

Effect of hibernation on bears



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Introduction

Bears are members of the family Ursidae, there are eight species alive today, with a large geographical range. They are found in North America, South America, Asia and Europe; they occupy a large range of habitats, from the Arctic tundra to temperate forests (Craighead Institute 2010). During winter, bears enter a state of dormancy.

Most animal species become dormant to some extent during their lives, as an energy saving mechanism. Sleep is the archetypal form of dormancy, with animals retiring to a nest, assuming a sleep posture, remaining behaviourally quiescent and exhibiting elevated arousal thresholds (Heller et al 2004).

A more extreme form of dormancy is torpor. Torpor is characterised by a controlled reduction of body temperature (T_b), metabolic rate, and other physiological functions (Geiser 2004). Torpor has the superficial appearance of sleep, indeed torpor and sleep are believed to be homologous. This has been supported by numerous electroencephalographic (EEG) studies (Heller et al. 2004). There are two basic forms of torpor used by heterothermic animals, hibernation (or prolonged torpor) and daily torpor. Daily torpor is usually not as deep as hibernation, lasts only for hours rather than days or weeks, and is usually interrupted by daily foraging and feeding (Geiser 2004).

There is a lack of agreement over whether the winter dormancy of bears constitutes “ true” hibernation. Hibernation is defined as “ the dormant condition into which many animals and plants pass when the temperature falls below certain limits; esp. the winter sleep of some warm-blooded

animals, as the dormouse, hedgehog, badger, bear, bat etc.” (Oxford Dictionary 2010) by the Oxford English Dictionary. However, within the scientific community more specific definitions are often used, and as such, whether bears are true hibernators or not depend upon the particular definition.

Bears endure the winter months in a condition of starvation, dehydration, mild hypothermia, hypotension and inactivity without bouts of active arousal. Although bears have depressed metabolic function during this period, defensive posturing and high respiratory rates in these animals within a very short period (seconds) of being disturbed has been observed. Because of this elevated level of arousal readiness and associated physiology that distinguishes bears from other hibernators, some avoid referring to the overwintering state exhibited by bears as “ true” hibernation (Laske et al. 2010).

However, research by G. E. Folk, Jr. and R. A. Nelson amongst others has led investigators to unequivocally state that hibernation is the fitting term for the dormant state of bears. Nelson argues that bear hibernation is the most refined response to starvation of any mammal (Hellgren 1998). Nelson is one of the most well renowned researchers of bears and *Ursus* is the leading journal regarding bears. As such for the purposes of this review, we will be considering the winter dormancy period of bears as a form of hibernation.

Triggers of Hibernation

Observation of behaviour prior to entering hibernation in the bear species has been conducted over many years yet the physiological causes is still

under debate. With the ability to rouse from winter hibernation, bears are less reliant on building up body reserves prior to entering this state.

The bear's annual cycle has been divided into four distinct categories based on levels of activity; hibernation, waking hibernation, normal activity and hyperphagia (Nelson et al. 1980). This assessment has been further reviewed to define the categories and provide insight into hyperphagia, the process of preparation for hibernation. Hyperphagia occurs in the autumn with food consumption increasing to 20,000 kilocalories over twenty hours each day. This causes a large rise in the nitrogen output in urine in contrast to the decrease in protein metabolite excretion during the actual stage of hibernation (Nelson et al. 1980). Increasing fat reserves result from this practice and prove vital for metabolic processes during hibernation. Bears voluntarily decrease their feed intake in late hyperphagia whilst continuing to excrete nitrogen at high concentrations to reduce metabolic accumulations which would prove fatal during winter dormancy. This causes increasing lethargy and bears prioritise resting over calorie consumption, sleeping for up to 22 hours per day. This contributes to a decrease in physiological mechanisms such as heart rate, which gradually drops from 80 beats per minute to 66 per minute at rest (North American Bear Centre).

Induction of hibernation in captive Japanese black bears (*Ursus thibetanus japonicus*) has also shown this voluntary decrease in intake but it was accompanied by a change in food preference before food supply was purposely stopped to provoke sleep. Hibernation in this study was also induced by decreasing light duration and temperature to mimic normal climatic changes, which was not considered in the previously described

studies (Itoh et al. 2010). In my opinion from these studies, it is still largely unknown as to the extent of natural behaviour exhibited by bears in captivity, so this may not be a true representation of the triggers of hibernation. Very few zoos have attempted to induce hibernation due to the vast input required in terms of preparation and provision of the correct environment. Nesting material was also provided for the Japanese black bears to allow gathering and choice of where to hibernate (Itoh et al. 2010).

Hibernation Induction Trigger (HIT) is found to induce hibernation in black bears (*Ursus americanus*) through sampling of plasma albumin, to which the small protein hormone is bound (Bruce et al. 1995). HIT has an opioid effect, binding to delta opiate receptors to cause hibernation in the winter. The effects are antagonised by mu and kappa opiate receptors, which may increase in number during the summer in the bear and oppose the induction of torpor during this time (Bruce et al. 1995). However the true effects, structure and regulation of HIT are not yet fully known, raising the question of how significant the hormone is in triggering winter torpor. Injection of bear HIT to ground squirrels (*Spermophilus parryii*) was capable of causing summer hibernation and decreased muscle contractility (Bruce et al. 1995). Polar bears (*Ursus maritimus*) do not enter true winter dormancy yet retain high winter albumin concentrations of HIT still causing summer hibernation in ground squirrels (Bruce et al. 1990). Hibernation may be “ a case of convergent evolution, no hibernation factor should be expected to be universal in promoting hibernation” so each bears species may have a differently structured HIT molecule (Bruce et al. 1990).

Both studies agree that HIT plays a key role in inducing winter torpor yet the true structure is undefined as it may be opioid in its own nature (Bruce et al. 1995) or induce the release of endogenous opioids during the autumn prior to hibernation (Bruce et al. 1990). The discovery that polar bears also have fluctuating HIT levels despite lack of hibernation can imply that it is not the key factor in causing hibernation yet may be part of the bears ability to wake during hibernation. The role of melatonin from the pineal gland in controlling circadian rhythms may also interact with HIT to cause hibernation due to changing day length (Bruce et al. 1990).

Overall, multiple factors appear to contribute to the altered behaviour of bears prior to hibernation from climatic components such as changing daylight to still as yet unknown hormones released endogenously in the autumn. These cause hyperphagia to commence in the brown (*Ursus arctos*) and black bear, with non-hibernating species such as the polar bear still displaying similar mechanisms despite the need to lower metabolism and enter hibernation.

Temperature

A bear has a normal summer body temperature of roughly 37.5°C. Generally a drop of roughly 3-5°C is seen which has been found in many studies (Hissa et al 1994, Hellgren et al 1990, Hissa 1997) however Harlow et al 2004 believe the drop to be slightly larger at 5-7°C. It is generally agreed that the temperature of the hibernating bear does not fall below 30°C which is in contrast to other small hibernating mammals such as the arctic ground squirrel whose temperature falls below freezing. One major issue with any temperature data is that very little has been collected from bears in the wild

in their winter dens, so it is unknown if bears maintain hypothermia or are involved in periods of activity leading to temperature increases (Harlow et al 2004). It has been theorized by Harlow et al 2004 that non-shivering thermogenesis is responsible for the maintenance of skeletal muscle, without the inadvertent rise in core body temp leading to a disturbance of torpor. Diurnal rhythms were seen with temperature fluctuations from 0.3°C to 1.2°C by Hissa et al 1994 however this may be due to external stimuli as staff worked in the surrounding area and it has been contested by Harlow et al 2004 who reported a 1.5°C range of core body temperature and that “spectral analysis did not identify a daily rhythm of body temperature changes in any of the bears during this period.” Hissa 1997 also observed a dramatic increase in the temperature of a pregnant bear prior to her delivery, with a steady decline that ceased at 34.5-35.0°C while Hellgren et al 1990 also observed a higher body temperature in nursing black bears

Thyroid Hormones

As a bear enters hibernation a considerable change to metabolic rate occurs. The thyroid gland being the endocrine organ by which metabolic homeostasis is regulated via the hormones T4, T3 in systemic blood flow. Thyrotropin Stimulating Hormone (TSH) is released via the hypothalamus and acts as a negative feedback loop in order to maintain optimum thyroid hormone levels. As the bear reduces the intake of food towards the winter months so does the basal metabolic rate of the bear decrease by as much as 35 to 75% (Hissa et al 1994) with T4 utilization rate reduced by 12 to 33% and T3 reduced by 50% (Tomasi, Hellgreen and Tucker 1997), however this makes the determination for reduced thyroid hormones difficult to identify as

it could be a consequence of the hibernation process or due to the lack of food intake, as both of these actions have been found to depress thyroid function (Hulbert and Hudson, 1976; Tomasi, 1991; Tomasi and Stribling, 1996). However, it was determined that hibernation caused a reduction in thyroid hormones irrespective of seasonality due to free hormone concentrations remaining low throughout the duration of the hibernation period. (Tomasi, Hellgreen and Tucker 1997). Inspection of the thyroid gland at a histological level showed that the gland appeared to be normal (Nelson et al 1973) therefore the reduced thyroid hormone levels were due to the hypothalamus lowering the production of Thyroid Releasing Hormone (TRH) resulting in hypothalamic hypothyroidism as suggested by Azizi et al (1979) As the bear leaves the hibernation state the levels of T3 and T4 rise as there is once again an output of TRH by the hypothalamus which thereby increases the output of Thyroid Stimulating Hormone by the anterior pituitary.

Weight

As winter approaches the bear will enter a stage of hyperphagia in which vast quantities of food are consumed (2 to 3 times the normal quantity) in order to lay down fat reserves for the coming hibernation. Hissa 1997 found that in this period the bear can build up its weight by 30 to 35%. As the bear prepares itself for hibernation it evacuates the contents of its gastrointestinal tract and ceases eating until the spring, this causes mobilisation of fat reserves which results in a loss of body condition. It has been consistently found that bears in both natural and captive environments lose about 20 to 25% of their body mass during the hibernation period (Hissa 1997, Nelson et al 1973, Hissa et al 1994 and Hellgren 1990). The mass lost each day seems

to vary greatly depending on gender, reproductive status and age however general figures range from 260grams per day culminating in a loss of 23.1% body mass (Hellgren et al 1990), 517grams per day culminating in a loss of 25% for a 2 year old male and 366grams per day and 22% for a 3 year old female (Hissa et al 1994) and for a comparison of how pregnancy affects weight loss 378grams per day compared with non-pregnant figures in the same bear of 286g/day (Hissa 1997). An important variable to mention is the effect of external stimuli on the bears in their hibernatory state as it has been found that bears which are disturbed and abandon their dens may lose 56% more body mass than those which are left alone (Hellgren 1990), this variable cannot be ruled out in any study which involves captive bears as keepers may affect the pattern of hibernation and therefore alter the rate of metabolism causing a change in percentage body mass.

Respiration Rate

The respiration rate of bears during the summer ranges from 15 to 30 beats per minute (bpm) depending on external environmental factors such as temperature (wildlifeinformation.org) In the study by Suzuki et al 2009 found that the bear they studied had a respiration rate of 10bpm prior to hibernation which reduced by 80% during the winter months to 2bpm. The change was very gradual and while fluctuation did occur it could be attributed to that of a circadian rhythm. The respiratory quotient during hibernation was found to be 0.60 compared to a summer value of 0.78 (Nelson et al 1973).

Cardiovascular changes

Grizzly bears (*Ursus arctos horribilis*) hibernate for approximately 7 months each year (Folk Jr. 1979) During this time their resting heart rate drops from roughly 84bpm to as low as 19bpm (Nelson et al. 2008). Bears maintain this very low heart rate and yet do not develop congestive heart failure or cardiac chamber dilation (Barrows et al. 2011) as is caused in bears with chronically low heart rates (Verduyn et al. 2001). The level of cardiac maintenance may be due to increased cardiac wall plasticity and titin isoform shift (Nelson et al. 2008); the same study demonstrated that this shift led to an increase in left ventricle wall stiffness during hibernation. This was because the diastolic filling pressure in the atria increases with chronically low heart rate and can put stress in the cardiac walls (Nelson and Robbins 2010). This is likely to prevent the atrophy associated with smaller hibernating species, though this is only hypothesised and has not yet been convincingly demonstrated by the investigators (Barrows et al. 2011)

Whilst the cardiovascular system of hibernating bears undergoes severe bradycardia (Milsom et al. 1999) there is not a significant drop in blood pressure (Nelson et al. 2003) although in the same study there was a significant drop when blood pressure was measured directly with a cuff, the authors discuss the possibility that the cuff used to directly measure blood pressure was too small and so gave an exaggeratedly high reading; further investigation into this area may be prudent to clarify the point further.

In 2003, Nelson et al. were unable to provide an explanation for the mechanisms by which cardiac alteration occurs in hibernating bears; last year the same author published results indicating that there was an

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alteration in gene expression for myosin heavy chains within the cardiac tissue and that this was responsible for the changes previously observed (Nelson et al. 2011). The triggers for these genetic changes are, as far as we are aware, unknown.

Bone

Usually, if routine bone stresses are removed, this has deleterious consequences for the integrity of the bone. Removal of these stresses may be due to immobilization, inactivity or reduced gravity. Unbalancing bone formation and bone reabsorption by reduced skeleton loading causes net bone loss. It takes 2 to 3 times longer to remobilize bone than it does to lose it through inactivity. However, annual periods of disuse during hibernation are experienced by bears in northern climates. These periods average 6 months in the black bear every year, yet they do not experience cortical bone mechanical or structural consequences with age (McGee-Lawrence 2008). It has been shown that black bears can maintain bone mass after 4 months of hibernation (inactivity) unlike other species where periods of inactivity result in substantial net bone loss (Hellgern 1998).

Smaller mammalian hibernations like ground squirrels do lose bone during hibernation as they excrete calcium liberated from their bone during periods of arousal leading to progressive bone loss over time. Bears have evolved to recycle calcium, prevent hypercalcemia, and maintain bone integrity. The bone of hibernating bears is shown to be less porous and more mineralized than that of active bears. They therefore maintain a balance between bone formation and bone reabsorption allowing them to keep their bone strength throughout the period of hibernation (McGee-Lawrence 2008). To contrast

with this it has also been shown that bear simply remodel the bone they have lost very quickly at the end of hibernation. This may be due to the fact that bears osteoblasts are more sensitive to mechanical stimulation due to altered circulating hormone levels (Seth 2003). As this study was on wild bears samples were not taken at very regular intervals and the stress of sampling may have affected the results as stress effects hormone levels in blood. It has been shown that black bears exhibit hyperactive bone metabolism in spring which can be interpreted as a response remodelling during hibernation (Hellgren 1998) which complements the article written by (Seth 2003).

It has been suggested that an osteoregulatory substance that permits continued osteoblast activity even during skeletal disuse exists. Osteoporosis is a disease in which bone become more porous and the density and mass of the bones decrease as a result. If a substance like this was found it would have profound uses in the treatment of osteoporosis across species (Hellgren 1998).

Fat and Water Metabolism

Bears use fat as their main source of energy when they are hibernating. Lean body mass remains essentially constant, in non-lactating bears, during hibernation (Nelson 1980), this leads to the hypothesis that the metabolism of fat must be the main source of energy for hibernating bears.

The respiratory quotient (RQ) in hibernating bears decreases from 0.78 to between 0.62 and 0.69 during hibernation (Nelson 1980). This shows that the bear is purely using fat as its metabolic substrate. Also, blood

concentration levels of cholesterol, triglycerides, fatty acids and phospholipids increase and remain elevated until the bear wakes up in the spring. There are also findings from (Lundberg 1976) on the black bear supporting this.

Carbon lost in catabolic pathways is replaced by glycerol released during lipolysis (Nelson 1980). Hibernating bears do not develop ketosis despite utilizing fat for metabolizable energy as increased triglyceride turnover in the winter sufficiently inhibits fatty acid entry into metabolic pathways of ketone production. Only slight increases of β -hydroxybutyrate and acetoacetate were found in hibernating bears (Nelson 1980).

Water is provided mainly by fat metabolism in hibernating bears in order to replace respiratory losses. The total body water therefore remains constant throughout the hibernation process. This has been shown by assessing total body water, plasma water content, blood volume and haematocrit (Nelson 1980).

The bladder filters 100ml of urine a day but it reabsorbs both water and solutes. This is a similar process to that in severely dehydrated dogs (Folk Jr. 1980). Subsequent research by Lundberg (1976) found conflicting information and cited problems with the original methodology.

Protein Metabolism and Muscle Maintenance

There is conflicting research on the topic of muscle maintenance during hibernation in bears. During 7 months in hibernation, the body temperature of a bear remains close to normal, falling from 38 C to 31. 2 C (Folk Jr. 1979). Bears do not eat, urinate or defecate during their period of dormancy

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(Nelson, 1980) but there is no net accumulation in the blood (Brown et al. 1979) or in the GI tract (Nelson, 1973) of products produced from the metabolism of protein. This could be interpreted to mean that there is a total cessation in protein metabolism during hibernation. This, however, is not true as demonstrated in 1973 by Nelson et al. who showed that plasma levels of creatinine triple in the first few days of hibernation to 3 mg/dl indicating an increase in protein turnover. Given that metabolites do not accumulate in the blood and neither are they stored in the intestines, Nelson supposed that the lean mass of bears must remain constant in hibernating bears. This supposition was later vindicated by Lundberg et al. in 1976 who used ¹⁴C labelled leucine and by a similar experiment by Ahlquist et al. in 1976 using ¹⁴C alanine; the levels of ¹⁴C was measured in metabolites of the bears such as urea, CO₂, and plasma proteins and from this the turnover rate of body protein was calculated. Both studies concluded that lean mass of bears remained unchanged throughout hibernation, a phenomenon unique to bears (Nelson, 1980).

Though the lean mass of bears remains constant there is continuous anabolism and catabolism of muscle in hibernating bears (Ahlquist et al. 1976). The study also showed that the rate of protein turnover was increased by 3 to 5 times in dormant compared to euthermic bears. This difference is actually even greater due to the fact that the basal metabolic rate is reduced during torpor by 73% (Kleiber 1947). It is apparent; therefore, that during hibernation there is a reciprocal relationship between protein turnover and urea production.

The final product of amino acid degradation is the production of urea that bears usually excrete in urine. Brown et al. (1971) demonstrated that during hibernation about 100ml of urine is filtered by the kidneys every day, this is then reabsorbed back into the blood and hence urination does not need to occur (Nelson, 1973). Several studies (Tempel et al. 1977 and Volkert et al. 1976) have shown that urine production decreases due to a reduction in the glomerular filtration rate during hibernation compared to non-hibernation. Tempel observed that this was due to an approximately 50% decrease in mean arterial blood pressure which in turn lowered ultrafiltration rates across the Bowman's capsule. Nelson et al. (1975) found that both water and urea are reabsorbed from the bladder at the same rate that urine was produced.

That the ability to reabsorb the produced urea is essential for bears as was shown by Wahner et al. (1973) when bears were given an intra circulatory injection of urea. The injection caused diuresis in the bears which led to cellular dehydration and a general disruption in hibernation.

Whilst it has been shown that urea and water are reabsorbed from the bladder as urine is produced (Nelson, 1975), no such uptake has been demonstrated for creatinine and uric acid waste products cleared from the blood (Brown et al. 1971), to prevent the accumulation of these metabolites in the blood they could be excreted via the biliary system (Groff et al. 1995) which would allow their storage or their breakdown by gut dwelling bacteria (Karasawa 1989).

Munro, 1970 discussed how a decline in one route of amino acid disposal was counter acted by a reciprocal increase in another. The three routes that he outlined were anabolism of protein, the production of small waste products such as creatinine and catabolism of amino acids. Therefore, if urea is not being produced by hibernating bears, the metabolites of protein turn over must be utilised elsewhere in the system.

Nelson later argued, in a 1980 publication, that such utilisation came in the form of increased levels of enzyme production especially lipolytic enzymes in order for bears to switch to fat metabolism for energy.

There have been many suggestions as to the reasons behind reabsorption systems within the bladder of the hibernating bear and none are mutually exclusive. Urea recycling may be linked to the acid-base balance of dormant bears (Guppy, 1986). Koebel et al. 1991 showed how oxidised amino acid ‘ skeletons’ provided a carbon source for the synthesis of glucose and of muscle glycogen.

Bears can lose around 10% (Barboza et al. 1997) of the protein and water from their lean muscle mass over the hibernation period. Barboza went on to hypothesise that this would not be a constant figure throughout all protein in the body and that some areas would be conserved more than others, for example, he states that the loss of any significant amount of protein from internal organs is very unlikely. Despite Tinker et al (1998) finding that the protein concentration in muscle decreased, it was also found that muscle fibre number and cross-sectional area was unchanged and there was limited muscle atrophy. Koebel et al. (1991) suggest that protein is mostly lost from

the skeletal muscle though they are clear that small reductions in the mass of several muscles is likely as upon arousal the bear does not have impaired locomotion.

Tinker et al (1998) found that when hibernating bears were lactating, they needed to undertake low levels of protein catabolism in order to mobilise metabolic water, to increase milk production.

To maintain their strength bears perform isometric contractions four times a day by shivering. (Nadis 2003). However, inconsistent information was found that black bears do not undergo periodic shivering (Tinker et al 1998).

Neither article has directly researched this mechanism nor quoted any research papers that have, leading me to believe that this issue requires greater research.

Special Features of Bears

There has been much debate about whether the bear is a true hibernator as there are many differences between them and other small hibernating mammals. Classic smaller mammalian hibernators allow their body temperature to fall to near the temperature of the hibernacula, the shelter of a hibernating animal (The Free Dictionary). The arctic ground squirrel is able to allow its core body temperature to drop as low as -2.9 °C without becoming frozen (Barnes 1989). Classic small hibernators also periodically wake up from dormancy every 3-10 days. During this time they urinate, defecate, drink and eat. Bats are an exception to this as they only wake from hibernation after over 39 days. Bears on the other hand do not drop their body temperature as low as small hibernators as such a sharp decline would

be a biological disadvantage as it would require several days to raise it again in a time of emergency (Folk G, E et al 2008). The body temperature of the brown bear remains between 31.2 °C – 36°C during hibernation which is slightly below the normal temperature of 37 °C – 38°C. This allows them to readily respond to external disturbances (Hershey et al 2008). The grizzly bear and the black bear can also remain dormant for 3 -7 months without urination, defecation, drinking and eating (Nelson et al 1983).

There are also some differences in hibernation between bear species. The polar bear, although related to the black and grizzly bear shows a number of differences. All three species share four physiological stages: 1) hibernation 2) walking hibernation 3) normal activity and 4) hyperphagia. The biggest difference is that the polar bear does not undergo extended winter denning like other northern ursids, unless she is a pregnant female requiring the den for parturition and raising the cubs. If stranded on land in summer, polar bears can fast and maintain low levels of activity for extended periods of time. Locomoting polar bears in this condition of fasting were physiologically similar to hibernating black bears; this state is therefore known as walking hibernation. As the polar bear developed from the brown/black bear line of evolution, they do share a metabolism and thermoregulation control system (Bruce et al 1989). Unlike other bears the polar bear does not seem to have a pattern of moving through the stages. They also eat a fat based diet and seem to feed irregularly (Nelson et al 1983).

Waking During and After Hibernation

At the onset of spring, hibernating bears rouse from hibernation to eventually assume normal active behaviour. Upon waking from hibernation,

bears enter a state of “ walking hibernation”. When black and grizzly bears leave dens in springtime, they are anorectic (depressed appetite). This phenomenon has been observed in the wild and in captive black bears taken out of their hibernation den. Captive animals, upon emergence from their dens, do not resume normal intake of food until 10 to 14 days have elapsed, although normal rations are available during this time. After 2 weeks they eat normally (Nelson et al. 1983).

Itoh et al. performed an observation of hibernation in captive black bears. The bears were induced to hibernate using artificial reduction in temperature and day length within the enclosure (Itoh et al. 2010).

Similar behaviours to those seen in the wild were reported: the bears chose a location where there would be minimal environmental change; they (the bears) did not eat or drink; they did not urinate or defecate; their body temperature and respiratory rate both fell; they hibernated in a curled-up position; they gathered nesting material and made a bed (Itoh et al. 2010). In the absence of detailed studies on wild bears, the observation of a high degree of similarities between behaviour under natural and artificial conditions allows conclusions drawn from the captive bear population to be applied to wild bears.

During hibernation, bears were observed to gather and rearrange nesting material, standing up within the den for durations varying from day to day. In the latter stages of hibernation, this behaviour gradually increased in duration. This is thought to indicate changes in behaviour leading to

awakening (Itoh et al. 2010). This graph shows the active time of the bears inside the hibernation den (measured with the use of infra-red cameras).

The temperature and illumination within the enclosure were increased from the beginning of March, to spring equinox levels. The active time gradually increased, eating and defecating were observed shortly thereafter.

Bears are capable of rapid arousal from hibernation when disturbed. Bears can wake and achieve relatively full mobility over a matter of minutes (Linnell et al. 2000). This adaptation allows bears to protect themselves from intrusion of the den by predatory animals (or humans). When disturbed, responses range along a continuum. A first response may be waking from non-rapid eye movement (NREM) sleep, slight body warming and increased heart rate. Following this, movement within the den and warming to normal body temperature (with accompanying 60-80% increase in metabolic rate). In some instances the bear may entirely abandon its den (Linnell et al. 2000).

Observations indicate that experimental bears are sensitive to sounds and may change physiological state in response to minor acoustic stimuli, although no experimental work is known which specifically rested these responses. The period required to regain their previous quiescent, hibernating state may vary from a few days to over a week (Linnell et al. 2000).

Conclusion

The stages of hibernation in bears have been reviewed in this paper in terms of behaviour, physiological changes and metabolic processes. This topic has

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been researched by a small number of people over many years, with greater emphasis on biochemical mechanisms such as protein turnover than behavioural changes. Other scientists have realised the potential of findings such as HIT and protein retention, which can be applied to other fields of research. Muscle maintenance a