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SHORT COMMUNICATION

Home range sizes correlate positively with resting metabolic rate in bush Karoo rats (*Otomys unisulcatus*)

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Abstract
Home range size limits the amount of resources an individual can access; hence, it often increases with energy demands. However, maintaining a large home range also requires more energy expenditure, and foraging over a larger area can decrease search efficiency, especially for central place foragers that travel frequently between a home base and food patches. So far, studies examining the relationship between home range size and individual energy management are limited. We investigated whether resting metabolic rate (RMR) was correlated with home range size in bush Karoo rats (*Otomys unisulcatus*). Using flow-through respirometry and mini-GPS dataloggers, we measured individual RMR and home range size of 25 female adult bush Karoo rats in the wild. No association was found between body mass and home range size, instead, RMR was positively associated with home range size. This indicates a larger home range provides sufficient energy to support increased RMR in female bush Karoo rats, supporting either greater body mass or to fuel energy-costly biological process, which feed back to the ability to utilize alarger home range.

Keywords Metabolic rate · Home range · Otomys unisulcatus · Energy metabolism

Introduction

Home ranges contain resources needed for individuals' survival and reproduction (Burt 1943). Larger home range potentially increase the amount of resources individuals can reach, for example food patches. Thus, it is directly linked to individual access to food and overall energy intake.

The association between body mass and home range has been found across taxa (Ofstad et al. 2016; Tucker et al. 2014). McNab (1963) hypothesized that this correlation is determined by basal metabolic rate, which increases with body mass as individuals need energy to maintain more cells, reflected in increased foraging effort and larger home range (Kleiber 1932). Subsequent studies found that the increase of home range was higher than the hypothesis predicted (Schoener 1968; Swihart et al. 1988), which may suggest the efficiency of energy acquisition decreases as the size of the home range expands (Harestad and Bunnell 1979).

Metabolic rate refers to the rate at which substrates are oxidized to produce energy. Resting metabolic rate (RMR) represents the metabolic rate when the individual is resting, it is an approximate substitute for the energy cost of maintaining basal biological functions, which counts as the major component of an individual's total energy expenditure (Steyermark et al. 2005). In mammals, RMR is allometrically related to body mass at species level (White and Seymour 2003), which also partly accounts for the variation in RMR between individuals (Burton et al. 2011). Therefore, body mass could be an important contributor to the association between RMR and home range size.

Different energy models have been developed to interpret the effect of energetically expensive process on RMR varaition between individuals (Careau and Garland 2012). The allocation model assumes a constrained energy budget, predicting that individuals spend more energy in foraging in a larger home range would have lower RMR. In contrast, the performance model assumes RMR reflects the size of

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the metabolic machinery needed to support high levels of locomotor activity (such as foraging), thus predicting a positive relationship between RMR and home range. As previous research demonstrated that increasing home range contributes to improving energy acquisition, we made our hypothesis based on the performance model. We studied how home range size of central place foraging rodents is associated with resting metabolic rate, considering the influence of body mass. We predicted that home range size was positively correlated with (1) body mass and (2) RMR.

Methods

Field site and study period

The field of 4.5 ha was located in the Goegap Nature Reserve, Northern Cape Province, South Africa, within the Succulent Karoo biome. The local climate is semi-arid with mean annual rainfall of 160 mm/year, and the ambient temperatures vary from −1.5 to 24 °C during winter and from 4 to 42 °C during summer (weather station at the field site). Season is divided into cold moist season (June - November) and hot dry season (December– May). This study was conducted during the dry season from 27th November 2022 to 2nd April 2023 with low abundance of food plants (Wolhuter et al. 2022). Since male bush Karoo rats disperse further and their home range depends on females for reproductive opportunities, this study focused on adult females.

Trapping and marking

Trapping was carried out at lodges occupied by bush Karoo rats. Sherman traps and locally produced Sherman-like live traps were baited with a mixture of bran flakes, salt and sunflower oil. At first capture, bush Karoo rats were individually marked with ear tags with a unique individual number (National Band and Tag Co., Newport, KY, USA). We recorded the rat ID, body mass, and lodge where it was trapped.

Determination of home range sizes

Like other central place foragers (Bell 1990), bush Karoo rats travel repeatedly between food patches and their stick lodge (containing the nest) to transport food. This foraging strategy requires frequent visit to the central place (lodge), which limits the home range to the surrounding area of its lodge. We measured home range as a proxy for home range. Trapped individuals were fitted with mini-GPS dataloggers (Gipsy 6 model from Technosmart, Italy). The mini-GPS weighed 4.5 g including the protective coating and represented less than 5% of the body weight of the rats. The mini-GPS were fit as a rucksack with a neck and belly belt consisting of wire put through a rubber tube to avoid skin irritation. Mini-GPS were programmed to be off on day 1 and 2 (habituation) and collected fixes (longitude, latitude, altitude and timestamp) every 5 min on day 3, after which the battery run empty, and we trapped the animals to remove the data loggers (Makuya et al. 2024). The dataloggers collected data for a full day (1.28 ± 0.46 days, range 1–2 days). To analyse the home range sizes, we used the autocorrelated Kernel density estimation (AKDE) implemented through a workflow in the R packages *ctmm* (Calabrese et al. 2016) and *ctmmweb* (Dong et al. 2018) taking the location error into account estimates (Fleming et al. 2021).

RMR measurement

Once a rat was recaptured and the mini-GPS removed, it was placed back into its trap and transferred to the respirometry laboratory to measure RMR during the non-active period between 10:00 and 15:00 (Brown and Willan 1991).

RMR was measured by oxygen consumption using a flow-through respirometry system with excurrent flow (Sable Systems International, SSI, Las Vegas, Nevada). The system includes a RH-300 water vapor analyzer, a FoxBox respirometer, one 1-liter respirometry chamber and two separate air channels. Ambient air (filtered but unscrubbed for H_2O and CO_2) was drawn from outdoors at a flow rate around 700 ml min^{-1}, either going through the baseline channel without animals for baseline measurement, or the measurement channel connected to respirometry chamber containing the animal for RMR measurement. Afterword, the airflow was directed through the RH-300 and FoxBox to record water vapor pressure, O_2 and CO_2 concentration. The respirometry chamber held one rat at a time, and was kept inside a thermally insulated foam box, with the temperature maintained at 30 °C.

Measurements lasted around 30 min, consisting of 20 min of RMR measurements and 10 min of baseline measurements. Multiple individuals could be tested in sequence within the same day. Individuals were monitored via webcam and real-time data reading, to observe if the individual had entered a resting state. The respirometry trials were able to capture the resting metabolic rate as the individual remained immobile and the O_2 concentration stabilized during this period. After the measurements were completed, the rat was returned to its lodge.

Statistics and sample size

Home range and resting metabolic rate were measured for 25 adult female bush Karoo rats during the dry season

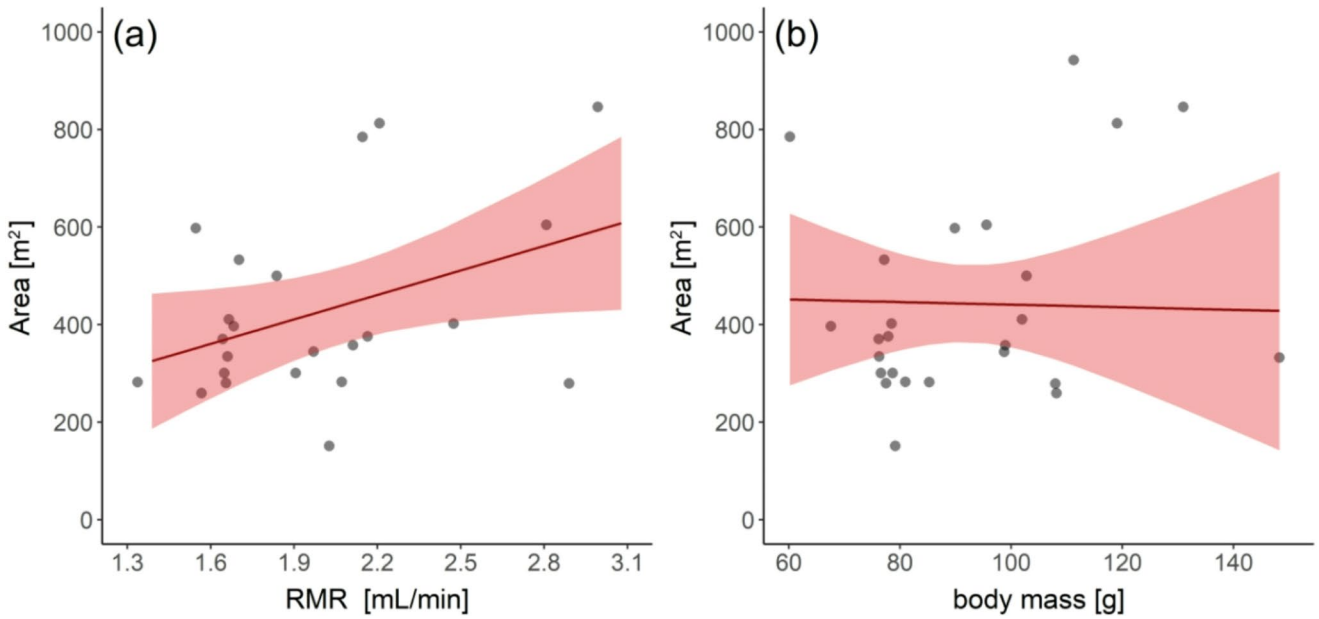

Fig. 1 Effect of individual RMR and body mass on home range size in bush Karoo rats (model 3, rerun using the unscaled data), (**a**) RMR and (**b**) body mass. The effect of RMR was significant. Regression lines and 95% confidence intervals are given as red line and shadings

Table 1 Summary of multiple linear regression models of 25 female Bush Karoo rats for the effects of body mass (g) and RMR (O_2 min^{-1}) on home range size (m^3). All predictors are standardized to facilitate comparison, all predictors were standardized. Standardized estimates (β) including their standard error (SE) are given, significant effects are given in bold

Models	Dependent variables	Predictors	β ± SE	*P*
Model 1	Home range	Body mass	58.61 ± 41.79	0.174
Model 2	Home range	RMR	101.97 ± 38.00	**0.013**
Model 3	Home range	Body mass	-5.50 ± 48.96	0.912
		RMR	105.32 ± 48.96	**0.043**

2022–2023. Statistical analyses were performed in R, version 4.3.0. To test the effect of RMR and body mass on individual home range size, we applied three multiple linear regression models, all having home range as dependent variable, the first model with body mass as predictor, the second model with RMR as predictor and the third model with both body mass and RMR as predictors. RMR was presented by individual O_2 consumption within 1 min (ml O_2 min^{-1}). In all models, predictors (RMR and body mass) were standardized to facilitate comparison, standardization was performed using the scale function in R, with all variables been transformed to have a mean of zero and a standard deviation of one. All data analysed during this study are included in the electronic supplementary material.

Ethics statement

The study was conducted according to international standards and guidelines for the use of animals in behavioral research (Vitale et al. 2018), and the legal requirements (Sect. 20 permit) of South Africa, where the study was carried out. Ethical clearance (2022/05/02B, 2003/34/3 and 2018-03-15B) was provided by Animal Research and Ethics Committee of the University of the Witwatersrand, South Africa.

Results

Home range size was 151.07 − 941.74 m^2 (mean 442.96 m^2 ± 208.82 SD, N = 25). RMR was 0.58 − 2.96 ml O_2 min^{-1} (mean 2.09 O_2 min^{-1} ± 0.63 SD), which was consistent with previous measures in bush Karoo rats (Agnani et al. 2020) and similar-sized grazing rodents (Bozinovic 1992). Body mass was 60.20–148.30 g (mean 92.25 ± 20.72 SD).

RMR had a significant positive effect on home range sizes (Fig. 1) when tested independently (model 2, Table 1) or with consideration of body mass (model 3, Table 1). Body mass had no significant effect on home range in any model (model 1 and model 3, Table 1).

Discussion

We studied whether body mass and resting metabolic rate were positively associated with home range size in adult female bush Karoo rats. Home range size was significantly and positively associated with individual RMR, but not with body mass, highlighting the role of RMR as the primary predictor of home range size, independent from body mass.

An individual's home range needs to meet the energy demands for maintaining basic biological functions, behaviors and reproduction (Haskell et al. 2002). As an important component of individuals' energy expenditure, RMR is hypothesized to be positively associated with home range size. Our results support this hypothesis in bush Karoo rats with a significant positive association between RMR and home range size. The mechanism behind this relationship could be bidirectional. On one hand, individuals with higher RMR can cover their energy demand by foraging in larger home range; on the other hand, foraging in larger range requires increased working capacity and therefore higher food requirements, which results in increase in RMR (Speakman and McQueenie 1996). Regardless of the causation, our results align with the performance model, demonstrating that there is a synergistic increase between RMR and energy-costly behaviors (foraging in large home range).

Furthermore, this relationship fits into the "pace-of-life" framework, which integrates the physiological (e.g., RMR) and behavioral traits with life history along a "fast-slow" axis (Réale et al. 2010). Behaviorally, bush Karoo rats show repeatable individual differences in docility, exploration and sprint speed, but none of them was associated with RMR (Agnani et al. 2020). Home range size may be more associated with individual's activity level, for example, proactive (more active, bold and explorative) individual (Qiu et al. 2024), may be more capable in occupying larger home range and having higher RMR, potentially adopt a series of corresponding traits of "fast" life history (e.g., short life span, high growth rate and younger age of first reproduction) and physiology traits (high metabolism; Réale et al. 2010).

On the species/population level, the allometric relationship that links body mass and metabolic rate has been fundamental for the interpretation of home range (Shokri et al. 2024), as increased energy demands require a larger home range to secure sufficient food supply (Haskell et al. 2002). Our study at the phenotypic level confirmed the link between energy demand and home range, but it cannot be explained by body mass, offering an example that heavier body mass is not the key factor in driving the positive relationship between RMR and home range within species/population. Similar results were also found in amphipod *Gammarus insensibilis*, where standard metabolic rate explained more variation in individual space use than body mass (Shokri et al. 2025).

In conclusion, our study provides insights into the factors influencing individual differences in home range. We confirmed the link between RMR and home range size, and suggest that at individual level, body mass may lack influence on this relationship.

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13364-025-00790-5.

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Author contributions JQ and LM conceived the ideas and designed methodology; JQ and LM collected the data; JQ and LM analysed the data; JQ and LM led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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Data availability Data are provided in the supplementary material.

Declarations

Conflict of interest We declare no competing interests.

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