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Hopping from the heat: The locomotory activity patterns of the Lesser Egyptian Jerboa (*Jaculus jaculus*)

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ABSTRACT

Arid-dwelling mammals are exposed to extreme daily temperatures, which puts these mammals at risk of overheating and dehydration, particularly while active, these risks are increased as the body size is reduced. Consequently, these small mammals often show strict nocturnality, confining their locomotor activity to the dark period of the day. One such animal is the Lesser Egyptian Jerboa (*Jaculus jaculus*), which occurs in the hyper-arid central regions of the Arabian Peninsula. In this study, twelve male *J. jaculus* were subjected to different light regimes. All the animals exhibited entrainment of their activity to the dark phase of each respective light regime. However, unlike other small arid dwelling mammals, *J. jaculus* confined most of its activity during the last few hours of the night rather than the initial hours of the night, a pattern which is consistent even under constant DD conditions. The last few hours of the night correlate to the coolest experienced temperatures in summer in the wild and, therefore, the ideal time for a very small mammal to be active. Larger small mammals, which may be less at risk of overheating, can afford to be active during the warmer periods of the night, namely the initial hours.

1. Introduction

All mammals have evolved to synchronize their internal biological processes and behaviours to cyclical patterns of biotic and abiotic variables (Aschoff, 1966; Daan and Aschoff, 1975; Patel et al., 2014). This has enabled mammals to survive and reproduce in all habitats of the world, including hyper-arid zones, such as deserts (Alagaili et al., 2014, 2017), caves (Abhilash and Sheeba, 2019; Simon et al., 2019), as well as subterranean niches (Hart et al., 2021a; Janse Van Rensburg et al., 2002; Oosthuizen and Bennett, 2022), to name a few. However, in the past, the innate circadian and circannual rhythmicity of these internal biological processes and behaviours was thought to arise due to so-called extrinsic advantages, namely predator avoidance or food availability (Alagaili et al., 2014, 2020; Boulos et al., 1989; Boulos and Terman, 1980; Oosthuizen and Bennett, 2022; Yamaguchi et al., 2013). More recently, however, the role of ambient temperature as the primary *zeitgeber* for the entrainment of circadian and circannual rhythms has been highlighted (Alagaili et al., 2017; El Allali et al., 2013; Farsi et al., 2020a, 2020b; Finn et al., 2022; Hart et al., 2018, 2020, 2021b, 2021c, 2022; Jacobs et al., 2020a, 2021, 2022; van Jaarsveld et al., 2019).

The decisive role of ambient temperature as a primary *zeitgeber* controlling biological rhythms has been primarily studied in arid-dwelling mammals (El Allali et al., 2013; Farsi et al., 2020a, 2020b) and, in particular, small mammals (Eissa et al., 1975; Hart et al., 2022; Kadhim et al., 1979; Sarli et al., 2015, 2016). Most small mammals in desert regions have similar behavioural and physiological adaptions to the extreme and harsh environmental conditions they experience. For example, these small mammals often possess short gestation cycles to allow for opportunistic breeding and offspring production during times of plenty, such as unpredictable rains and reduced ambient

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temperatures (Happold, 1970; Hart et al., 2018; Yamaguchi et al., 2013). Some small mammals even resort to heterothermy and torpor to avoid decreased food abundance or temperature extremes (El Ouezzani et al., 2011; Kadhim et al., 1979; Soukri et al., 1996; Yamaguchi et al., 2013). Furthermore, small mammals that inhabit arid regions often exhibit seasonal breeding (circannual rhythm) and strict nocturnal locomotor activity profiles (circadian rhythm) (Alagaili et al., 2017, 2020; Hart et al., 2018, 2020, 2021b; Sarli et al., 2015, 2016). The seasonal breeding of arid-dwelling small mammals has been driven primarily by changes in ambient temperature, then by rainfall patterns followed by photoperiod [duration of daily photic (light) stimuli] (Alagaili et al., 2017; Hart et al., 2018, 2020, 2021b; Sarli et al., 2015, 2016). This contrasts with small mammals residing in less arid regions where photoperiod is the primary *zeitgeber* for reproduction (Medger et al., 2010, 2012). Likewise, small mammals that inhabit less arid climatic regions possess greater plasticity in their daily rhythm of locomotor activity (LA). For example, the King jird (*Meriones rex)* occurs on the mountainous slopes of the southwestern parts of the Asir mountains in the Arabian Peninsula, where climatic conditions are more temperate than in the central deserts of Arabia (Alagaili et al., 2013). King jirds are not constrained to a strictly nocturnal activity pattern and favour some daytime activity (Alagaili et al., 2013). In contrast, the Libyan jird (*M. libycus*) (Alagaili et al., 2013) and the Desert hedgehog (*Paraechinus aethiopicus*) (Alagaili et al., 2020) that inhabit the extreme central deserts of Saudi Arabia (a hyper-arid region), possess some degree of crepuscular activity and are predominantly nocturnal (less plasticity) in both the laboratory and field.

As climate change, begins to take effect, many regions will experience an increase in average ambient temperature and increased frequency and intensity of extreme heat events (Jacobs et al., 2022; 2020b; Lubar and McGeehin, 2008). This will dramatically affect animals living in these arid areas, especially small mammals, due to their large surface area to volume ratio, exposing them to increased risks of dehydration and hyperthermia (Lovegrove, 2003; McKechnie and Wolf, 2019; van Jaarsveld et al., 2021; Wallace et al., 2021), and ultimately exposing them to physiological changes, including oxidative stress, which could affect their health- and life-span and reproductive output (Jacobs et al., 2022; 2020b). Therefore, understanding the behaviour of small mammals that inhabit arid regions could be pivotal in understanding the possible changes that will arise in other small mammal species facing future climate extremes. However, more research is needed to truly identify the connection between ambient temperature and the daily rhythm of LA in arid-dwelling small mammals.

The superfamily Dipodoidea is the most taxonomically rich and oldest group of bipedal rodents, including 51 species, 33 of which are bipedal jerboas and inhabit desert regions of North Africa, the Middle East and Asia (Villacís Núñez et al., 2022). Most species construct simple burrow systems to avoid the temperature extremes of the desert they inhabit; these burrow systems offer approximately a 10 °C temperature buffer to the surrounding ambient temperature (mean burrow temperature in summer ±25 °C and winter ±20 °C) (Eissa et al., 1975). In addition, circannual rhythms of reproduction have been observed in most species, with the primary *zeitgeber* controlling their seasonality of breeding being ambient temperature and rainfall (Hart et al., 2020, 2021b; Oukouchoud et al., 2003). Past field-based studies have revealed that these species are most active during the initial hours of the night (sunset), with a minor activity peak just before sunrise (Eissa et al., 1975; Kadhim et al., 1979). A recent laboratory study on the Greater Egyptian Jerboa (*Jaculus orientalis*) revealed that under 12 h light: 12 h dark (12L:12D) lighting regime, all individuals showed nocturnal behaviour (El Moussaouiti et al., 2010). At the same time, most individuals maintained robust circadian rhythmicity even under 24-h dark conditions (DD), with clearly defined activity onsets and offsets with similar percentages of activity occurring during the subjective night (El Moussaouiti et al., 2010). This may indicate that light is not the primary *zeitgeber* entraining locomotor activity of *J. orientalis*. However, there are no field observations to collaborate these findings.

In this current study, we attempted to build on the existing body of literature on LA profiles of the rodent family Dipodidae by characterising the activity profiles, under varying lighting regimes and constant ambient temperature, of the Lesser Egyptian Jerboa (*J. jaculus*) under laboratory conditions. *Jaculus jaculus* LA patterns have been well documented in the field, namely in the extreme desert regions of Iraq and Kuwait and exhibit characteristic activity patterns of jerboas (described above) (Eissa et al., 1975; Kadhim et al., 1979). However, no laboratory experiment has been conducted on *J. jaculus.* The *J. jaculus* utilised in this study were collected from the extreme central deserts of Saudi Arabia, with average summer temperatures often climbing to well above 40 °C (Fig. 1). Therefore, as with laboratory-based studies on other small mammals captured in this region (Alagaili et al., 2013, 2020) and field observations from Iraq and Kuwait (Eissa et al., 1975; Kadhim et al., 1979), we predicted that *J. jaculus* would show a strict nocturnal LA pattern, with activity starting and being greatest during the initial hours of the night (dark).

2. Methods and materials

2.1. Study site and animal capture

A total of twelve male *J. jaculus* (67.2 ± 0.2 g) were captured on land outside the city of Riyadh, Riyadh Province (24.7136°N, 46.6753°E), Saudi Arabia, between February 2017 and January 2018. The capture areas comprised of desert ecosystems with annual grasses, small herbaceous plants, small trees, rocky outcrops and occasionally small wadis, or gentle valleys. The *J. jaculus* were captured after sunset by hand using a beam light while driving around a designated site (Alagaili et al., 2017; Hart et al., 2018, 2020,2021). Captured animals were transported back to the animal facility at the Zoology Department, King Saud University.

In the laboratory, the body mass of each *J. jaculus* was recorded using a Sartorius U4600P balance 1200 g Capacity, with 0.1 g readability. The animals were subsequently placed in individual plastic containers (50 x 40 × 40 cm) provided with wood shavings and alfalfa as nesting materials. The animals were fed pelleted rodent food daily, with cut-up carrots and cucumber being supplied every second feeding day. Food and water were provided *ad libitum.* In order to avoid entrainment of animals to a fixed feeding regime, the animals were fed at varying times of the day and night (Golombek and Rosenstein, 2010). During the feeding period, the general health and condition of the animals were monitored. Animals were placed in a climate-controlled room, allowing for a constant temperature of 25 °C and constant humidity of 40–60% throughout the experiment, where light and dark cycles could be adjusted.

The plastic containers housing the *J. jaculus* between experimental cycles were cleaned, and new shavings and nesting material were provided. The room was fitted with double doors to ensure the integrity of the light cycles inside the room. A dim red light was used during feeding and cleaning times when during dark phase or constant dark (DD) conditions (light intensity <1 lux). The experimental protocol was approved by the Animal Use and Care Committee of the University of Pretoria, South Africa, ethics clearance number EC035-16.

2.2. Experimental conditions

A total of eight experimental light treatments were carried out on the *J. jaculus.* The animals were first maintained on a 12L:12D cycle (06:00–18:00 Light, 1st LD) for 14 days to observe how well they entrain to light cycles (Fig. 2). The animals were subsequently exposed to a period of total darkness (24 h DD for 21 days) to assess if they possessed an endogenous circadian free-running rhythm (Fig. 2). The animals were then re-entrained by once again being placed on a 12L:12D cycle (06:00–18:00 Light, 2nd LD) for 14 days (Fig. 2). The fourth light cycle

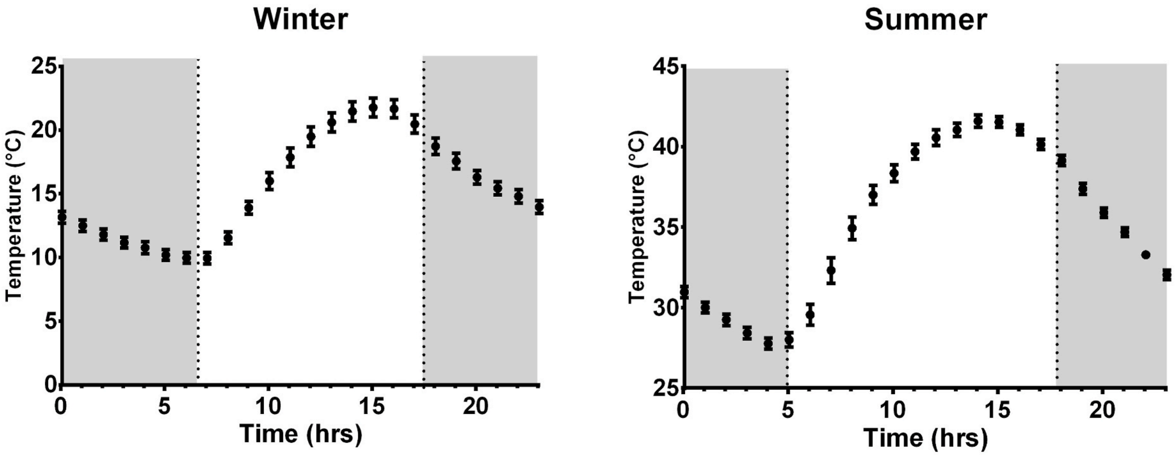

Fig. 1. Mean (±standard error) ambient temperature for Riyadh, Riyadh Province (24.7136°N, 46.6753°E), Saudi Arabia for months of winter (December 2016 to February 2017) and summer (June 2016 to August 2016). Ambient temperatures were obtained from the weather service TuTiempo.net (https://en.tutiempo.net) and Weather Underground (https://www.wunderground.com).

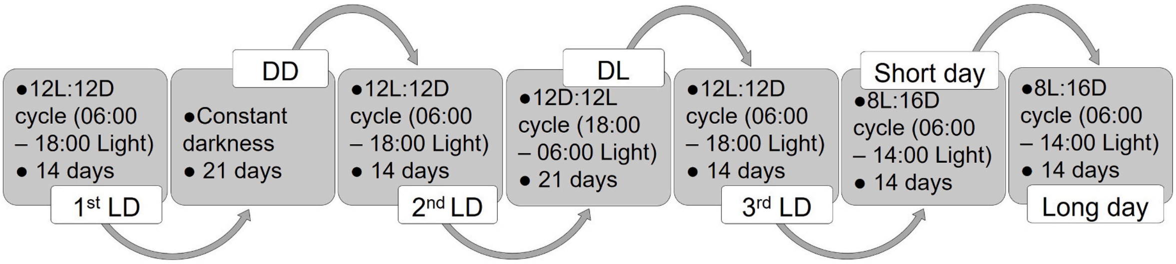

Fig. 2. A flow chart showing the different experimental light cycles experienced by all 12 male Lesser Egyptian jerboas (*J. jaculus*). L represents the light phase (light was on), and D represents the dark phase (light was off).

included an inverse of the LD cycle, 12 D:12L cycle (18:00–06:00 Light, DL), which was carried out for a period of 21 days (Fig. 2). This inverse was used to determine whether or not any change would occur in *J. jaculus* LA. The third 12 L:12D cycle (06:00–18:00 Light, 3rd LD) was used to once again re-entrain the subjects for 14 days (Fig. 2). The following two light cycles were used to observe differences in LA patterns based on different photoperiods the animals experience in their natural habitat for 14 days. Short day cycle – winter- (8 L:16D cycle (6:00–14:00 light) was then followed by a long day cycle – summer - 16 L:8D cycle (06:00–22:00 light) (Fig. 2).

2.3. Activity measurements

An infrared captor (Quest PIR internal passive infrared detector; Elite security products (ESP), Electronic lines, UK) was fitted above each of the cages in which the jerboa was housed. These sensors were placed in the middle of each cage to detect any movement that the animal made in any area of the cage. Activity was recorded continuously, and total counts per minute were captured with an automated recording system using the program VitalView (Vital View, Minimitter Co., Inc., Sunriver, OR, USA; www.minimitter.com).

2.4. Statistical analysis

Actograms and *tau* (τ) of LA were calculated using RythmicAlly in R (Abhilash and Sheeba, 2019; R Development Core Team, 2018). The proportion of activity within a cycle for each hour of the day (Equation (1)) was calculated for the last seven days of each cycle (1st LD, DD, DL, short day and long day) and presented as a percentage. To assess whether the proportion of activity within the night (dark) or subjective night varied between each cycle (1st LD, DD, DL, short day and long day), a generalised linear mixed-effects model fitted with a beta distribution (Eskelson et al., 2011) using the *GlmmTMB* package in R (Brooks et al., 2017), was conducted with cycle and body mass as predictor variables. Furthermore, individual ID was included as a random factor to account for pseudoreplication. *Post-hoc* comparisons were made using Tukey's honestly significant difference (HSD) tests using the *emmeans* package (Lenth et al., 2018). We refrained from commenting on total activity counts as biotic and abiotic factors readily influencing this (Halle 2000; Hart et al., 2021c; Kronfeld-Schor and Dayan 2008). Reported values are presented as the percentage of activity within a cycle (1st LD, DD, DL, short day and long day) for each hour of the day. Data are presented as percentages (mean ± standard error (s.e.m)).

$$Hourly\ activity = \frac{\sum_{i=1}^{24} Counts}{\sum Counts} \qquad \text{Equation 1}$$

3. Results

The majority of activity (~80%) was observed during the dark phase under 12L:12D (1st LD) of the light cycle (Fig. 3, Fig. S1). When the 12L:12D was inversed to 12D:12L (DL), the activity pattern shifted (entrained) to allow for the majority of activity (~90%) to be observed in the dark phase (Fig. 3, Fig. S2). Interestingly, maximum activity was seen 1 h prior to lights on (12L:12D: 05:00–9.62 ± 0.79%; 12D:12L: 17:00–12.5 ± 1.19%, Fig. 3). Likewise, under the short-day light cycle the majority of activity (~90%) was observed in the dark phase (Fig. 4, Fig. S3), with the peak activity 1 h prior to lights on (8L:16D: 05:00–12.1 ± 1.12%) (Fig. 4). In contrast, under the long-day light cycle, only approximately half of the activity (~45%) was observed in the dark phase (Fig. 4, Fig. S4). Furthermore, peak activity was observed 1 h after lights were turned on (16L:8D: 07:00 15.2 ± 1.02%, Fig. 4). Similarly,

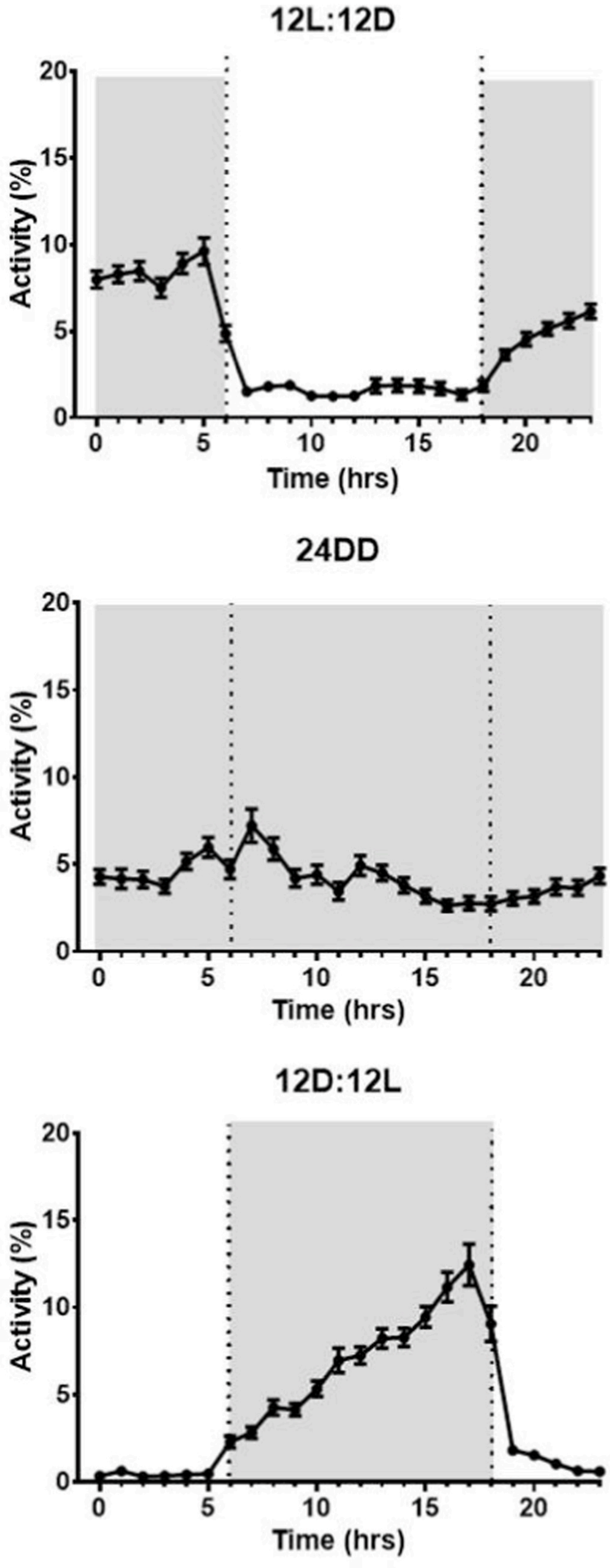

Fig. 3. Percentage (%) of daily locomotor activity expressed per hour for 12 male Lesser Egyptian jerboa (*Jaculus jaculus*) over the last seven days of each respective cycle. Solid lines indicate the mean ± s.e.m. percentage (%) of daily locomotor activity expressed per hour, whereas grey and white bars indicate the absence or presence of light, respectively.

under DD only approximately half of the activity (~50%) was observed in the subjective dark phase (18:00–06:00), with peak activity being observed 1 h after the subjective day (06:00–18:00) would begin (24DD: 07:00 7.23 ± 0.96%) (Fig. 3). Most (9 from 12 *J. jaculus*) displayed a free-running period under constant DD conditions, with an average τ of 24.0 ± 0.2 h (Fig. 3, Fig. S5).

The experimental cycle significantly affected hourly proportions of LA ($z = -4.75$, $p < 0.001$). No effect of body mass ($z = 0.75$, $p = 0.45$) was reported. The 1st LD, DL and short-day light regime showed a similar proportion of activity during the dark phase of the light regime ($p > 0.77$, for all, Fig. 5). Furthermore, the 1st LD, DL and short-day light regime showed a higher proportion of activity during the dark phase compared to the subject night and dark phase of the DD and long-day light regimes, respectively ($p < 0.001$, for all, Fig. 5). Likewise, the DD light regime showed a higher proportion of activity during the subjective night phase compared to the dark phase of long-day light regime ($p = 0.001$, Fig. 5).

4. Discussion

As predicted, in this study *J. jaculus* from the hyper-arid central deserts of Saudi Arabia showed strict nocturnal LA patterns by restricting their activity to the dark part of all light/dark cycles. Very little to no LA occurred during the light phase in any lighting regimes, barring the first 2 h of the long-day light regime. This corroborates with the findings from field observations on *J. jaculus* from Iraq and Kuwait (Eissa et al., 1975; Kadhim et al., 1979). Conforming to a strict nocturnal pattern in a hyper-arid environment is not unusual for small mammals such as *J. jaculus* (Alagaili et al., 2013, 2020). Small mammals dwelling in hyper-arid regions, such as the central deserts of Saudi Arabia, are exposed to extremely high temperatures with relatively low humidity during the day. Due to the large surface area to volume ratio of small mammals, and the associated risks of dehydration and hyperthermia during extreme daytime temperatures, it is, therefore, more advantageous to be active primarily at night, when the temperature is cooler and the loss of water and risk of overheating are reduced (Alagaili et al., 2013, 2020).

Unsurprisingly, nocturnality is a shared trait between *J. jaculus* and other small arid-dwelling mammals; however, unlike other small arid-dwelling mammals (Alagaili et al., 2013, 2020), the greatest proportion of activity was not during the initial hours (first 6 h) of the night (dark), but rather the last few hours of the night. Moreover, even under constant DD conditions, *J. jaculus* showed a spike in activity close to the end of the subjective night, suggesting there is an endogenous rhythm driving the spike in activity between 05:00 and 07:00. During this time, ambient temperatures, in both winter and summer (Fig. 1), are well below the suggested thermoneutral zone of *J. jaculus* (~33 °C–35 °C) (Ben Faleh et al., 2010; Hooper and Hilali, 1972). Hart et al. (2021c) suggested that small mammals can tolerate increased activity below their thermoneutral zone to avoid exercise-induced hyperthermia from metabolic heat. While, Speakman and Król (2010) suggests that the energetics of a small mammal could increase through enhanced heat dissipation capacity, thus, increased activity during the cooler periods may potentially allow for increased energetic output during LA. Both these reasons may explain the apparent presence of increased activity between 05:00 and 07:00 (even under DD conditions) as a method to avoid exercise-induced hyperthermia and/or to increase access to more energy. Furthermore, the activity spike during the long day light cycle which is seen at 07:00 coincides with the ambient temperature of 32.5 °C which again is below the speculated thermoneutral zone of *J. jaculus* ultimately allowing increased LA (Hart et al., 2021c; Speakman and Król 2010). Yet, an noticably drop in LA occurs at 08:00 under the long day light cycle as at this time ambient temperature is greater than the speculated thermoneutral zone of *J. jaculus.* Hart et al. (2021c) suggested that nocturnal, diurnal, or crepuscular activity observed in mammalian species could be an evolutionary artefact of temperature

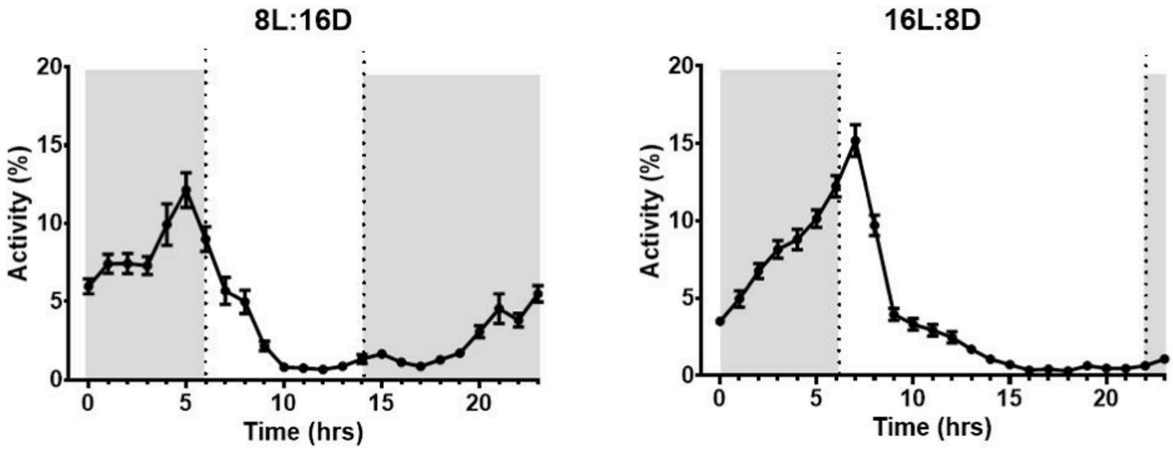

Fig. 4. Percentage (%) of daily locomotor activity expressed per hour for 12 male Lesser Egyptian jerboa (*Jaculus jaculus*) over the last seven days of each respective cycle, namely short day (8L:16D-winter) and long day (16L:8D-summer). Solid lines indicate the mean ± s.e.m. percentage (%) of daily locomotor activity expressed per hour, whereas grey and white bars indicate the absence or presence of light, respectively.

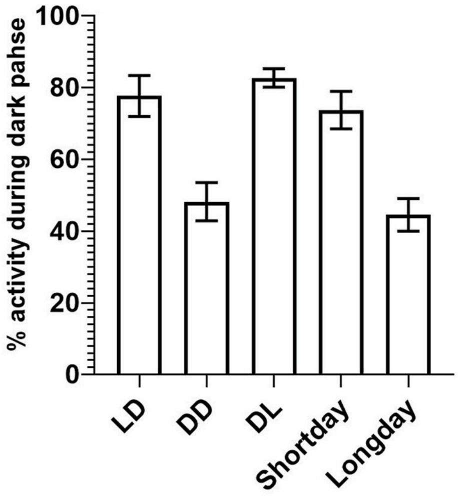

Fig. 5. The combined percentage (%) of daily locomotor activity expressed per hour during the dark and subjective night phases of 1st LD (12 L:12D), 1st DD (24D), DL/inverse (12D:12 L), short day (8 L:16D) and long day (16 L:8D) light regimes for 12 male Lesser Egyptian jerboa (*Jaculus jaculus*) over the last seven days of each respective regime.

entrainment rather than light entrainment, a hypothesis supported by increased LA of *J. jaculus* during time periods of reduced subjective natural ambient temperatures even under varying light cycles (such as long day and DD light regimes) and constant ambient temperature in the laboratory.

Jaculus jaculus are very small mammals (~70g), compared to other small mammal species tested from central Saudi Arabia (Libyan jird: ~190g and Desert hedgehog: ~550g), and therefore have a very high surface to volume ratio. As such, *J. jaculus* is at high risk of overheating whilst being active compared to the Libyan jird and Desert hedgehog, and one would characterise *J. jaculus* as being more temperature sensitive than Libyan jird and Desert hedgehog. Farsi et al. (2020a) and Hart et al. (2021c) hypothesised that a mammals' sensitivity to changes in ambient temperature would determine the strength of ambient temperature as a *zeitgeber*. Small mammals that inhabit hyper-arid environments, for example, *J. jaculus*, the Libyan jird and the Desert hedgehog, would be at more risk of overheating while being active compared to temperate-arid dwelling small mammals, such as the King jird and Arabian spiny mouse (*Acomys dimidiatus*), due to the extreme temperatures of hyper-arid regions (this study; Alagaili et al., 2020, 2014, 2013). Small mammals in hyper-arid regions are more sensitive to daily temperature changes than those in temperate-arid regions. The smallest hyper-arid dwelling mammals are at the highest risk of overheating due to their higher surface-to-volume ratio. Therefore, it is possible that small mammals in hyper-arid regions are more likely to synchronize their activities with daily temperature changes, especially the smallest hyper-arid dwelling small mammals (Hart et al., 2021c). Therefore, unsurprisingly, the smallest hyper-arid dwelling small mammal tested, *J. jaculus*, was the most active during the last few hours of the dark phase of the 12L:12D light regime, which would coincide with the coolest ambient temperatures in summer in the wild (05:00–07:00; Figs. 1 and 6). While the largest hyper-arid dwelling small

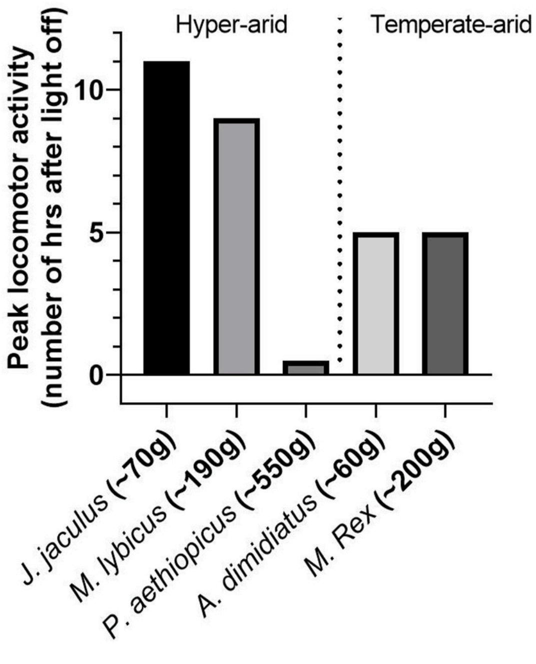

Fig. 6. The number of hours (hrs) after lights off in 12 Light:12 Dark (06:00–18:00 Light) that the peak locomotor activity occurred in small mammals that inhabit hyper-arid regions, namely the Lesser Egyptian Jerboa (*Jaculaus Jaculus;* this study), Libyan jird (*Meriones libycus*; Alagaili et al., 2013) and Desert hedgehog (*Paraechinus aethiopicus*; Alagaili et al., 2020), and temperate arid regions, namely the King jird (*M. rex;* Alagaili et al., 2013) and the Arabian spiny mouse (*Acomys dimidiatus*; Alagaili et al., 2014). The average body mass (grams) of each species is given.

mammal tested, the Desert hedgehog, was active during the earliest period of the dark phase of the 12L:12D light regime, which would coincide to the warmer period of the dark phase in the wild (18:00; Figs. 1 and 6). The hyper-arid dwelling small mammal species with medium-large body size, the Libyan jird, showed a peak activity in the middle of the dark phase of the 12:12D light regime, which would coincide with the period of the dark phase in the wild that exhibits an intermediate ambient temperature (22:00; Figs. 1 and 6). Therefore, one would speculate that body size dictates the risk of overheating during activity and temperature sensitivity in hyper-arid regions. In regions where the ambient temperature is not as extreme, small mammals, in general, will not be as temperature sensitive since the risk of overheating during activity is low, and, therefore, LA rhythms would be less dependent on ambient temperature and ultimately, body size (Fig. 6).

Compared to mesic regions, the evolutionary pressures driving nocturnal activity in small mammals that inhabit arid regions are great. This is likely due to the increased risk of dehydration and overheating if active during the day, the hottest period of the 24-h cycle. However, small mammals that inhabit more arid regions are disproportionately at higher risk of overheating compared to those inhabiting a less arid region (van Jaarsveld et al., 2021), resulting in an increased sensitivity to ambient temperature. Furthermore, this increased sensitivity to ambient temperature is exaggerated by a smaller body size, thus forcing the smallest hyper-arid dwelling small mammals, such as *J. jaculus,* to confine their activity to the coolest periods of the day. Likely, the extreme selective pressure for activity during the coolest period of the day has resulted in *J. jaculus* being strictly nocturnal and showing increased activity during the subjective coolest period of the day (early morning). This hypothesis is confirmed by observing increased activity during the subjective early morning period of the DD light regime.

As the effects of climate change become more apparent, small mammals from cool mesic regions of the world will experience increased daily ambient temperature extremes, which in turn will affect the daily rhythms of these mammals. This study suggests the smallest of these species would be affected first, and as such, monitoring field activity rhythms of the smallest mesic-dwelling mammals would be an ideal indicator of the effect of climate change and subsequent aridification.

CRediT authorship contribution statement

N.C. Bennett: Conceptualization, Methodology, Investigation, Data curation, Validation, Writing – original draft, Resources, Project administration, Funding acquisition, Writing – review & editing. **D.W. Hart:** Conceptualization, Methodology, Investigation, Data curation, Validation, Writing – original draft, Resources, Project administration, Writing – review & editing, Formal analysis, Visualization, Project administration. **S. Munro:** Data curation, Validation, Writing – original draft. **N. Amor:** Investigation, Data curation, Validation, Writing – original draft, Resources, Project administration. **O.B. Mohammed:** Investigation, Data curation, Validation, Writing – original draft, Resources, Project administration. **A.N. Alagaili:** Conceptualization, Methodology, Investigation, Data curation, Validation, Writing – original draft, Resources, Project administration, Funding acquisition.

Declaration of competing interest

We the authors declare no competing interest or use of Generative AI and AI-assisted technologies in the writing process beyond echnologies to improve readability and language.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jaridenv.2023.105116.

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