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PRACTICE INSIGHTS

Identifying social behaviours related to disease transmission in banded mongoose from accelerometer data

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Abstract

1. Current methods for identifying and predicting infectious disease dynamics in wildlife populations are limited. Pathogen transmission dynamics can be complex, influenced by behavioural interactions between and among hosts, pathogens and their environments. These behaviours may also be influenced directly by observers, with observational research methods being limited to habituated species. Banded mongoose *Mungos mungo* are social, medium size carnivores infected with the novel tuberculosis pathogen *Mycobacterium mungi*. This pathogen is principally transmitted during normal olfactory communication behaviours. Banded mongoose behavioural responses to humans change over the landscape, limiting the use of direct observational approaches in areas where mongoose are threatened and flee.
2. The accelerometers in bio-logging devices have been used previously to identify distinct behaviours in wildlife species, providing a tool to quantifying specific behaviours in ecological studies. We deployed Axy-5X model accelerometers (TechnoSmArt) on captive mongoose to determine whether accelerometers could be used to identify key mongoose behavioural activities previously associated with *M. mungi* transmission.
3. After two collaring periods, we determined that three distinct behavioural activities could be identified in the accelerometer data: bipedal vertical vigilance, running and scent marking activity; behaviours that have been shown to vary across land type in the banded mongoose.
4. Results from this work advance current data analytics and provide modifications to data analysis works flows, updating and expanding upon current methodologies. We also provide preliminary evidence of successful mathematical classification of the target behaviours, supporting the future use of these devices. Methods applied here may allow model estimates of *M. mungi* transmission in free-ranging mongoose to be refined with possible application to other systems where direct observation approaches have limited application.

KEYWORDS
accelerometer, behaviour, mongoose, *Mycobacterium mungi*, transmission dynamics

1 | INTRODUCTION

Pathogen transmission processes are complex and can be variably impacted by behavioural interactions that occur between and among hosts, pathogen communities and the environment (Alexander et al., 2018; Alexander & McNutt, 2010; Arthur et al., 2017; Lopes et al., 2016). Infection can also modify or alter host behaviour, further impacting how other members of associated host communities respond to and interact with infected individuals (e.g. Beltran-Bech & Richard, 2014; Curtis, 2014; Heil, 2016; Lopes et al., 2016). These behavioural changes can alter contact rates and pathogen transmission dynamics, leading to changes in pathogen spread across host communities and landscapes (Alexander et al., 2016, 2018; Behringer et al., 2006; Cremer et al., 2007; Lopes et al., 2016; Sattenspiel & Simon, 1988). Current methods for evaluating complex behaviours in wildlife species remain challenging, with most studies being limited to species that can be habituated in landscapes in which they feel safe. Habituation, the state of reduced reactivity to human presence, is often vital to collecting behavioural and social data from a variety of different species (Allan et al., 2020; Blumstein, 2016; Hanson & Riley, 2018; Thompson & Spencer, 1966). It has been argued, however, that data collected from habituated populations is biased by observer presence, which may, in turn, influence or modify species behaviour (Allan et al., 2020; McDougall, 2012; Welch et al., 2018). Furthermore, observation of habituated wildlife can expose researchers to multiple risks in the field, such as predator attacks and exposure to zoonotic diseases (Garland-Lewis et al., 2017). These may include hantavirus, plague, brucellosis and rabies (Bosch et al., 2013; Garland-Lewis et al., 2017; Gomo, 2015; Kelt et al., 2007; McLean, 1994; Schneider et al., 2009; Tarrant et al., 2020), or novel infectious pathogens.

In northern Botswana the banded mongoose *Mungos mungo*, a small carnivorous species of the Herpestidae family is effected by the novel tuberculosis pathogen *Mycobacterium mungi* (Alexander et al., 2010, 2016; Verble et al., 2021). *Mycobacterium mungi* causes significant mortality in this species and can presents a threat to the persistence of smaller troops (Alexander et al., 2010, 2016). This pathogen is shed and transmitted between mongoose through infected anal gland secretions used in olfactory communication behaviours (Alexander et al., 2016; Jordan et al., 2010, 2011). There is a great need to advance our understanding of the manner in which the environment, humans, conspecifics and other species influence pathogen transmission dynamics. While other banded mongoose populations have been successfully habituated to facilitate behavioural studies (Marshall et al., 2018), this acclimatization process is not possible across the range of the *M. mungi*-infected population in Northern Botswana. In this region, extremely high density of wildlife such as elephants and dense vegetation make it difficult and dangerous to traverse on foot and prohibit the use of a vehicle. Furthermore, banded mongoose respond variably to humans across the landscape due to differences in human reactions to mongoose and persecution of this and other wildlife species (Alexander & Nichols, 2020). These factors limit the study of mongoose behaviours and pathogen transmission potential across complex landscapes, requiring alternative approaches to be advanced.

Accelerometers have previously been used in bio-logging devices to identify distinct behaviours in wildlife species, and have proven to be a useful tool for quantifying animal behaviour (Fehlmann et al., 2017). For example, accelerometers have been used to study energy expenditure, daily activity rates and patterns, and frequency of certain behaviours (Chakravarty et al., 2019). Accelerometers have not, however, to our knowledge been utilized to study disease transmission dynamics in wildlife. Most accelerometers utilized for wildlife study capture two measures of acceleration: static and dynamic acceleration. Static acceleration is caused by the force of the Earth's gravitational field, and the accelerometer's subsequent orientation with respect to that field, and dynamic acceleration is due to animal movement (Fehlmann et al., 2017; Nathan et al., 2012; Shepard et al., 2008). Tri-axial accelerometers function by recording total acceleration values across three dimensions, including surge or forward acceleration, sway or lateral acceleration, and heave or vertical acceleration (Figure 1). Behaviours can then be identified or summarized from the commonalities that arise in the patterns of acceleration across these three axes (Nathan et al., 2012; Shepard et al., 2008).

We herein report the use of an Axy-5X model accelerometer (TechnoSmArt) on captive mongoose as a proof-of-concept study to evaluate if accelerometers could be used to identify key mongoose behavioural activities relevant to *M. mungi* transmission. These behaviours included bipedal vertical vigilance, running and scent marking activity previously shown to vary across the landscape in this system (Alexander & Nichols, 2020). We also include evaluation of the data analytics and modifications to the data analysis works flows, updating and expanding upon current methodologies. Finally, we provide preliminary evidence of successful mathematical classification of the target behaviours, advancing the analytical toolbox for use of these approaches in banded mongoose.

2 | MATERIALS AND METHODS

2.1 | Data collection

An Axy-5X model accelerometer (TechnoSmArt) was attached to a collar and placed on a captive adult female mongoose housed at the Centre for Conservation of African Resources: Animals, Communities and Land Use (CARACAL) at the Chobe Research Institute in Northern Botswana (IACUC Number 19-251 (FWC) Amendment #1). Captive mongoose at CARACAL can be handled without the need for chemical immobilization and are easily observed, thus providing a controlled environment to evaluate Axy-5X model accelerometer performance. To size the collar, one finger was placed in between the collar and the neck of the mongoose to ensure a secure but non-restrictive fit. The

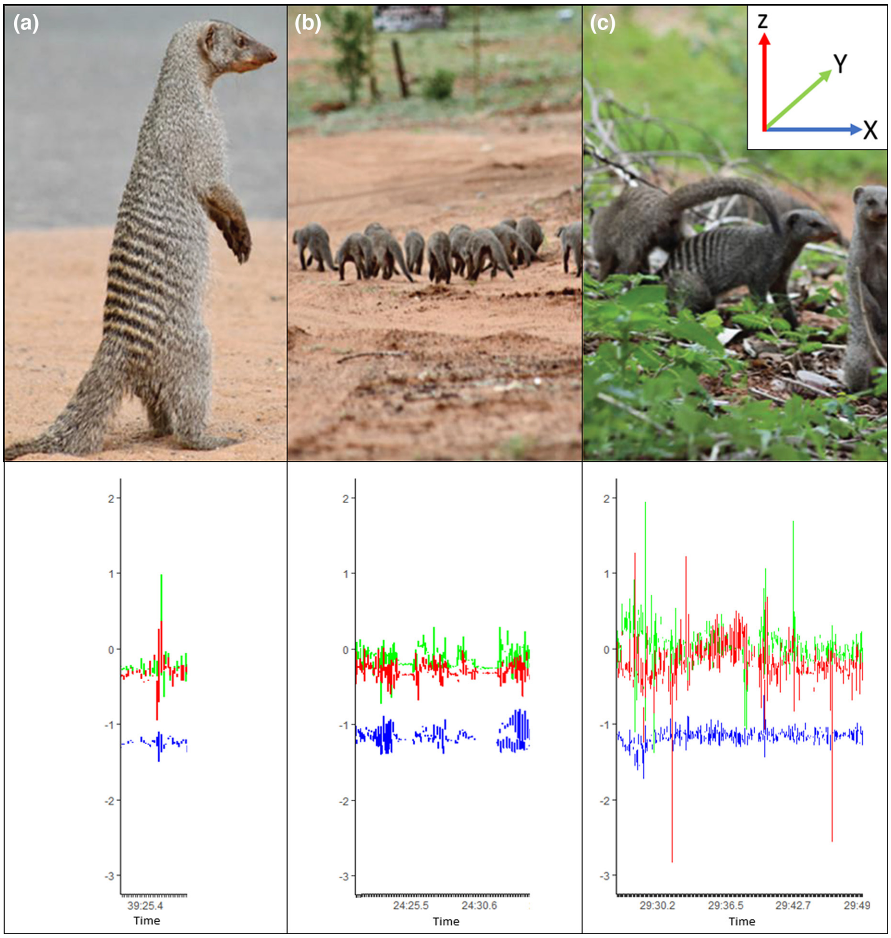

FIGURE 1 Behaviour identification via accelerometer data. Inset image denotes acceleration sensor axes orientation and colour corresponding with the lower panel. X = surge or forward acceleration (blue), Y = sway or lateral acceleration (green) and Z = heave or vertical acceleration (red). (a) Vertical vigilance behaviour (upper panel) and corresponding acceleration measurements across three axes. (b) Running behaviour (upper panel) and corresponding acceleration measurements across three axes. (c) Scent marking behaviour (upper panel) and corresponding acceleration measurements across three axes.

accelerometer and collar weighed approximately 4 g (<5%–10% body weight recommendation; Boitani & Fuller, 2001), and as such could be worn without limiting activity. Data capture settings were set at a sampling rate of 25 Hz, G full scale of ±4 with resolution set to eight bits. Collaring was performed for 2 h on November 8th 2021 to calibrate the accelerometer and to gather preliminary data on mongoose behaviour. Collaring was repeated for a 12-h period on November 11th 2021 to gather additional movement and behavioural data. Specific behaviours were recorded using an iSight model camera and timestamped using Coordinated Universal Time (UTC).

2.2 | Data analysis

Data from the accelerometers were downloaded and converted using X Manager Software (provided by the manufacturer). The data were then calibrated based on manufacturer recommendations using the PRACMA and RGL packages in R version 4.1.0 (R Core Team, 2019; Van de Vuurst & Alexander, 2023). The UTC of the recorded activities was then used to match and isolate specific mongoose activities. These activities were then tagged with their associated time stamp for future analysis. Data were visualized in R Studio (version 2021.09.1) with the use of the GGPLOT2 package (Wickham, 2016).

2.3 | Mathematical behaviour classification

Other studies have applied mathematical classification techniques such as *k*-means clustering, linear discriminant analysis, quadratic discriminant analysis, and support vector machines (SVMs) to discern different behaviours from accelerometer data characteristics (Carter et al., 2022; Nathan et al., 2012; Nielsen et al., 2010; Sakamoto et al., 2009; Watanabe et al., 2005). We therefore utilized these techniques to assess how readily the three target behaviours could be categorized with these standardized classification methods. Using a subset of the data from the November 11th which had all three target behaviours (i.e. scent marking, running and vertical vigilance), we used the *fviz_nbclust* function (*factoextra* package version 1.0.7) to identify the optimal number of centres for *k*-means clustering using the within sum squares method (Kassambara & Mundt, 2020).

2.4 | Research permission

The methods used for this study were approved by the Virginia Tech Institutional Care and Use Committee (#19-251-FWC, Amendment 1). Research and fieldwork permission for this project was provided by the Botswana Government, Ministry of

Environment, Natural Resources Conservation, and Tourism (permit EWT8/36/4).

3 | RESULTS

Three key activities were distinguishable using the tri-axial accelerometer data: vertical vigilance, rapid quadrupedal movement (i.e. running) and scent marking (Figure 1). Vertical vigilance was characterized by a rapid and isolated spike in the Y- and Z-axes (Figure 1a). These patterns were likely caused by the rapid vertical movement of the mongoose standing on its hind legs, and thus thrusting the collar and accelerometer vertically against gravity. Running was characterized by rhythmic, short burst patterns of acceleration across all three axes (Figure 1b). There was not, however, a convergence of the Y and Z acceleration axes with the X-axis. Scent marking, in contrast, was characterized by a marked dip of acceleration along the Z-axis below the X-axis of acceleration (Figure 1c). This could be caused by the mongoose dipping its head downward while performing the distinctive activity.

Results from the mathematical classification methods varied, but were consistently better than random at delineating each of the three target behaviours (McNemar's test $p<0.01$). Average classification accuracies ranged from 63% to 76.3%. *K*-means clustering with three centres yielded a between sum of squares/total sum of squares (BSS/TSS) ratio of 64.9%. The most successful classification method was SVM ($76.3 \pm 1.6\%$; McNemar's test $p<0.001$). Within the subset of data used for the classification metrics, we determined that only 5.4% of the data were classified at 'running'. This result is comparably lower than the other target behaviours (25.2%), yet was still classified successfully.

4 | DISCUSSION

Camera traps previously provided that landscape type variably influenced *M. mungi* transmission behaviours at the den site (Alexander & Nichols, 2020; Fairbanks et al., 2014). Our results showed that accelerometer-derived data may also be used to identify these same mongoose behaviours critical to pathogen transmission across larger landscape areas. Deployment of these units in wild populations provides a possible mechanism of extending our data collection across landscape types where observational approaches are impractical or impossible.

Our data cleaning and classification effort also yielded evidence supporting the utility of accelerometer implementation in this system. Notably, all target behaviours were successfully identified using standard supervised classification methods, including the detection of comparably rare behaviours (e.g. running in our sample). It is important to emphasize that proper data calibration and processing were necessary for successful analysis (see data availability). As such, data processing and calibration should be performed in conjunction with confirmed behavioural training data in future studies using these tools.

It is also important to note the limitations of this study related to the small sample size used in our analysis. Data, however, provided that triaxial accelerometers can discriminate crucial behaviours found to be important in *M. mungi* transmission and their deployment on wild populations is an important next step in this research. The results also highlight the critical importance of advancing our infectious disease toolbox for monitoring animal behaviour across complex landscapes where direct observation of a species may not be possible and the utility of accelerometers in these efforts.

AUTHOR CONTRIBUTIONS

Kathleen A. Alexander procured the funding for this project, conceived and developed the research idea, and supervised data collection. Paige Van de Vuurst curated all data. Analysis and code development was completed by Paige Van de Vuurst with assistance from Kathleen A. Alexander. Paige Van de Vuurst led the manuscript writing together with Kathleen Alexander. Kathleen A. Alexander and Paige Van de Vuurst edited drafts of the manuscript. All authors contributed critically to drafts and approved the final version of the manuscript.

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CONFLICT OF INTEREST STATEMENT

The authors declare that there are no conflicts of interest.

DATA AVAILABILITY STATEMENT

Accelerometer data calibration and processing code can be accessed via GitHub at https://github.com/pvandevuurst/Accelerometer_Callibration_Mongoose_Behavior.git, or via Zenodo at https://doi.org/10.5281/zenodo.7767741 (Van de Vuurst & Alexander, 2023).

PEER REVIEW

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