Hibernation does not affect memory retention in bats

Ireneusz Ruczynski1,2,* and Björn M. Siemers1

1 Sensory Ecology Group, Max Planck Institute for Ornithology, Eberhard-Grimmer-Straße, 82519 Steinegen, Germany
2 Mammal Research Institute, Wózienica 1, 12-230 Białowieża, Poland
*Author for correspondence (ruczynski@orn.mpg.de).

Long-term memory can be critically important for animals in a variety of contexts, and yet the extreme reduction in body temperature in hibernating animals alters neurochemistry and may therefore impair brain function. Behavioural studies on memory impairment associated with hibernation have been almost exclusively conducted on ground squirrels (Rodentia) and provide conflicting results, including clear evidence for memory loss. Here, we for the first time tested memory retention after hibernation for a vertebrate outside rodents—bats (Chiroptera). In the light of the high mobility, ecology, and long life of bats, we hypothesized that maintenance of consolidated memory through hibernation is under strong natural selection. We trained bats to find food in one out of three maze arms. After training, the pre-hibernation performance of all individuals was at 100 per cent correct decisions. After this pre-test, one group of bats was kept, with two interruptions, at 7°C for two months, while the other group was kept under conditions that prevented them from going into hibernation. The hibernated bats performed at the same high level as before hibernation and as the non-hibernated controls. Our data suggest that bats benefit from an as yet unknown neuroprotective mechanism to prevent memory loss in the cold brain.

Keywords: hibernation; memory retention; life history; Myotis myotis; Vespertilionidae

1. INTRODUCTION

Long-term memory can be critically important for animals in a variety of contexts [1], and yet the extreme reduction in body temperature observed in hibernating animals alters neurochemistry and may therefore impair brain function and memory retention (reviewed in Roth et al. [2]). Specifically, hibernating rodents experience a significant loss of synapses [3], a change in synaptic morphology and an overall loss of synaptic efficacy (reviewed in Roth et al. [2]). Behavioural studies on memory impairment associated with hibernation have been almost exclusively conducted on ground squirrels and provide conflicting results, including clear evidence for memory loss ([4,5]; reviewed in Roth et al. [2] and in Clemens et al. [6].

by removing the bat from the maze. We stopped training and pro-
ceeded to conduct the pre-test when all bats choose the correct arm 10 times in the first 10 trials of a session. This was achieved after five weeks of training.

During training and experiments, the maze was cleaned with warm water and detergent between each bat to remove any odour cues. Within a session with an individual bat, the different maze arms were interchanged to remove the possibility that a bat would simply follow its own scent cues. In the wild, mouse-eared bats regularly crawl quadrupedally in roost crevices, etc. and accordingly our subjects very readily started to crawl in the test maze.

The pre-test was conducted on 12 December 2009, after 48 h of food deprivation; a duration of food deprivation which is most unnatural for temperate bats. After this pre-test, the control group was kept in a flight cage at 18–20°C, with daily access to food ad libitum as well as the possibility to fly. Each individual ate at least 5 g of mealworms per day. These conditions effectively prevented the control bats from going into hibernation.

The hibernation group was prepared for hibernation by transient exposure to low temperatures, which would simulate the onset of winter. Specifically, the bats were kept at 7°C in a climate chamber (KB53, Binder, Möhringen-Tuttlingen, Germany) for 48 h, then winter. Specifically, the bats were kept at 7°C in a climate chamber (KB53, Binder, Möhringen-Tuttlingen, Germany) for 48 h, then

Figure 1. Schematic representation of the test maze.

Figure 2. (a) Average proportions of correct decisions and average time to complete a trial (b) for hibernated and control bats before (grey bars) and after (white bars) the hibernation period. Means+1 s.d. For statistics, see text.

The bats must have been in deep torpor for most of the hibernation treatment, with exception of the first and the last day (see above), but perhaps arousing a little more often or for longer times than wild hibernating bats. After hibernation, all 13 bats were kept at 18–20°C in separate flight cage divisions for one week, fed to recover pre-hibernation body weight and then both groups were tested in the same foraging task again (retention test).

After training, the pre-hibernation performance of all individuals was at 100 per cent correct decisions (figure 2a). All seven hibernated bats and five of the six control bats showed a correct decision in the very first retention trial (no difference between groups, Fisher exact test, p = 0.46). Over a series of 10 retention trials, the proportion of correct decisions was at the same high level as in the pre-test for both the hibernated bats (figure 2a; Wilcoxon signed-rank test, Z = −1, p = 0.32) and the control (i.e. non- hibernated) bats (Z = −1, p = 0.32). Importantly, the proportion of correct decisions did not differ between hibernated and control bats before (Mann–Whitney test, U = 21, p = 1.0) or after hibernation (U = 22, p = 0.82). Moreover, the average time a bat needed to complete a trial did not differ between pre- and retention tests in the hibernated (figure 2b; paired t-test, t = 1.7, p = 0.14) and control bats (t = 1.6, p = 0.18), nor did it differ between groups before (t-test, t11 = 0.90, d.f. = 11, p = 0.39) and after hibernation (t11 = 0.75, d.f. = 11, p = 0.47).

3. RESULTS

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4. DISCUSSION

Our data demonstrate that hibernation did not affect memory retention in bats. As a cautionary note, we reiterate that uninterrupted cold phases lasted only 17, 22 and 25 days and the exact lengths of torpor bouts were unknown. As memory loss might be linked to the duration of hibernation (6)—although their own marmot data contradict this duration hypothesis), three or four months of uninterrupted hibernation should be tested with bats in a next step.
We hypothesized that a long lifespan, high mobility and complex environments favour the evolution of effective memory protection over hibernation, because for species with such a life history and ecology, accumulation of experience over a lifetime will be especially adaptive. At the present stage, the investigated number of species is far too limited for any formal test of such a life-history hypothesis. However, it receives some qualitative support. Species of ground squirrels, in contrast to bats, live in two-dimensional environments, do not forage over large distances, do not migrate and live much shorter times (up to 4–6 years [12]) than bats (even over 30 years [8]) and indeed their memory is more affected by hibernation [13,14] than it was in our bats. Marmots again not migrate and live much shorter times (up to 4–6 years [12]) than bats (even over 30 years [8]) and species with such a life history and ecology, accumulate memory protection over hibernation, because for bats the retention of consolidated memory is not affected by low temperatures in Lymnaea. Bats make use of torpor not only during hibernation, but also on cool days during their active season. It will thus be an interesting future experiment to investigate whether bats experience a trade-off between saving energy (by becoming torpid) and consolidating newly acquired learned information (by staying warm).

We acknowledge Renate Heckel for help with bat husbandry, Leonie Baier for scoring videos and preparing figure 1, Markus Schuller for setting up the climate chamber, Erwin Kulzer, John Lesku, Ewald Müller and Niels Rattenborg for discussion and two anonymous referees for comments. The study was funded by Max Planck Society and supported by the Polish Ministry of Science and Higher Education (programme ‘Support for International Mobility of Scientists’).