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Physiological and behavioural responses of a small heterothermic mammal to fire stimuli

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HIGHLIGHTS

- We report behavioural and physiological responses of a mammal to fire cues.
- Smoke exposure caused immediate arousal in dunnarts (*Sminthopsis crassicaudata*).
- After smoke exposure torpor use decreased and activity increased.
- Charcoal/ash substrate resulted in a decrease in torpor use and activity.
- Food withdrawal reduced the impacts of smoke and charcoal/ash substrate.

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ABSTRACT

The predicted increase of the frequency and intensity of wildfires as a result of climate change could have a devastating impact on many species and ecosystems. However, the particular physiological and behavioural adaptions of animals to survive fires are poorly understood. We aimed to provide the first quantitative data on physiological and behavioural mechanisms used by a small heterothermic marsupial mammal, the fat-tailed dunnart (*Sminthopsis crassicaudata*), that may be crucial for survival during and immediately after a fire. Specifically, we aimed to determine (i) whether captive torpid animals are able to respond to fire stimuli and (ii) which energy saving mechanisms are used in response to fires. The initial response of torpid dunnarts to smoke exposure was to arouse immediately and therefore express shorter and shallower torpor bouts. Dunnarts also increased activity after smoke exposure when food was provided, but not when food was withheld. A charcoal/ash substrate, imitating post-fire conditions, resulted in a decrease in torpor use and activity, but only when food was available. Our novel data suggests that heterothermic mammals are able to respond to fire stimuli, such as smoke, to arouse from torpor as an initial response to fire and adjust torpor use and activity levels according to food availability modulated by fire cues.

1. Introduction

Changes in ambient temperatures (T_a) are only one of the many predicted outcomes of climate change and one of the consequences that is already being observed worldwide is an increase in intensity and frequency of wildfires [1,13,20,36,38,46,53]. Australia is particularly susceptible to fires [4,47] and the effect of climate change in Australia is apparent by the recent early starts to the fire season. While fires are a natural part of the Australian landscape, a shift in the timing and an increase in the frequency of fires may negatively impact on a range of plants and animals, even those that are adapted to fire, making correct management of prescribed fires vitally important [6,47,58].

Ecological data on how animal populations recover from wild and prescribed fires are available to some extent [1,3,9,11,15,27,36,47]. In contrast, data on how individuals cope behaviourally and physiologically during and also after a fire in the subsequent denuded landscape are scant [14,45,47]. Obviously, an understanding of the interactions between behaviour and physiology is important in general [49], but it also has been identified as being fundamentally vital in regard to the sustainable management of fires [13–15,38,45].

Emerging research indicates that many species, especially small mammals that shelter in burrows and rock crevices, are able to survive fire [19,25,45]. As far as insectivorous mammals and birds are concerned, insect abundance is often significantly reduced after a fire, but foraging might become easier [8,12,41,47,54,59]. Along with possible changes in food availability, another important issue in Australia is the presence of introduced predators that hunt more successfully in the open environments created by the fire and, therefore, post-fire predation of small vertebrates can be dramatically increased [23,25,30].

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Therefore, the response of individuals to fire is dependent on the particularities of the fire itself, habitat, life history traits and most importantly how a species manage their daily energy budget [16,26,27,32,45,59].

Energy expenditure in small mammals is generally high but can be substantially decreased by the use of torpor, which is characterised by a reduction in metabolic rate, body temperature (T_b) and water loss and is often used in times of energetic stress to conserve energy [37,40,44]. Clearly, in the aftermath of a fire torpor would be advantageous because it enables small mammals to conserve large amounts of energy and perhaps survive until conditions become more favourable. However, torpor could potentially also be detrimental if it prevents an animal from evading an approaching fire front and the individual is torpid in a location susceptible to destruction by a fire. Surprisingly, quantitative data on the use of torpor directly in relation to fire are scant [45], but torpor has been linked to the survival of many species dealing with environmental challenges in general and in Australia recent mammalian extinctions encompassed mainly homeotherms that are unable to use torpor [18].

The purpose of our study was to examine torpor and activity patterns in fat-tailed dunnarts (*Sminthopsis crassicaudata*; henceforth referred to as 'dunnarts') in relation to the effects of fire. We examined whether dunnarts are able to detect smoke during torpor, how dunnarts respond to smoke exposure after torpor, and how torpor and activity are modified on a charcoal/ash substrate as in post-fire environments when resources and refuges are likely to be limited. Dunnarts belong to the marsupial family Dasyuridae and are nocturnal carnivores/insectivores that live in a range of habitats throughout southern Australia, many of which periodically experience fires (*e.g.* hummock grassland) [31]. They use daily torpor throughout most of the year, but increase torpor use during winter [17,51]. Dunnart species are under pressure from a range of native and introduced predators such as feral cats and European foxes [35,42]. As dunnarts often take refuge under fallen woody debris, rocks, cracks in the soil or Spinifex hummocks, they also appear to be vulnerable to fires [33,52]. Importantly, in Australia many small mammals including a number of dunnart species live in particularly fire-prone habitats [24–27,32]. Considering the ecology and biology of dunnarts and other small mammals, we hypothesised that adjustments of activity and torpor patterns during and after a fire event will be important for their long-term survival.

2. Material and methods

2.1. Animals

Captive-bred dunnarts were used for our study and were housed individually in cages (35 × 27 × 21 cm) that were lined with wood shavings and cleaned regularly. Dunnarts were also provided with a nest box containing shredded paper, 2 cardboard rolls and a running wheel. Water was always provided ad libitum, whereas food was provided ad libitum on most days, but was withheld during the experiments for a maximum of one day at a time. Dunnarts were fed once daily in the late afternoon with a mixture of canned cat food and dry cat food soaked in water, supplemented with mealworms and minced meat. The room used for both experimental procedures was kept on a short photoperiod of L:D 10:14 h to simulate natural winter conditions and T_a was maintained at 18.0 ± 0.9 °C (recorded at 10 min intervals using a calibrated iButton Thermochron DS1921G, resolution 0.5 °C, Maxim Integrated Products, Inc., USA). Dunnarts were housed in these conditions for two to four weeks prior to commencement of the experiments. Throughout experiments animals were weighed weekly to the nearest 0.1 g with an electronic balance.

2.2. Smoke treatment

To record T_b throughout the smoke treatment dunnarts ($n = 5$ adult females) were implanted with temperature-sensitive radio-transmitters (1.25 to 1.44 g, Sirtrack, Havelock North, New Zealand). Before implantation these transmitters were coated with inert wax (Paraffin/Elvax) and calibrated in a water bath in a temperature range of 14 to 43 °C to the nearest 0.1 °C. For each individual a transmitter was chosen that was <10% of body mass as recommended by Rojas *et al.* [39]. General isoflurane/oxygen anaesthesia was used for surgery and 70% alcohol for sterilisation of the skin, transmitters and surgical instruments. Transmitters were implanted intraperitoneally and the surgical incisions to the muscle and skin layers were closed using coated Vicryl (3.0 metric, Ethicon Inc.). A topical anaesthetic (Xylocaine, AstraZeneca Pty Ltd., North Ryde, NSW, Australia) and Leuko Spray Bandage (BSN medical (Aust) Pty Ltd., Clayton, Vic, Australia) was applied to the surgery site following the completion of the surgery to promote wound healing. Children's Panadol (Ermington, NSW, Australia) was also provided for post-surgery recovery.

After two weeks of recovery from surgery and acclimation to their new surroundings, the experimental smoke treatment began and lasted for four weeks. Two feeding regimes were used, one involved food ad libitum and the other was no food. On a weekly basis food was withheld on two days, one with smoke and one without smoke, with at least two days of recovery with ad libitum food between these days. By burning 50 g of *Eucalyptus* leaves in a fireproof container, smoke was introduced into the room twice weekly at 8:00 h for 15 min: (i) following a night where food was provided ad libitum and (ii) following a night when food was withheld. A smoke spot tester kit (Testo 308, Testo AG, Lenzkirch, Germany) was used to measure the density of smoke particles in the air. The smoke number scale ranges from zero (clean air) to six (thick smoke) and a measurement was taken prior to lighting the fire and then at 5 min intervals throughout the experiment. During the experiment the smoke number was maintained around the approved midrange of three, which mimicked a control burn, but was enough to elicit sustained discomfort in the experimenter. The fire was controlled by replacing or removing the lid of the fireproof container.

Throughout the four weeks of the experiment we continuously recorded T_b and activity patterns of dunnarts. A remote receiver/data logger system [22] was placed in the room to record the T_b of the animals every 10 min. Activity was measured continuously with passive infrared sensors, which are triggered by movements from an object with a temperature different from the surrounding temperature [21]. These sensors were attached to the top of each cage and activity was summed over 10 min periods and stored on a custom-made logger (Electronic Services Unit, UNE, Armidale). Activity data induced by experimenters entering the room, usually for feeding at 15:00–16:00 h, were removed. Additionally, an experimenter entered the room on days without smoke at the same time as when smoke would be introduced (8:00 h) to determine whether any responses observed were due solely to smoke or to perhaps the presence of an experimenter.

2.3. Substrate treatment

For the substrate treatment, dunnarts ($n = 7$ adult females) were acclimated to the conditions of a new holding room for two weeks. The animals had been implanted previously with subcutaneous transponders (IPTT-300 Bio Medic Data Systems Implantable Programmable Temperature Transponder, Delaware, 0.13 g, 14 mm × 2 mm, for details see [50]). The subcutaneous temperatures (T_{sub}) of dunnarts were scanned (DAS-7006/7R/S Handheld Reader, Bio Medic Data Systems) daily between 9:00 and 10:00 h, during which time torpor in dunnarts is usually most pronounced. Nevertheless, since it is unlikely that this single daily measurement would have recorded the minimum T_{sub} for every day, we only analysed the absolute minimum for each animal per treatment.

Once acclimated, individuals were exposed to a charcoal/ash substrate for a period of four days and this was repeated two weeks later using the same method although for a period of eight days.