techniques (Aschoff 1967a, 1967b; Aschoff et al. 1967a; Piccione et al. 2008a, 2008b, 2010; Aube et al. 2017). In large animals, the experimental design of most chronobiological studies uses 5-min interval to record LA rhythm (Bertolucci et al. 2008; Piccione et al. 2010). In the present study, a 30-min interval has been used instead but has also provided a robust LA rhythm. In fact, this interval was imposed because, to our knowledge, there is no free access smartphone application that provides an interval less than 30 min. The obtained data from smartphone NHM application are well sensitive and enough accurate for monitoring the LA rhythm in the camels, goats, and humans. Indeed, the curves obtained with smartphone NHM application in the three species studied were fully superimposable to those obtained with Actiwatch-Mini actograms. In addition, the mathematical regression using Cosinor method showed no statistical differences for the parameters that characterize a daily rhythm, particularly the period, the acrophase and the robustness.

Results also demonstrate and confirm the diurnal pattern of LA in the human, goat, and camel as previously reported by other authors (Aschoff 1967a, 1967b; Aube et al. 2017; Piccione et al. 2008a, 2008b, 2010). As expected, the smartphone NHM application enables a reliable recording of the total activity including conscious and unconscious movements which, according to several researchers, are important to measure in many large animals studies (Davimes et al. 2017; Gravett et al. 2017; Hetem et al. 2012; Piccione et al. 2008a, 2008b, 2010). The onset and the offset of the LA were always associated with light-dark cycles in the camel and the goat. However, in humans, the acrophase is delayed compared to the two other species and the LA extended into the first hours of the night. The obtained results using the smartphone application and the Actiwatch-Mini highlight the effect of well-known social factors and lifestyle in humans (Aschoff et al. 1967b). The rhythm robustness, calculated

by the Cosinor regression, was higher in the camel. The interspecies difference in the LA rhythm regularity could be explained by the behavioral peculiarities of each species, especially the human's activity that extends during early night and that of the goat which exhibits some peaks of activity during the dark phase.

The smartphones become the most important digital device available nowadays. They are provided with several software applications. These include global positioning systems (GPS), geographical information systems (GIS), microphones, accelerometers, high-resolution photography cameras, video recording as well as access to internet. The quantity and quality of applications are particularly enhanced showing a high competition between different international companies. The software manufacturers and developers are competing against time to develop reliable applications to assist researchers in different scientific fields or for education (Cho et al. 2016, 2015; Dufau et al. 2011; Giavazzi et al. 2014; Gopinath et al. 2014; Jiang et al. 2014; Kos et al. 2013; Nicolini et al. 2015; Snaddon et al. 2013; Teacher et al. 2013; Worthington et al. 2012). Recently, smartphone technology has further offered the opportunity to use this tool as a professional device for scientific research such as the smartphone-based fluorescence microscope or the smartphone-based fast and simple immunoassay to detect bacteria and infection (Cho et al. 2016, 2015; Giavazzi et al. 2014; Gopinath et al. 2014; Jiang et al. 2014; Nicolini et al. 2015); but also in environmental biology, cognitive investigation and meteorological sciences (Dufau et al. 2011; Kos et al. 2013; Snaddon et al. 2013; Teacher et al. 2013; Worthington et al. 2012).

It appears clearly from our study that the smartphone is able to monitor LA rhythm reliably, as compared to the established accurate professional acti-watches. This indicates that the Mobile-phone pedometer applications could be used with enough accuracy in chronobiology and ecological studies. The smartphone with NHM application provided 10 consecutive days recording. Under laboratory conditions, this period is long enough to conduct chronobiological studies (Refinetti et al. 2007). For long-lasting experiments, it is recommended to change the battery by another one fully charged. This was experienced and was a fast manipulation without disturbing the animals. In addition, no recorded data were missed following this operation. However, recording animal's activity in their ecosystems is a challenge, particularly for elusive species, such as the forest-dwelling or range-over vast distances animals (Gervasi et al. 2006). In such field studies, quantification of activity requires longer periods of recording and need an additional power supply. Frequent changes of batteries are therefore impracticable. The use of combined external power bank which can provide prolonged energy supply for the smartphone could be a solution (Narayan et al. 2018; Xie et al. 2016). This procedure which has been tested under controlled conditions in our laboratory using an external power bank of 22000 mAh allowed a 40 days recording. Ecological studies face also the problem of device retrieval. We assume that the use of the satellite systems incorporated in smartphones would allow a transmission of coordinate's data for localizing the animal and to allow device retrieval. Such simulation could be conducted in future studies on animals in the field and under different ecosystems. Moreover, due to the easy access to smartphones, there would be no limiting number of individuals that can be surveyed. This is an important advantage in the wild field since this technique will generate reliable data regarding to the amount of samples.

The new generation of smartphones are resistant to shocks and temperatures (-20°C to 45°C) but are also somewhat fragile with easily breakable touch screens. In the present study, the used protective material has successively prevented any damages. Compared to the commercial automatic devices such as Actiwatch, replacement of any defective smartphone is easier because it is widely ubiquitous, accessible and low costing.

Being inexpensive, lightweight and with powered battery, the smartphone can be used by different laboratories in low-income countries that have several non investigated interesting wild large animal populations, such as rhino, buffalo, lion, Blue Wildebeest, Burchells Zebra, Bushbuck, and Impala. This could also be applied to laboratories monitoring biomedical studies using LA activity in humans.

Conclusion

In the present study, we have shown that the smartphone device using NHM application provided a highly reliable recording of locomotor activity in large animals and human subjects. Thus, it seems that this device can be easily used in experimental studies of chronobiology in various laboratories around the world, especially where financial aspects are the main issues facing the research. In low-income countries, especially those in desert, tropical and equatorial zones, this reliable and cheap technique will make possible the study of animal populations and their interactions with human habitats, which are essential for comparative approaches in the field of chronobiology and ecology.

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Disclosure Statement

The authors declare no actual or potential conflict of interest.

References

- Aschoff J. 1960. Exogenous and endogenous components in circadian rhythms. *Cold Spring Harb Symp Quant Biol.* 25:11–28.
- Aschoff J. 1967a. Circadian rhythm in man in isolation. *Verh Dtsch Ges Inn Med.* 73:941–942.
- Aschoff J. 1967b. Human circadian rhythms in activity, body temperature and other functions. *Life Sci Space Res.* 5:159–173.
- Aschoff J. 1979. Circadian rhythms: influences of internal and external factors on the period measured in constant conditions. *Z Tierpsychol.* 49:225–249.
- Aschoff J, Gerecke U, Wever R. 1967a. Desynchronization of human circadian rhythms. *Jpn J Physiol.* 17:450–457.
- Aschoff J, Gerecke U, Wever R. 1967b. Phase relations between the circadian activity periods and core temperature in humans. *Pflugers Arch Gesamte Physiol Menschen Tiere.* 295:173–183.
- Aube L, Fatnassi M, Monaco D, Khorchani T, Lacalandra GM, Hammadi M, Padalino B. 2017. Daily rhythms of behavioral and hormonal patterns in male dromedary camels housed in boxes. *PeerJ* 5:e3074.
- Bertolucci C, Giannetto C, Fazio F, Piccione G. 2008. Seasonal variations in daily rhythms of activity in athletic horses. *Animal.* 2:1055–1060.
- Cho S, Islas-Robles A, Nicolini AM, Monks TJ, Yoon JY. 2016. In situ, dual-mode monitoring of organ-on-a-chip with smartphone-based fluorescence microscope. *Biosens Bioelectron.* 86:697–705.
- Cho S, Park TS, Nahapetian TG, Yoon JY. 2015. smartphonebased, sensitive μ PAD detection of urinary tract infection and gonorrhoea. *Biosens Bioelectron.* 74:601–611.
- Davimes JG, Alagaili AN, Bertelsen MF, Mohammed OB, Hemingway J, Bennett NC, Manger PR, Gravett N. 2017. Temporal niche switching in Arabian oryx (*Oryx leucoryx*): seasonal plasticity of 24h activity patterns in a large desert mammal. *Physiol Behav.* 177:148–154.
- De Nazelle A, Seto E, Donaire-Gonzalez D, Mendez M, Matamala M, Nieuwenhuijsen M, Jerrett M. 2013. Improving estimates of air pollution exposure through ubiquitous sensing technologies. *Environ Pollut.* 176:92–99.
- Dufau S, Dunabeitia JA, Moret-Tatay C, McGonigal A, Peeters D, Alario FX, Balota DA, Brysbaert M, Carreiras M, Ferrand L, et al. 2011. Smart phone, smart science: how the use of smartphones can revolutionize research in cognitive science. *PLoS One.* 6:e24974.
- Ensing EP, Ciuti S, de Wijs FA, Lentferink DH, Ten Hoedt A, Boyce MS, Hut RA. 2014. GPS based daily activity patterns in European red deer and North American elk (*Cervus elaphus*): indication for a weak circadian clock in ungulates. *PLoS One.* 9:e106997.

- Ericsson. 2013. Ericsson mobility report. (Interim Update Feb 2013). Available at: <http://www.ericsson.com/res/docs/2013/ericsson-mobility-report-February-2013.pdf> (Accessed February 19, 2013).
- Gervasi V, Brunberg S, Je S. 2006. An individual-based method to measure animal activity levels: a test on brown bears. *Wildl Soc Bull.* 34:1314–1319.
- Giavazzi F, Salina M, Ceccarello E, Ilacqua A, Damin F, Sola L, Chiari M, Chini B, Cerbino R, Bellini T, et al. 2014. A fast and simple label-free immunoassay based on a smartphone. *Biosens Bioelectron.* 58:395–402.
- Gopinath SCB, Tang TH, Chen Y, Citartan M, Lakshmi Priya T. 2014. Bacterial detection: from microscope to smartphone. *Biosens Bioelectron.* 60:332–342.
- Gravett N, Bhagwandin A, Sutcliffe R, Landen K, Chase MJ, Lyamin OI, Siegel JM, Manger PR. 2017. Inactivity/sleep in two wild free-roaming African elephant matriarchs – Does large body size make elephants the shortest mammalian sleepers? *PloS One* 12:e0171903.
- Halle S, Stenseth NC. 2000. Activity patterns in small mammals: an ecological approach. Berlin, Germany: Springer.
- Hetem RS, Strauss WM, Fick LG, Maloney SK, Meyer LC, Shobrak M, Fuller A, Mitchell D. 2012. Does size matter? Comparison of body temperature and activity of free-living Arabian oryx (*Oryx leucoryx*) and the smaller Arabian sand gazelle (*Gazella subgutturosa marica*) in the Saudi desert. *J Comp Physiol B.* 182:437–449.
- Hut RA, Mrosovsky N, Daan S. 1999. Nonphotic entrainment in a diurnal mammal, the European ground squirrel (*Spermophilus citellus*). *J Biol Rhythms.* 14:409e419.
- Jiang J, Wang X, Chao R, Ren Y, Hu C, Xu Z, Liu GL. 2014. Smartphone based portable bacteria pre-concentrating microfluidic sensor and impedance sensing system. *Sens Actuators B Chem.* 193:653–659.
- Kos S, Brčić D, Musulin I. 2013. Smartphone application GPS performance during various space weather conditions: A preliminary study. Proc. 21st International Symposium on Electronics in Transport (ISEP). Ljubljana, Slovenia, March 25–26.
- LeGates TA, Altimus CM. 2011. Measuring circadian and acute light responses in mice using wheel running activity. *JoVE.* 48:2463.
- Narayan R, Venkateswarlu M, Jagadish M. 2018. Studies on portable power banks for recharging electronic gadgets. *Int Res J Eng Technol.* 5:1549–1553.
- Nelson W, Tong YL, Lee JK, Halberg F. 1979. Methods for cosinor rhythmometry. *Chronobiologia.* 6:305–323.
- Nicolini AM, Fronczek CF, Yoon JY. 2015. Droplet-based immunoassay on a ‘sticky’ nanofibrous surface for multiplexed and dual detection of bacteria using smartphones. *Biosens Bioelectron.* 67:560–569.
- Pasquali V, Scannapieco E, Renzi P. 2006. Validation of a microwave radar system for the monitoring of locomotor activity in mice. *J Circadian Rhythms.* 4:7.
- Piccione G, Giannetto C, Assenza A, Fazio F, Giovanni C. 2008a. Locomotor activity and serum tryptophan and serotonin in goats: daily rhythm. *J Appl Biomed.* 9:43–48.
- Piccione G, Giannetto C, Casella S, Caola G. 2008b. Circadian activity rhythm in sheep and goats housed in stable conditions. *Folia Biol (Krakow).* 56:133–137.
- Piccione G, Giannetto C, Casella S, Caola G. 2010. Daily locomotor activity in five domestic animals. *Anim Biol.* 60:15–24.
- Refinetti R. 1999. Relationship between the daily rhythms of locomotor activity and body temperature in eight mammalian species. *Am J Physiol.* 277:R1493–R1500.
- Refinetti R. 2004. Non-stationary time series and the robustness of circadian rhythms. *J Theor Biol.* 227:571–581.
- Refinetti R. 2006. Variability of diurnality in laboratory rodents. *J Comp Physiol A.* 192:701–714.
- Refinetti R, Kaufman CM, Menaker M. 1994. Complete suprachiasmatic lesions eliminate circadian rhythmicity of body temperature and locomotor activity in golden hamsters. *J Comp Physiol A.* 175:223–232.

Refinetti R, Kenagy GJ. 2018. Diurnally active rodents for laboratory research. *Lab Anim (NY)*. 52:577–587.

Refinetti R, Lissen GC, Halberg F. 2007. Procedures for numerical analysis of circadian rhythms. *Biol Rhythm Res*. 38:275–325.

Signer C, Ruf T, Schober F, Fluch G, Paumann T, Arnold W. 2010. A versatile telemetry system for continuous measurement of heart rate, body temperature and locomotor activity in free-ranging ruminants. *Methods Ecol Evol*. 1:75–85.

Snaddon J, Petrokofsky G, Jepson P, Willis KJ. 2013. Biodiversity technologies: tools as change agents. *Biol Lett*. 9:20121029.

Suselbeek L, Emsens WJ, Hirsch BT, Kays R, Rowcliffe JM, Zamora-Gutierrez V, Jansen PA. 2014. Food acquisition and predator avoidance in a Neotropical rodent. *Anim Behav*. 88:41–48.

Teacher AG, Griffiths DJ, Hodgson DJ, Inger R. 2013. Smartphones in ecology and evolution: a guide for the app-rehensive. *Ecol Evol*. 3:5268–5278.

Vatine JJ, Ratner A, Dvorkin M, Seltzer Z. 1998. A novel computerized system for analyzing motor and social behavior in groups of animals. *J Neurosci Methods*. 85:1–11.

Worthington PJ, Silvertown J, Cook L, Cameron R, Dodd M, Greenwood R, McConway K, Skelton P. 2012. Evolution MegaLab: A case study in citizen science methods. *Methods Ecol Evol*. 3:303–309.

Xie L, Li J, Cai S, Li X. 2016. Design and experiments of a self-charged power bank by harvesting sustainable human motion. *Adv Mech Eng*. 8:1–10.

Table 1. Results of the Spearman Rank Correlation test comparing the data of NHM application and of the Actiwatch-Mini.

Group of camels	Correlation Coefficient r_s	<i>P</i> Value
Camel 1	0.893	
Camel 2	0.901	
Camel 3	0.886	
Camel 4	0.975	
Camel 5	0.914	
Camel 6	0.912	
Mean	0.913 ± 0.020	P < .0001
Goat 1	0.828	
Goat 2	0.845	
Goat 3	0.792	
Goat 4	0.793	
Goat 5	0.871	
Goat 6	0.802	
Mean	0.825 ± 0.026	P < .0001
Human subject 1	0.914	
Human subject 2	0.861	
Human subject 3	0.875	
Human subject 4	0.964	
Mean	0.903 ± 0.035	P < .0001

Table 2. Locomotor activity rhythm parameters calculated for smartphone NHM application and Actiwatch-Mini in camel, goat and human subjects.

Subject	Devices	Period	Mesor	Amplitude	Robustness	Acrophase	<i>P</i> value (Cosinor regression)
Camel	NHM App	24.0 ± 0,10h	66.42 ± 14.61	83.52 ± 10.46	26.2%±5.66	11:38 ± 0,41h	P < .0001
	Actiwatch-Mini	23.9 ± 0,10h	87.19 ± 5.35	104.05 ± 20.57	27.7%±3.62	11:50 ± 0,37h	P < .0001
Goat	NHM App	24.0 ± 0,03h	73.09 ± 13.38	86.50 ± 10.93	17.6%±1.82	11:24 ± 0,23h	P < .0001
	Actiwatch-Mini	24.0 ± 0,06h	121.60 ± 29.10	415.75 ± 98.23	18.7%±6.65	11:35 ± 0,27h	P < .0001
Human	NHM App	24.0 ± 0,03h	122.47 ± 23.11	157.16 ± 21.12	22.8%±3.2	13:04 ± 0,10h	P < .0001
	Actiwatch-Mini	24.0 ± 0,04h	167.76 ± 30.81	591.3 ± 64.71	23.7%±2.1	12:57 ± 0,15h	P < .0001

Table 3. Comparison of the period and acrophase between smartphone NHM application and Actiwatch-Mini across the three species: the camel, goat, and human.

Species	Period		Acrophase	
	NHM †	Actiwatch-Mini ‡	NHM §	Actiwatch-Mini #
Camel 1	24.0h	23.9h	11:12	11:22
Camel 2	23.9h	23.9h	11:16	11:16
Camel 3	23.8h	23.8h	11:01	11:01
Camel 4	24.1h	23.9h	12:09	12:14
Camel 5	24.0h	24.0h	13:12	13:12
Camel 6	24.0h	24.0h	11:03	11:59
Mean^a	24.0 ± 0.08h	23.9 ± 0.04h	11:40 ± 0.35h	11:41 ± 0.35h
Goat 1	24.1h	24.0h	11:22	11:22
Goat 2	24.0h	24.1h	11:00	11:33
Goat 3	24.0h	23.9h	11:06	11:05
Goat 4	24.0h	24.0h	12:00	11:02
Goat 5	24.0h	24.1h	12:01	12:33
Goat 6	23.9h	24.0h	11:00	12:00
Mean^b	24.0 ± 0.03h	24.0 ± 0.06h	11:25 ± 0.19h	11:37 ± 0.25h
Human subject 1	24.0h	23.9h	12:49	12:57
Human subject 2	24.0h	24.1h	13:12	13:08
Human subject 3	24.0h	24.0h	13:01	13:05
Human subject 4	24.1h	24.0h	13:15	13:11
Mean^c	24.0 ± 0.03h	24.0 ± 0.04h	13:04 ± 0.11h	13:51 ± 0.28h

Note:

- 1) Two ways ANOVA analysis for the period: the comparison of the † with ‡ indicates that there was no significant difference ($F_{(1,26)} = 0,481$; $P = 0.494$) in the period between the two systems. The comparisons of the ^{a,b}, and ^c indicate that there was no significant difference ($F_{(2,26)} = 2,897$; $P = 0.073$) in the period across different species.
- 2) Two ways ANOVA analysis for the acrophase: the comparison of the § with # indicates that there was no significant difference ($F_{(1,26)} = 0,298$; $P = 0,590$) of acrophase between the two systems. The comparisons of the ^{a,b}, and ^c indicate that there was a statistically significant difference for Humans vs goat and Humans vs camel ($F_{(2,26)} = 16,694$; $P < 0.001$), but not for camel vs goat ($P = 0.384$).

Legends to figures

Figure 1.

Pictures of the used tools in the present study. A: the smartphone with a screenshot showing the NHM application and B: the Actiwatch-Mini and its USB Reader.

Figure 2.

Actogram of the locomotor activity of the camel under natural conditions for 10 consecutive days recorded by the smartphone NHM application (black color) and the Actiwatch -Mini (red color) at 30 min intervals. The black and white rectangles at the top of the figure correspond to the succession of the night (natural dark phase) and the day (natural light phase).

Figure 3.

Actogram of the locomotor activity of the goat under natural conditions for 10 consecutive days recorded by the smartphone NHM application (black color) and the Actiwatch -Mini (red color) at 30 min intervals. The black and white rectangles at the top of the figure correspond to the succession of the night (natural dark phase) and the day (natural light phase).

Figure 4.

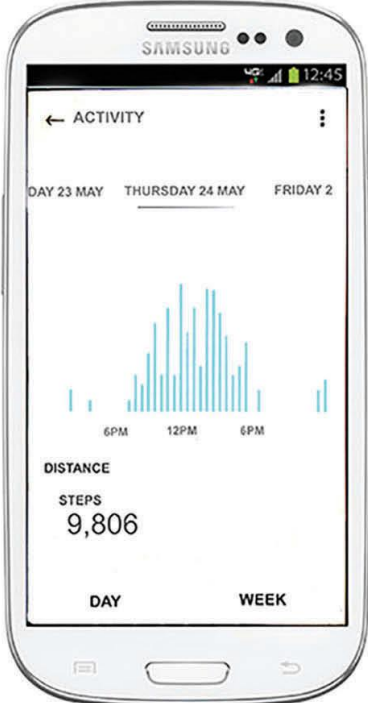
Actogram of the locomotor activity in humans under natural conditions for 10 consecutive days recorded by the smartphone NHM application (black color) and the Actiwatch -Mini (red color) at 30 min intervals. The black and white rectangles at the top of the figure correspond to the succession of the night (natural dark phase) and the day (natural light phase).

Figure 5.

Cosinor Regression performed on the mean of 10 days locomotor activity on the Actiwatch-Mini data a, b, and c for camel, goat, and humans, respectively ($p < .0001$) and on the NHM application smartphone data d, e, and f for the camel, goat and humans ($p < .00001$). The regression represents the best fitting curve (in red) that superimposes the 24 h raw data curve (black dot). For each species, the curves show that acrophases occurred around midday.

Figure 1

a



b



Figure 2

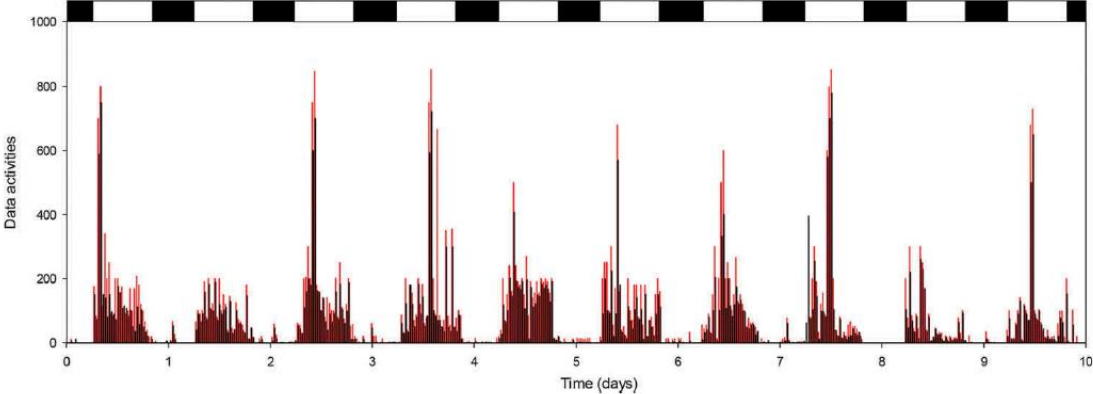


Figure 3

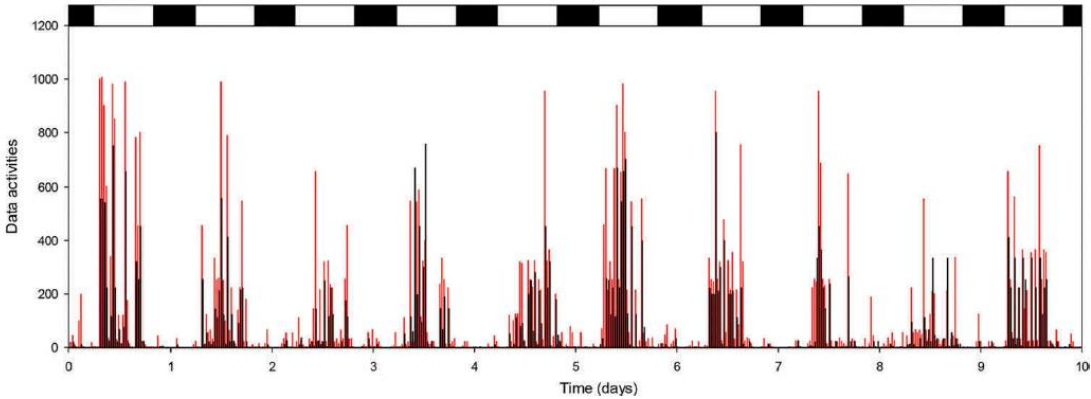


Figure 4

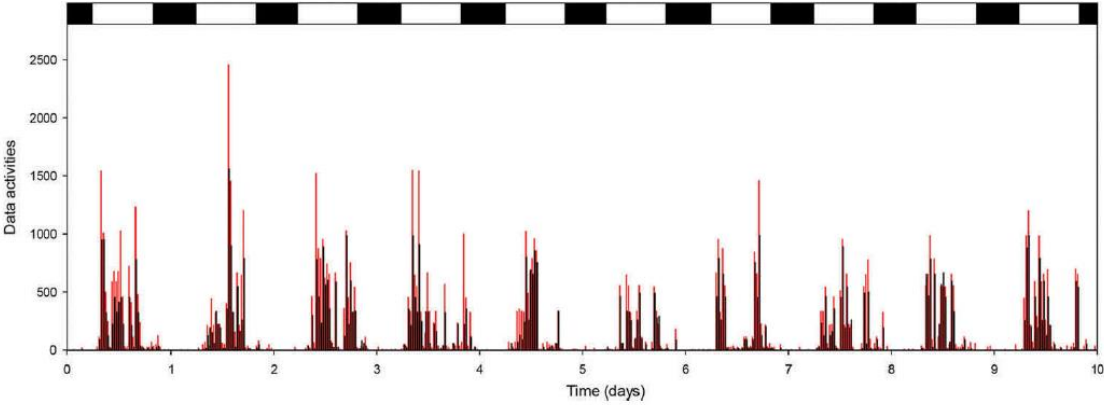


Figure 5

