Behavioral and physiological characteristics of grizzly and polar bears and their relation to bear repellents

Gary D. Miller

The University of Montana

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BEHAVIORAL AND PHYSIOLOGICAL CHARACTERISTICS OF GRIZZLY AND POLAR BEARS, AND THEIR RELATION TO BEAR REPELLENTS

By

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B.S., Oregon State University, 1975

Presented in partial fulfillment of the requirements for the degree of

Master of Arts

UNIVERSITY OF MONTANA

1980

Approved by:

[Signatures]

Date 8/15/80
Miller, Gary D., M.A., August 1980  Zoology

Behavioral and Physiological Characteristics of Grizzly and Polar Bears, and Their Relation to Bear Repellents.

Director: Donald A. Jenni

The purpose of this study was to develop and evaluate techniques to monitor the behavior and physiology of grizzly and polar bears and to relate the physiological parameters to the bears' behavior. This information was then integrated into tests of possible bear repellents.

Using captive animals (2 male grizzlies Ursus arctos horribilis, and 2 female polar bears U. maritimus) behavioral observations were made while simultaneously measuring heart rate, deep body temperature, and sub-cutaneous temperature. Observations were done first on undisturbed animals and then while the animals were presented with possible repellent stimuli. In addition to laboratory studies, possible repellents were tested on free-ranging polar bears.

The physiological parameters are related to the behavioral parameters, but the relationships are complex. It is possible to predict what a bear's behavior is by analyzing the physiological parameters that can be monitored with radio-telemetry.

The behavior and physiology of the bears were also observed during repellent tests. Fifteen to 18 stimuli were tested on each bear. The stimuli were chosen from a list of possible repellents that included recorded bear and people sounds, bells, horns, chemicals, and others. Extremely loud and sharp sounds were consistently repellent, as were most of the chemicals. The use of captive animals is a valid method for testing many stimuli in a relatively short time.

The field tests of possible repellents were made on free-ranging polar bears near Churchill, Manitoba. The polar bears were attracted to the observation area with sardine baits. After a 2-week control period, commercial dog repellents and household chemicals were broadcast around 10 bait sites. A speaker was placed at another site to test recorded sounds on the bears and a freon-powered horn was tested in the area when possible.

Most bears (81%, n = 31) were repelled with the horn, but the behavioral reactions to the taped sounds were variable. The chemical repellents did not prevent bears from visiting the sites, but the bears spent less time at all the treated sites than at the controls. The field tests compliment the laboratory tests by allowing tests with a few stimuli on many different bears.
ACKNOWLEDGEMENTS

Many people deserve thanks for their help throughout this project. First and foremost I thank Dr. C. Jonkel. This project would not have been possible without his financial, logistic, and moral support. I also thank Dr. D. Jenni as my advisor for his ideas, advice, and critical review of my progress throughout the project. Finally, Dr. E. W. Pfeiffer also reviewed my progress at critical points along the way.

Linda Jordan deserves special thanks for her support, patience, and enthusiasm throughout the research and the writing of the thesis. She also helped with tasks from feeding bears to drawing Figures 5 and 6. I thank Janet Ellis for her help in delivering repellent stimuli, tending the animals, and drawing the remaining figures. Bruce Cushing and Sheridan Stone assisted me in handling animals and implanting the transmitters. Nan Keeling and the staff at the Churchill Health Centre gave technical assistance. The field studies would not have been possible without Don Wooldridge and Scott Mair. The Manitoba Dept. of Renewable Resources and Transportation Services, especially R. Bukowsky and S. Kearney, helped by providing permits, facilities, and equipment. The Churchill Northern Studies Centre also furnished facilities.

This project was funded by National Science Foundation Grant No. 7617644, C. Jonkel and B. O'Gara co-principle investigators, the Arctic Petroleum Operators Association, the Univ. of Guelph, and was supported with permits and occasional funding by the U. S. Fish and Wildlife Service.
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Chapter 1

INTRODUCTION

Each year, bears of the three species in North America damage property and cause human injury. The number of human injuries caused by grizzly bears (*Ursus arctos horribilis*) has increased with the greater number of people visiting the National and Provincial parks of the United States and Canada (Herrero 1970a, 1970b, 1976, Mundy and Flook 1973). Conflicts between bears and people have also increased as new areas are developed and human populations increase in areas used by bears (Jonkel 1975). Three recent human encounters with polar bears (*U. maritimus*) that resulted in injury, including one death, have been reported for the Churchill, Manitoba area (Jonkel 1970a), while other injuries from polar bears have been reported from the Northwest Territories (Schweinsburg 1976) and throughout the Arctic.

Because of the damage and injuries caused by bears, there is much interest in bear repellents and in methods to keep bears away from human settlements, work camps, campgrounds, etc., or to avert specific attacks on people by bears. A greater understanding of bear ecology and behavior will do much to reduce the problem by reducing the number of encounters between bears and people. The use patterns of hikers and campers in parks can be adjusted to avoid areas frequented by bears. Similarly, restrictions placed on development in bear habitat can reduce encounters between bears and people, but there probably will be incidents each year.
The purpose of this study was to develop and evaluate techniques to monitor basic behavioral and physiological responses of grizzly and polar bears to external stimuli and to relate the physiological parameters to the bears' behavior. This information was then integrated into the study of bear repellents. Because most people encounter or are attacked by bears while hiking or camping (Herrero 1970a, 1976), I have concentrated on safe, effective personal repellents that can be carried by hikers or campers as they travel in bear habitat. In addition, stimuli were tested that would be suitable for keeping bears away from specific areas or sites.

The study was done in two parts, the first in the laboratory and the second in the field. In the laboratory, using implanted radio-transmitters I measured heart rate, deep body temperature, and subcutaneous temperature while I observed the bear's behavior. A series of observations were done on undisturbed animals and while the animals were presented with possible repellent stimuli. Finally, in the field I observed non-radio-equipped, free-ranging polar bears as they encountered possible repellent stimuli at baited sites.

Background

There have been few studies of bear behavior that are applicable to interpreting the behavioral reactions of bears to the artificial confrontations that represent tests for repellent stimuli. When grizzlies congregate at the McNeil River in Alaska each summer to feed on salmon, a social hierarchy develops and is maintained by aggressive encounters between bears. Visual signals such as body position, head orientation, and facial expression are important in deciding the outcome of bear-bear encounters (Stonorov and Stokes
Far position, facial expression, and vocalizations are also important in black bear (*Ursus americanus*) encounters (Henry and Herrero 1974). Analyses of encounters between grizzlies and humans in national parks suggest that bears react to the encounters as if they were encountering another bear (Herrero 1970b, 1976).

The behavior of wild bears while held captive in foot snares is different for the three species of North American bears. Black bears usually remain calm, grizzlies are extremely vocal and aggressive, while polar bears are usually quiet and only occasionally charge (Jonkel 1970b).

The behavior of polar bears is less well-known than the behavior of either black or grizzly bears. There are good accounts of denning behavior of polar bears (Harington 1968, Jonkel et al. 1972, and Lentfer 1975) but they do not relate to this study. Although Meyer-Holzapfel (1957) provides an extensive account of the behavior of European brown bears in bear pits, her conclusions based on popular accounts of the behavior of wild bears (including polar bears) are suspect. Afonskaya and Krumina (1975) discuss the behavior of polar bears in the Moscow Zoo, but in other studies the behavioral observations are often brief and secondary to the main goals of the research (Knudsen 1975). The most thorough study of polar bear behavior is a time budget study of unmarked individuals based on 602 bear-hours of observation on Devon Island, Canada (Stirling 1974). Stirling describes some encounters between polar bears, but those kinds of observations are generally absent from the literature.

With recent advances in physiological telemetry, it is possible to measure such parameters as heart rate, and various body...
temperatures of unrestrained animals, including bears. Most of the studies using physiological telemetry have attempted to measure the ecological energetics of the species (Folk and Copping 1973, Gessaman 1973). There is great value in understanding the energetics of an animal when attempting to develop models of the food and habitat requirements of that animal. Unfortunately, the need to understand how these relatively easily measured physiological parameters relate to behavior has been largely overlooked.

Heart rate is a very labile physiological parameter. Heart rate increases with exercise and is an indicator of overall activity (Astrand and Rodahl 1977, Guyton 1971). Attempts to correlate heart rate with energy consumption in dogs, sheep, and Blue-winged Teal indicate that psychological stress or excitement can obscure the relationship between heart rate and metabolism (Barger et al. 1955, Brockway and McEwan 1969, Owen 1969, respectively). In addition, in humans, increases in heart rate can correlate directly with novel tasks or the anticipation of a difficult or painful task without a concomittant increase in metabolic rate (Blix et al. 1974, Cohen 1973, Malcuitt 1973, and Obrist et al. 1970). These psychological effects make it necessary to measure parameters in addition to heart rate in order to be able to predict a behavior pattern successfully from a physiological record (Johnson and Gessaman 1973).

Heat from increased activity initially accumulates in the acting muscle masses, but after a short delay, the overall body temperature rises (Mitchell 1977). The body core temperature of young and adult polar bears increases with exercise (Øritsland 1969, Best 1976). Body temperature also varies with psychological state. For example the
rectal temperature of bighorn sheep (Ovis canadensis) increases with increased excitedness of the animal while obtaining the temperature (Franzmann and Hebert 1971). A caged Mexican wolf (Canis lupus baileyi) showed an immediate small rise in body temperature when approached by an attendant for feeding (Williams et al. 1968). This small rise was followed by a large and prolonged drop in body temperature after feeding.

Skin temperature also relates to overall activity because the skin is a major avenue of heat loss for an animal. However, skin blood flow (the main avenue of heat exchange) may be reduced during activity to compensate for demands elsewhere (Breugelman 1977). This reduction in skin blood flow can produce a reduction in skin temperature at the onset of exercise (Astrand and Rodahl 1977). The skin temperature of the neck of a bird dog peaked each time the dog pointed during a quail hunt (Baldwin 1973). Because a point does not necessarily relate to a peak in energy consumption, these data suggest that skin temperature may indicate the psychological state of the animals.

Most of the physiological information available for bears concerns their physiology during winter sleep or their ecological energetics. Polar bears and grizzlies in winter dens show marked bradycardia and slightly lower body temperatures than active bears (Folk et al. 1970, 1973). Heart rates of active polar bear cubs decrease with age as the cubs grow larger (Hock 1968). The deep body temperatures of polar bear cubs vary with different activities (Øritsland 1969). The heart rate of polar bears shows characteristic values and changes for various activities and levels of treadmill exercise (Folk et al. 1973,
Øritsland et al. (1977). The metabolic rate of captive polar bears relates to their walking speed and their heart rate, body temperature, and stride frequency (Best 1976).

The variability of the heart rate, skin temperature, and body temperature suggests that a combination of these parameters can be used to predict the bears’ behavior from its physiology.

Studies of aversive conditioning indicate that there is a constellation of factors that determine the effectiveness of aversive stimuli. The effectiveness of a stimulus depends on the perceptual system of the animal involved. Visual, auditory, and tactile clues are important to quail but not to rats in developing an aversion to a food that induces illness, while novel tastes are important clues for both rats and quail (Wilcoxin et al. 1971). Taste aversions can be induced with a prolonged delay in punishment if the taste clue is sufficiently unique. On the other hand, electric shock cannot induce an aversion to auditory or visual cues if there is a long delay between the stimulus and punishment (Garcia et al. 1966). If the punishment is illness, rats cannot develop an aversion to an odor without additional taste cues, and the strength of taste aversion depends primarily on the strength of the novel taste but also depends on the strength of the illness and the delay between stimulus and punishment (Garcia et al. 1974). Vision is the most important sense in coyote predation of rabbits, followed by audition and olfaction (Wells and Lehner 1978).

Attempts to induce an aversion for killing and consuming prey have had variable results. Rats can be made to stop killing mice (Meyer 1966). Chemical irritants put on sheep to stop coyote predation are generally ineffective (Jankovsky et al. 1974, Olsen and Lehner...
1978) unless also supported by auditory and visual stimuli (Olsen and Lehner 1978). An aversion in coyotes to eating sheep or chicken carcasses that were laced with LiCl (an emetic) was not generalized to prevent the killing of live prey (Conover et al. 1977). There has been some success with inducing prey specific aversions to prey killing and eating in coyotes (Bekoff 1975, Gustavson et al. 1974, 1975).

It is apparent that the characteristics of the resource being damaged and the animal doing the damage determine the choice of the aversive stimuli. Taste aversion probably will not be effective in keeping bears from particular sites, but they work well for specific problems like beeyard depredations (Dorrance and Gilbert 1977, Gilbert and Roy 1977). Repellents that are visual, auditory, and/or tactile should be more effective in averting encounters between bears and people because of the nature of such encounters.

Electric fences deliver a strong tactile stimulus and can protect beeyards from black bear depredations (Gilbert and Roy 1977, Storer et al. 1938). Electric fences have also been used with reasonable success to exclude polar bears from baits (Wooldridge pers. comm.).

Biologically significant sounds may also be effective stimuli for repelling bears. Killer whale (Orcinus orca) sounds repel both gray whales (Eschrichtus robustus) and beluga (Delphinapterus leucas) (Cummings and Thompson 1971, Fish and Vania 1971). The recorded sounds of barking dogs repel Yezo brown bears (U. a. yezoensis) but pile-hammer or jet plane sounds do not (Haga 1974). Finally, aggressive sounds that were recorded during an aggressive encounter between two male polar bears and synthetic imitations of those sounds, repelled
captive and wild polar bears, wild black bears, and captive kodiak brown bears (*U. a. middendorfii*) (Wooldridge and Belton in press).
Chapter II
MATERIALS AND METHODS, LABORATORY STUDIES

Laboratory tests were carried out at the Churchill Bear Lab, Churchill, Manitoba. One grizzly bear (Growly) was tested in September-October 1977. A second grizzly (Snarly) and two polar bears (Guen and Magdalene) were tested July-October 1978.

The laboratory facility in Churchill is a large (42 x 19 m) unheated building which was formerly the laundry for Fort Churchill. It has been modified and cages have been built for holding bears (Fig. 1).

The cages, constructed of 5 cm steel pipe, are elevated off the floor. They are all 1.4 m high and the bears cannot stand fully erect in them. A floor to ceiling wall around cage 3 isolates it visually from laboratory activity. The partition also affords much olfactory but very little auditory isolation. Cage 3 was used for attractant studies while cages 1 and 2 were used only for holding animals prior to tests.

In addition to the cages, there are three cells. These experimental/living chambers are fully enclosed rooms with cement block walls. Each cell is 3.7 x 6.1 m with a 4.6 m ceiling and has a built-in well for drinking water. The doorways are fitted with a barred metal door and the window openings are barred. Cells 1 and 3 have raised observation blinds that allow a full view of the rooms. The windows to the chambers are open to ventilate airborne chemicals or odorants. The chambers' solid wall construction and their location at the corner of the building, allow complete visual and olfactory isolation, but only
Figure 1. Floorplan of the Churchill Bear Laboratory.
moderate isolation from noise in the main part of the lab. One bear was housed in cell No. 3 for observations, while the remaining 3 bears were each tested in cell No. 1.

The laboratory also has a large workshop and a heated office/operating room with a full compliment of instruments needed to perform the implantations.

Four animals were used in the laboratory studies, 2 grizzlies and 2 polar bears. The first subject, Growly, an adult male grizzly (200 kg), was 7.5 years old when studies were initiated in September 1977. He had been captured as a problem bear in September 1976 in Glacier National Park, Montana. Growly was transported to Churchill in November 1976 and hibernated in a chamber there. He had been in captivity for a full year before the experiments, but no other experiments had been done with him prior to my study.

The other grizzly, Snarly (160 kg), was a 5.5 year-old male when he was tested in July 1978. He was also a problem bear and was captured near Glacier Park in June 1977, but was held in Missoula, Montana, until 1978 before being transported to Churchill. He was held in the experimental chamber for 2 weeks before observations began.

The 2 polar bears used were both females and were captured in the Churchill area from a helicopter using the method described by Lentfer (1968). The first, Guen (160 kg), was estimated to be 2.5 years old. She was captured 17 August 1978, and was used for study immediately. My last subject, Magdalene (200 kg), was 4.5 years old. She was captured 20 July 1978 and was used for attractant studies (in cage 3) prior to my study in September-October 1978.
Upon completion of the repellent tests, the 2 polar bears were released 100 km north of Churchill near the Knife River. Growly was donated to the Columbus, Ohio, Zoo and Snarly was sacrificed.

The transmitters used on Growly were implantable, low-power, heart rate and temperature transmitters described by Skutt et al. (1973). The implants transmitted on the FM band and produced a series of 'clicks' on an FM receiver. This output was recorded with a Gould Analog Chart Recorder (Gould Inc., Cleveland, Ohio). The other three animals were monitored with heart rate transmitters from J. Stuart Enterprises (Grass Valley, Calif.) and temperature transmitters from Telonics (Tempe, Ariz.). The signals were received on Telonics receivers and recorded on the chart recorder. Each pulse from the heart rate transmitters corresponds to a heart beat. Because the temperature transmitters send pulses at a rate proportional to the temperature, they were calibrated in a temperature-controlled water bath before being implanted (Appendix A).

Procedures for the implantations developed at Churchill by Best (1976) were modified slightly. The animals were anesthetized with 1:1 Sernylan:Sparine mixture for the operations (Seal and Erickson 1969). The body temperature transmitters were implanted between the peritoneal lining and the abdominal muscle sheet. The sub-cutaneous temperature and heart rate transmitters were implanted sub-cutaneously near the dorsal midline of the neck and upper shoulder respectively.

Each bear was watched closely during a recovery period of 3 days or more, depending on the condition of the bear before behavioral observations were begun. Following the recovery period, baseline
observations were begun by observing the undisturbed bears while simultaneously recording the telemetered physiological data.

Baseline observations on Growly covered all hours from dawn to dusk twice during a 3-day period. The remaining subjects were observed in blocks of time not less than four hours and not more than eight hours in duration over a 5 day period to include three sequences of hours from 0700 to 2000 hours or 3 dawn to dusk periods, whichever was shorter (Table 1).

Observations of the bear's activity, posture, orientation, vocalizations, and ear position were noted at 15 second intervals. Examples of typical postures and ear positions are shown in Figures 2, 3, and 4. External noises were also noted when they occurred. Recordings of the physiological parameters were taken every 10 minutes for a period of 1 minute for each parameter.

After completing observations on each undisturbed animal, observations of that animal's responses to repellent tests began. The schedule for Growly allowed for 6 tests over 5 days. The tests were 2 hours apart and observations were made for at least one-half hour before and after each test. The daily observation schedules for the other 3 bears were similar to their schedules for baseline observations (Table 2). The repellent tests were superimposed on this schedule. Two repellent stimuli were tested in each observation period, but there were at least 2 hours between stimuli. No more than 4 tests were performed in one day. The method of observations was the same as for baseline observations except that the physiological parameters were recorded continuously from 3 minutes before stimulus presentation until the animal returned to pre-test behavior (usually less than 10 minutes).
Table 1: Baseline observation schedules.

<table>
<thead>
<tr>
<th>Bear</th>
<th>Day</th>
<th>Date</th>
<th>Time of day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Growly</td>
<td>1</td>
<td>12 Oct. 77</td>
<td>0730-1400-1540-1900</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>13 Oct. 77</td>
<td>0730-1030-1355-1900</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>14 Oct. 77</td>
<td>1030-1530</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>15 Oct. 77</td>
<td>0730-1130</td>
</tr>
<tr>
<td>Snarly</td>
<td>1</td>
<td>7 July 78</td>
<td>0700-1130-1500-2000</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>8 July 78</td>
<td>1100-1500-1600-2000</td>
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<td></td>
<td>3</td>
<td>9 July 78</td>
<td>0700-1212-1600</td>
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<td></td>
<td>4</td>
<td>10 July 78</td>
<td>0700-1100-1200-1600</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>11 July 78</td>
<td>1100-1600</td>
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<tr>
<td>Guen</td>
<td>1</td>
<td>28 Aug. 78</td>
<td>1100-1500-1600-2000</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>29 Aug. 78</td>
<td>0700-1100-1500-2000</td>
</tr>
<tr>
<td></td>
<td>3</td>
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</tr>
<tr>
<td></td>
<td>5</td>
<td>1 Sept. 78</td>
<td>1100-1600</td>
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<tr>
<td>Magdalene</td>
<td>1</td>
<td>24 Sept. 78</td>
<td>1045-1500-1600-2000</td>
</tr>
<tr>
<td></td>
<td>2</td>
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</tr>
<tr>
<td></td>
<td>5</td>
<td>30 Sept. 78</td>
<td>1100-1600</td>
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Figure 2. Ear positions. A. Ears relaxed, B. Ears directed forward, C. Ears partly back.
Figure 3. Typical lying down postures. A. Sphinx. B. Lying on back with feet in the air. C. Lying on belly with chin on paw and hind feet extended back. D. Lying on side, curled, with front foot over nose.
Figure 4. Typical active postures. A. Standing up. B. Standing with head low. C. Sitting hunched over.
Table 2: Repellent observation schedules.

<table>
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<th>Date</th>
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<td><strong>Growly</strong></td>
<td>4</td>
<td>25 Oct. 77</td>
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<td>0745-0830, 0930-1045, 1130-1235, 1330-1435, 1530-1635, 1730-1825</td>
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<td>27 Oct. 77</td>
<td>0755-0825, 0930-1030, 1130-1235, 1330-1435, 1530-1635, 1735-1835</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>28 Oct. 77</td>
<td>0915-1030, 1130-1235, 1330-1431, 1530-1631, 1750-1826</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>29 Oct. 77</td>
<td>0730-0830, 0930-1030, 1130-1230, 1330-1435, 1530-1631, 1730-1826</td>
</tr>
<tr>
<td><strong>Snarly</strong></td>
<td>6</td>
<td>15 July 78</td>
<td>0700-1100 1200-1600</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>16 July 78</td>
<td>0700-1200 1600-2000</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>17 July 78</td>
<td>1100-1500 1600-2000</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>18 July 78</td>
<td>0700-1100 1500-2000</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>19 July 78</td>
<td>1100-1500 1600-2000</td>
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<tr>
<td></td>
<td>11</td>
<td>27 July 78</td>
<td>1100-1500 1600-2000</td>
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<tr>
<td></td>
<td>12</td>
<td>28 July 78</td>
<td>0700-1500 1600-2000</td>
</tr>
<tr>
<td></td>
<td>13</td>
<td>29 July 78</td>
<td>0700-1100 1600-2000</td>
</tr>
<tr>
<td><strong>Guen</strong></td>
<td>6</td>
<td>3 Sept. 78</td>
<td>0700-1200 1600-2000</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4 Sept. 78</td>
<td>0700-1100 1500-2000</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5 Sept. 78</td>
<td>1100-1500 1600-2000</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>9 Sept. 78</td>
<td>0700-1100 1200-1600</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>10 Sept. 78</td>
<td>1100-1500 1600-2000</td>
</tr>
<tr>
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<td>11</td>
<td>11 Sept. 78</td>
<td>0700-1100 1600-2000</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>12 Sept. 78</td>
<td>1100-1500 1600-2000</td>
</tr>
<tr>
<td><strong>Magdalene</strong></td>
<td>6</td>
<td>1 Oct. 78</td>
<td>0700-1200 1600-1930</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>4 Oct. 78</td>
<td>1100-1500 1550-1930</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>5 Oct. 78</td>
<td>0700-1100 1500-1930</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>6 Oct. 78</td>
<td>0700-1100 1200-1600</td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>7 Oct. 78</td>
<td>1100-1700 1700-1900</td>
</tr>
<tr>
<td></td>
<td>11</td>
<td>8 Oct. 78</td>
<td>1100-1500 1600-1900</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>9 Oct. 78</td>
<td>0700-1100 1600-1900</td>
</tr>
</tbody>
</table>
The bear's physiology was then recorded periodically as in the baseline observations. The stimuli and controls were delivered by an assistant who stood outside the cell. The assistant stood at the door of the cell for the grizzly bears, but the polar bears would only approach if the assistant stood at the window of the cell. The tests on the polar bears were given from the window.

The majority of the stimuli were either sounds or chemicals (Table 3). The sounds were either taped, biologically significant sounds, or bells, whistles or explosive sounds such as a firecracker-like 'Thunderflash'. The taped sounds were played with a Hitachi TRK-5190 recorder. The chemicals were sprayed at the bear's eyes with a 30 ml syringe, or in the case of the commercial dog repellents, they were sprayed directly from aerosol cans. Enough chemical was used to wet the bear's face. The loom stimulus consisted of the assistant suddenly presenting the flat face of a 1 x 1.5 m piece of plywood (Appendix B provides a more detailed description of individual stimuli).

A random sample of the stimuli (and appropriate controls) was selected for each animal. Twenty-nine tests and controls were performed on Growly, 18 on Snarly, 24 on Guen, and 23 on Magdalene. My scientific permit did not allow me to test the chemical repellents on the polar bears which were to be released back into the wild at the conclusion of the tests.

Data Analysis

The heart rate was recorded as a series of ticks on a chart recorder. I divided each 1 minute sample of the heart rate into 5 second units and averaged those units to obtain the mean heart rate (HR) and the standard deviation of the heart rate (SHR) over that minute.
Table 3: List of repellent stimuli and controls.*

<table>
<thead>
<tr>
<th>Taped sounds</th>
<th>Other sounds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Human growling (SGrowl)</td>
<td>Thunderflash</td>
</tr>
<tr>
<td>Human hissing (SHiss)</td>
<td>Bells</td>
</tr>
<tr>
<td>Human barking (SBark)</td>
<td>Control (ring silent bell)</td>
</tr>
<tr>
<td>Human shouting (SShout)</td>
<td>Boat horn</td>
</tr>
<tr>
<td>Grizzly growling (GGrowl)</td>
<td>Control (hold up horn)</td>
</tr>
<tr>
<td>Grizzly barking (GBark)</td>
<td>Sound 911</td>
</tr>
<tr>
<td>Polar bear sounds (1977PR)</td>
<td>Dog whistle</td>
</tr>
<tr>
<td>Polar bear sounds (GUEN)</td>
<td>Referee's whistle</td>
</tr>
<tr>
<td>Killer whale sounds (ORCA)</td>
<td>Control (pretend to whistle)</td>
</tr>
<tr>
<td>Radio (field trials only)</td>
<td>Trucktone horn</td>
</tr>
<tr>
<td>Control (hold up speaker)</td>
<td>Control (Trucktone horn)</td>
</tr>
<tr>
<td></td>
<td>Cap-chur gun</td>
</tr>
<tr>
<td>Chemicals</td>
<td></td>
</tr>
<tr>
<td>Onion juice</td>
<td>Ortho Scram (dog repellent)(field)</td>
</tr>
<tr>
<td>Windex (ammonia)</td>
<td>Bear Trail (for training dogs)</td>
</tr>
<tr>
<td>Ammonia (field trials)</td>
<td>Control (shoot water in bear's face)</td>
</tr>
<tr>
<td>Pine Sol (field trials)</td>
<td></td>
</tr>
<tr>
<td>Mustard</td>
<td></td>
</tr>
<tr>
<td>Halt (dog repellent)</td>
<td>Strobe light</td>
</tr>
<tr>
<td>Dog Stopper (dog repellent)</td>
<td>Loom</td>
</tr>
<tr>
<td>Git (dog repellent)</td>
<td>Control (stand at door quietly)</td>
</tr>
<tr>
<td>Chaperone (dog repellent)</td>
<td></td>
</tr>
</tbody>
</table>

* Repellent stimuli are described in detail in Appendix B.
In addition to HR and SHR, I determined the maximum HR and minimum HR for the minutes that had above average and below average HR's respectively (MMHR). Finally, the bears occasionally showed a marked sinus arrhythmia that was obvious on the heart rate record. I recorded the presence and intensity of the sinus arrhythmia (SA) as either absent, light, moderate, or strong.

The body temperature (TB) and the sub-cutaneous temperature (TS) were also recorded as ticks on the chart recorder for Growly. The average beats/minute were determined for the minute intervals. For the remaining bears, the Telonics receiver/digital processor read the milliseconds per beat of the transmitter directly and true point observations were obtained. The transmitted beats/minute were then transformed to temperatures (°C) with the appropriate calibration equation (Appendix A). Thus, the physiological record consisted of body temperature, sub-cutaneous temperature, heart rate, standard deviation of heart rate, sinus arrhythmia, and maximum or minimum heart rate (TB, TS, HR, SHR, SA, MMHR). The ambient temperature was recorded periodically.

The behavioral observations were recorded at 15 s intervals and written long-hand in field notes. These data were coded into a numerical format and reorganized for computer analysis. Each minute that had physiological data was selected and 13 digit number was coded to characterize the behavior in that minute (Table 4). The minute within the preceding 10 minutes in which the present behavior began was also coded (start time, START). Finally I summarized the behavior in the 9 minutes prior to the minute being coded. Three sets of 8 codes were selected to best describe each 3 minute period in the preceding 9 minutes (Table 4).
Table 4: Codes used for computer analyses.

<table>
<thead>
<tr>
<th>Overall activity (OA)</th>
<th>Transitions, posture (TP)</th>
<th>Gross body position (GBP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Elimination</td>
<td>0 No transitions</td>
<td>1 Lying belly</td>
</tr>
<tr>
<td>1 Sleep</td>
<td>1 Lying to sitting</td>
<td>2 Lying side</td>
</tr>
<tr>
<td>2 Quiet</td>
<td>2 Lying to standing</td>
<td>3 Lying back</td>
</tr>
<tr>
<td>3 Eat/drink</td>
<td>3 Sitting to standing</td>
<td>4 Sitting</td>
</tr>
<tr>
<td>4 Light activity</td>
<td>4 Sitting to lying</td>
<td>5 Sitting up</td>
</tr>
<tr>
<td>5 Moderate activity</td>
<td>5 Standing to sitting</td>
<td>6 Standing</td>
</tr>
<tr>
<td>7 &quot;Frozen&quot;</td>
<td>6 Standing to lying</td>
<td>7 Standing up</td>
</tr>
<tr>
<td>8 Stretch or shifting</td>
<td>7 Up and down from window</td>
<td>8 Pullup at window</td>
</tr>
<tr>
<td>9 No data</td>
<td>8 Standing to standing up</td>
<td>9 No data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head position (HP)</td>
<td>Transitions, activity (TA)</td>
<td>Ear position (EP)</td>
</tr>
<tr>
<td>0 Head shake</td>
<td>0 No change</td>
<td>0 Ears mobile</td>
</tr>
<tr>
<td>1 Head up</td>
<td>1 Sleep to awake</td>
<td>1 Ears relaxed or up</td>
</tr>
<tr>
<td>2 Head down</td>
<td>2 Quiet to light act.</td>
<td>2 Ears directed forward</td>
</tr>
<tr>
<td>3 Head normal</td>
<td>3 Quiet to heavy act.</td>
<td>3 Ears partly back</td>
</tr>
<tr>
<td>4 Head low but level</td>
<td>4 Light act. to quiet</td>
<td>4 Yawn and EPB</td>
</tr>
<tr>
<td>5 Head curled</td>
<td>5 Heavy act. to quiet</td>
<td>5 yawn and ER</td>
</tr>
<tr>
<td>6 Head extended</td>
<td>6 Light to heavy act.</td>
<td>6 EDF and EPB</td>
</tr>
<tr>
<td>7 Hibernator position</td>
<td>7 Heavy to light act.</td>
<td>7 Ears flattened</td>
</tr>
<tr>
<td>8 Chin on paw or tire</td>
<td>8 Stretch or shifting</td>
<td>8 EDF and yawn</td>
</tr>
<tr>
<td>9 No data</td>
<td>9 No data</td>
<td>9 No data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Head orientation (HO)</td>
<td>Vocalizations (VOC)</td>
<td>Miscellaneous (MISC)</td>
</tr>
<tr>
<td>0 No special direction</td>
<td>0 None</td>
<td>0 Front feet in well</td>
</tr>
<tr>
<td>1 Looking about</td>
<td>1 Deep sigh</td>
<td>1 Mouth open</td>
</tr>
<tr>
<td>2 Looking up or down</td>
<td>2 Panting</td>
<td>2 Mouth closed</td>
</tr>
<tr>
<td>3 Directed to object</td>
<td>3 Snore</td>
<td>3 Eating or biting</td>
</tr>
<tr>
<td>4 &quot;Frozen&quot;</td>
<td>4 Growl/moan</td>
<td>4 Licking</td>
</tr>
<tr>
<td>5 Sniffing object</td>
<td>5 Growl (moderate)</td>
<td>5 Yawn</td>
</tr>
<tr>
<td>6 Sniffing self</td>
<td>6 Growl (vigorous)</td>
<td>6 Eyes open</td>
</tr>
<tr>
<td>7 Eat/drink</td>
<td>7 Bark</td>
<td>7 Eyes closed</td>
</tr>
<tr>
<td>8 Directed stare</td>
<td>8 His</td>
<td>8 Digging or sweeping</td>
</tr>
<tr>
<td>9 No data</td>
<td>9 No data</td>
<td>9 No data</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Test condition (TEST)</td>
<td></td>
<td>Ambient temp.(TAM)</td>
</tr>
<tr>
<td>0 30 min. period pre-test</td>
<td></td>
<td>Three digits for the ambient temperature to the nearest degree Centigrade.</td>
</tr>
<tr>
<td>1 Test and 30 min. after</td>
<td></td>
<td>999 No data</td>
</tr>
<tr>
<td>10 30 min. pre-control</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Control and 30 min. after</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20 30 min. pre-feeding</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21 Feeding and 30 min. after</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 None of the above</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Table 4: Codes used for computer analyses (continued).

<table>
<thead>
<tr>
<th>Front feet positions (FFP)</th>
<th>Hind feet positions (HFP)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Typical</td>
<td>0 Typical</td>
</tr>
<tr>
<td>1 Extended forward</td>
<td>1 Extended forward</td>
</tr>
<tr>
<td>2 Extended back</td>
<td>2 Extended back</td>
</tr>
<tr>
<td>3 Split forward and back</td>
<td>3 Tucked</td>
</tr>
<tr>
<td>4 Curled or tucked</td>
<td>4 Curled</td>
</tr>
<tr>
<td>5 Manipulating object</td>
<td>5 In the air or on wall</td>
</tr>
<tr>
<td>6 Front feet in well</td>
<td>6 Split in the air</td>
</tr>
<tr>
<td>7 Pounding</td>
<td>7 Spread eagle</td>
</tr>
<tr>
<td>8 Front foot over nose</td>
<td>9 No data</td>
</tr>
<tr>
<td>9 Spread eagle</td>
<td></td>
</tr>
</tbody>
</table>

Outside Noises (NOISE) Starting time (START)

| 0 None                     | 0 Same as behavior of 10 min. ago |
| 1 Faint noises             | 1 Behavior began 9 min. ago       |
| 2 Dogs barking             | 2 Behavior began 8 min. ago       |
| 3 Voices/working outside   | 3 Behavior began 7 min. ago       |
| 4 Lab door                 | 4 Behavior began 6 min. ago       |
| 5 Truck/car/motorcycle     | 5 Behavior began 5 min. ago       |
| 6 Work noises (inside)     | 6 Behavior began 4 min. ago       |
| 7 Test disturbance         | 7 Behavior began 3 min. ago       |
| 8 Airplane                 | 8 Behavior began 2 min. ago       |
| 9 No data                  | 9 Behavior began in previous min. |

Summary variables

Three sets of summary variables were coded for each 3 minute interval in the 9 min. prior to the minute being coded. Each code contained; OA, TP, TA, GBP, HO, EP, VOC, and Noise.
A large data file was created by joining each physiological record with the appropriate behavioral code and identifying it with the bear, day, and time of the observation. Most of the analysis was done by accessing this data file with the Statistical Package for the Social Sciences (SPSS, Nie et al. 1975).

Student-Newman-Keuls (SNK) multiple range tests and multivariate discriminant analyses were used in addition to standard statistical procedures to analyze the data. SNK tests were performed on the TB, TS, HR, and SHR to test differences between bears, and for each behavioral parameter on each bear. This test averages the physiological parameter for each bear (or each code of the behavioral parameter) and ordains them from lowest to highest. It then does stepwise comparisons of all the combinations of bears or behavioral codes to determine if they can be sorted into groups that are significantly different from each other (at p<0.05 level, Nie et al. 1975).

Multivariate discriminant analyses were performed on the behavioral parameters to determine how well the measured physiological parameters can predict the bears' behavior. All the physiological parameters that can be measured without observing the animal (TB, TS, HR, SHR, SA, MMHR) and the ambient temperature (TAM) were used to discriminate the codes on the behavioral parameters. Discriminant analysis creates functions which allow for the greatest possible separation between the groups being discriminated. Once the functions are calculated, the SPSS program uses the discriminant variables (physiological parameters) to predict the group membership of the behaviors. It then compares the computed group membership with the actual group membership to see how many were predicted correctly (Sparling and Williams 1978).
Discriminant analyses on OA were performed with different combinations of the physiological parameters for all the bears together, grizzly bears, polar bears, and each bear separately. Overall activity was also discriminated with different behavioral codings and for the baseline and repellent observations data separately. The best overall combination of parameters to predict OA includes MMHR. The sample for those analyses was greatly reduced, however, because MMHR was not calculated for heart rates that were average. Consequently, the analyses on the remaining behavioral parameters were performed without using MMHR as a discriminating variable.
Chapter III

RESULTS, LABORATORY STUDIES

The complete cycle from the time the transmitters were first implanted until they were removed at the end of repellent tests averaged 29 days. Growly's required 30 days, Snarly 36 days, and Guen and Magdalene took 20 and 30 days respectively. A complete series of observations should take 18 days. The difference was due to extended recovery periods and the replacing of heart rate transmitters that ceased to function. The last 3 days of Snarly's repellent trials were completed without the heart rate transmitter operating.

I collected 4,258 recordings of the physiological parameters (Growly 1113, Snarly 1202, Guen 981, and Magdalene 962). Each of these data points contained one or more of the physiological parameters and the appropriate behavioral code. Averages of the physiological parameters were calculated over all the observations (Table 5).

There were significant differences between the bears in all 4 physiological parameters, TB, TS, HR, SHR (p<0.001 for each parameter, one-way ANOVA, Table 6). All 4 bears differ significantly from one another in TB and TS (p<0.05, Student-Newman-Keuls (SNK) multiple range tests). Guen and Magdalene had similar HRs, but they were significantly lower than Growly's and Snarly's HRs (p<0.05, SNK). Although Growly and Snarly had significantly different HRs (p<0.05, SNK), there was no difference in their SHR. Guen and Magdalene's SHR's differed significantly from one another and from the grizzlies (p 0.05, SNK, Table 6).
Table 5: Distributions of physiological parameters.

<table>
<thead>
<tr>
<th>Bear</th>
<th>Mean</th>
<th>St. dev.</th>
<th>Minimum</th>
<th>Maximum</th>
<th>Range</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Body temperature (TB)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>36.71</td>
<td>0.58</td>
<td>34.92</td>
<td>38.45</td>
<td>3.53</td>
<td>465</td>
</tr>
<tr>
<td>Snarly</td>
<td>38.64</td>
<td>0.40</td>
<td>37.87</td>
<td>39.71</td>
<td>1.84</td>
<td>653</td>
</tr>
<tr>
<td>Guen</td>
<td>38.23</td>
<td>0.28</td>
<td>37.50</td>
<td>39.02</td>
<td>1.52</td>
<td>602</td>
</tr>
<tr>
<td>Magdalene</td>
<td>36.55</td>
<td>0.40</td>
<td>35.65</td>
<td>37.96</td>
<td>2.31</td>
<td>626</td>
</tr>
<tr>
<td><strong>Sub-cutaneous temperature (TS)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>37.53</td>
<td>0.48</td>
<td>36.13</td>
<td>38.82</td>
<td>2.69</td>
<td>568</td>
</tr>
<tr>
<td>Snarly</td>
<td>38.73</td>
<td>0.47</td>
<td>36.98</td>
<td>39.79</td>
<td>2.81</td>
<td>650</td>
</tr>
<tr>
<td>Guen</td>
<td>37.70</td>
<td>0.31</td>
<td>36.91</td>
<td>38.52</td>
<td>1.61</td>
<td>608</td>
</tr>
<tr>
<td>Magdalene</td>
<td>34.58</td>
<td>0.49</td>
<td>32.85</td>
<td>35.81</td>
<td>2.96</td>
<td>626</td>
</tr>
<tr>
<td><strong>Heart rate (HR)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>78</td>
<td>15.99</td>
<td>41</td>
<td>144</td>
<td>103</td>
<td>913</td>
</tr>
<tr>
<td>Snarly</td>
<td>95</td>
<td>24.87</td>
<td>48</td>
<td>148</td>
<td>100</td>
<td>1041</td>
</tr>
<tr>
<td>Guen</td>
<td>68</td>
<td>25.97</td>
<td>34</td>
<td>170</td>
<td>136</td>
<td>981</td>
</tr>
<tr>
<td>Magdalene</td>
<td>69</td>
<td>29.66</td>
<td>31</td>
<td>168</td>
<td>137</td>
<td>947</td>
</tr>
<tr>
<td><strong>Standard deviation of heart rate (SHR)</strong>*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>9.05</td>
<td>3.92</td>
<td>0.00</td>
<td>30.20</td>
<td>30.20</td>
<td>884</td>
</tr>
<tr>
<td>Snarly</td>
<td>9.33</td>
<td>4.76</td>
<td>0.00</td>
<td>47.40</td>
<td>47.40</td>
<td>1041</td>
</tr>
<tr>
<td>Guen</td>
<td>10.42</td>
<td>6.46</td>
<td>0.00</td>
<td>42.40</td>
<td>42.40</td>
<td>981</td>
</tr>
<tr>
<td>Magdalene</td>
<td>9.86</td>
<td>5.37</td>
<td>0.00</td>
<td>49.70</td>
<td>49.70</td>
<td>942</td>
</tr>
</tbody>
</table>

* Standard deviation of heart rate over each minute sample of HR.
Table 6: One-way analysis of variance of TB, TS, HR, and SHR on each bear.

<table>
<thead>
<tr>
<th>Physiological parameter</th>
<th>Between groups mean squares</th>
<th>Within groups mean squares</th>
<th>F-ratio</th>
<th>sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Body temperature (TB)</td>
<td>663.0</td>
<td>0.17</td>
<td>3802.1</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SNK groups*</td>
<td>(Magdalene) (Guen) (Snarly) (Growly)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skin temperature (TS)</td>
<td>2005.0</td>
<td>0.20</td>
<td>10275.4</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SNK groups</td>
<td>(Magdalene) (Growly) (Guen) (Snarly)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heart rate (HR)</td>
<td>151057.0</td>
<td>610.92</td>
<td>247.3</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SNK groups</td>
<td>(Guen-Magdalene) (Growly) (Snarly)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Standard deviation of heart rate (SHR)</td>
<td>349.0</td>
<td>27.38</td>
<td>12.7</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>SNK groups</td>
<td>(Growly-Snarly) (Guen) (Magdalene)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* SNK=Student-Newman-Keuls multiple range test. The bears are arranged from lowest to highest values of the parameters and divided into groups that are distinguishable at the p<0.05 level of significance.
Individual differences are as great as species differences in TB and TS, but polar bears can be distinguished from grizzlies with the heart rate parameters (HR and SHR).

The body temperature and sub-cutaneous temperature "track" each other well over days in all of the bears (Figs. 5 and 6). The separation between TB and TS is different for different bears and occasionally TS is higher than TB. Patterns in HR are often more difficult to see, but in the case of Snarly, HR also tracks TB and TS. Extended periods of heavy activity (dark bars along the tops of the graphs) correlate with rising TB and TS. With Snarly, every major peak in TB and TS is during heavy activity. Heart rate also peaks with heavy activity, although there are peaks in HR that are not accompanied by heavy activity. Snarly's TB and TS drop slightly when he eats, but eating precludes heavy activity and the drop may be due to resting. Finally, it is important to note that the observation schedule used for Growly's repellents (Fig. 6) makes it very difficult to observe the overall patterns of physiology that can be seen in the other bears.

All 4 bears behaved significantly different when their heart rates were elevated more than 1 standard deviation above the mean than when their heart rates were normal (p<0.001, X²'s for, overall activity (OA), transitions in posture (TP), transitions in activity (TA), gross body position (GBP), and the test condition (TEST) between 'normal' and 'extreme' physiology, Table 7). The bears behaved differently for some but not all of the behavioral parameters when TS was more than 1 standard deviation above the mean (Table 7). All 4 bears behaved differently for OA and GBP with extreme physiology, but only the grizzlies differed in TA. For body temperature, the behavioral
Figure 5. Baseline physiology. TB is solid line, TS is dotted line, HR is dashed line. Vertical bars along top of graph represent periods of heavy activity. Horizontal lines indicate periods when the bear was eating. Vertical arrows represent disturbances when the assistant entered the cell area. F = Feeding, C = Control (Stand at door).
Table 7: $X^2$ test results on behavioral differences between 'extreme' and 'normal' physiology.

<table>
<thead>
<tr>
<th>Behavioral parameter</th>
<th>Growly</th>
<th>Snarly</th>
<th>Guen</th>
<th>Magdalene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$X^2$ d.f. sig.</td>
<td>$X^2$ d.f. sig.</td>
<td>$X^2$ d.f. sig.</td>
<td>$X^2$ d.f. sig.</td>
</tr>
<tr>
<td><strong>Body temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>15.7 6 0.02*</td>
<td>58.0 5 &lt;0.001*</td>
<td>15.4 6 0.02*</td>
<td>8.0 7 0.33</td>
</tr>
<tr>
<td>TP</td>
<td>6.9 7 0.46</td>
<td>8.2 8 0.41</td>
<td>10.8 7 0.15</td>
<td>5.3 7 0.63</td>
</tr>
<tr>
<td>TA</td>
<td>7.3 5 0.20</td>
<td>4.6 6 0.59</td>
<td>56.3 5 &lt;0.001*</td>
<td>11.2 7 0.14</td>
</tr>
<tr>
<td>GBP</td>
<td>22.9 7 0.007*</td>
<td>46.1 6 &lt;0.001*</td>
<td>3.0 4 0.56</td>
<td>25.2 6 &lt;0.001*</td>
</tr>
<tr>
<td>TEST</td>
<td>21.3 6 0.003*</td>
<td>12.8 6 0.12</td>
<td>16.5 4 0.007*</td>
<td>10.2 6 0.12</td>
</tr>
<tr>
<td><strong>Sub-cutaneous temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>16.2 6 0.02*</td>
<td>104.0 5 &lt;0.001*</td>
<td>28.6 6 &lt;0.001*</td>
<td>17.8 7 0.02*</td>
</tr>
<tr>
<td>TP</td>
<td>16.2 5 0.52</td>
<td>12.2 6 0.15</td>
<td>7.9 7 0.34</td>
<td>11.7 7 0.11</td>
</tr>
<tr>
<td>TA</td>
<td>3.5 7 0.03*</td>
<td>20.4 8 0.005*</td>
<td>6.9 6 0.33</td>
<td>13.1 7 0.07</td>
</tr>
<tr>
<td>GBP</td>
<td>18.2 7 0.01*</td>
<td>105.8 6 &lt;0.001*</td>
<td>20.8 4 &lt;0.001*</td>
<td>21.5 6 0.003*</td>
</tr>
<tr>
<td>TEST</td>
<td>39.8 6 &lt;0.001*</td>
<td>10.3 6 0.12</td>
<td>51.4 4 &lt;0.001*</td>
<td>6.7 6 0.36</td>
</tr>
<tr>
<td><strong>Heart rate</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>207.3 6 &lt;0.001*</td>
<td>601.7 6 &lt;0.001*</td>
<td>530.4 7 &lt;0.001*</td>
<td>673.5 8 &lt;0.001*</td>
</tr>
<tr>
<td>TP</td>
<td>46.6 8 &lt;0.001*</td>
<td>221.0 8 &lt;0.001*</td>
<td>537.8 8 &lt;0.001*</td>
<td>653.7 7 &lt;0.001*</td>
</tr>
<tr>
<td>TA</td>
<td>32.1 5 &lt;0.001*</td>
<td>41.6 6 &lt;0.001*</td>
<td>402.4 8 &lt;0.001*</td>
<td>136.6 8 &lt;0.001*</td>
</tr>
<tr>
<td>GBP</td>
<td>172.9 7 &lt;0.001*</td>
<td>337.4 6 &lt;0.001*</td>
<td>404.8 4 &lt;0.001*</td>
<td>667.3 6 &lt;0.001*</td>
</tr>
<tr>
<td>TEST</td>
<td>28.9 6 &lt;0.001*</td>
<td>75.2 6 &lt;0.001*</td>
<td>119.2 4 &lt;0.001*</td>
<td>93.4 6 &lt;0.001*</td>
</tr>
</tbody>
</table>

* p<0.05
differences in OA, GBP, and TEST are significant for the grizzlies, while TA and TEST are significant for Guen and Magdalene (Table 7).

Body temperature and sub-cutaneous temperature are highly correlated in each bear except Magdalene (Pearson's correlation coefficients, Table 8). The ambient temperature was correlated to TS in Guen and to TB in Magdalene. HR correlated with TB and TS in Snarly and with SHR in Guen, but did not correlate with any other physiological parameter.

Several of the behavioral parameters correlated with TB and/or TS in Snarly (correlation ratios, $\eta^2$, Table 8), but few correlated in Growly. None of the behavioral parameters explained more than 8% of the variance in TB or TS in either of the polar bears. Heart rate is correlated to most of the behavioral parameters in all the bears ($\eta^2 > 0.10$).

Heavy and moderate activity resulted in significantly higher TB and TS in Snarly than all other activities (SNK, $p < 0.05$). Similarly, hind foot positions in Guen resulted in TB and TS dividing into significantly different groups (SNK, $p < 0.05$, Table 9). The behavior results in significantly different groupings of HR in 19 cases and SHR in 11 cases (Table 9). In general, the behavior of the bears did not result in significantly different values for the physiological parameters.

The behaviors that result in high (or low) TB for a bear also result in high (or low) TS for that bear, but behaviors that result in high (or low) TB and TS for one bear are not the same for another bear. Where the values of the physiological parameters differ significantly for different behaviors, there is fairly good agreement between bears in which behaviors result in high (or low) physiology (e.g., HR on OA
### Table 8: Correlations among physiological and behavioral parameters.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Growly</th>
<th>Snarly</th>
<th>Guen</th>
<th>Magdalene</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TB</td>
<td>TS</td>
<td>HR</td>
<td>SHR</td>
</tr>
<tr>
<td><strong>Physiological</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB</td>
<td>--</td>
<td>0.43*</td>
<td>0.05</td>
<td>0.01</td>
</tr>
<tr>
<td>TS</td>
<td>0.43*</td>
<td>--</td>
<td>0.02</td>
<td>0.00</td>
</tr>
<tr>
<td>HR</td>
<td>0.05</td>
<td>0.02</td>
<td>--</td>
<td>0.04</td>
</tr>
<tr>
<td>SHR</td>
<td>0.01</td>
<td>0.00</td>
<td>0.04</td>
<td>--</td>
</tr>
<tr>
<td>TAM</td>
<td>0.00</td>
<td>0.01</td>
<td>0.02</td>
<td>0.01</td>
</tr>
</tbody>
</table>

| **Behavioral** |       |        |      |           |        |        |      |           |        |        |      |           |
| OA         | 0.04   | 0.07   | 0.44*| 0.16*    | 0.12*  | 0.18* | 0.83*| 0.00     | 0.03   | 0.08   | 0.73*| 0.37*    | 0.02   | 0.02   | 0.71*| 0.05     |
| TP         | 0.03   | 0.01   | 0.11*| 0.01     | 0.01   | 0.02   | 0.25*| 0.01     | 0.03   | 0.04   | 0.43*| 0.37*    | 0.02   | 0.01   | 0.65*| 0.05     |
| TA         | 0.01   | 0.02   | 0.05 | 0.01     | 0.01   | 0.02   | 0.09*| 0.01     | 0.02   | 0.03   | 0.33*| 0.34*    | 0.02   | 0.02   | 0.15*| 0.04     |
| GBP        | 0.06   | 0.11*  | 0.01 | 0.09     | 0.10*  | 0.14* | 0.72*| 0.00     | 0.01   | 0.05   | 0.67*| 0.31*    | 0.03   | 0.04   | 0.75*| 0.05     |
| HP         | 0.09   | 0.07   | 0.34*| 0.05     | 0.03   | 0.10* | 0.56*| 0.02     | 0.04   | 0.00   | 0.53*| 0.14*    | 0.01   | 0.02   | 0.35*| 0.01     |
| HO         | 0.04   | 0.10*  | 0.31*| 0.12*    | 0.12*  | 0.18* | 0.73*| 0.01     | 0.02   | 0.06   | 0.57*| 0.18*    | 0.01   | 0.01   | 0.59*| 0.03     |
| EP         | 0.03   | 0.05   | 0.22*| 0.03     | 0.04   | 0.05   | 0.33*| 0.02     | 0.02   | 0.05   | 0.42*| 0.08    | 0.01   | 0.02   | 0.56*| 0.02     |
| MISC       | 0.04   | 0.07   | 0.17*| 0.10*    | 0.16*  | 0.21* | 0.64*| 0.01     | 0.02   | 0.06   | 0.45*| 0.06    | 0.04   | 0.04   | 0.53*| 0.03     |
| VOC        | 0.14*  | 0.13*  | 0.10*| 0.01     | 0.24*  | 0.25* | 0.12*| 0.01     | 0.01   | 0.02   | 0.40*| 0.31*    | 0.03   | 0.02   | 0.11*| 0.05     |
| FFP        | 0.04   | 0.07   | 0.17*| 0.10*    | 0.07   | 0.18* | 0.50*| 0.04     | 0.02   | 0.04   | 0.16*| 0.01    | 0.01   | 0.04   | 0.29*| 0.02     |
| HFP        | 0.03   | 0.06   | 0.02 | 0.01     | 0.04   | 0.05   | 0.13*| 0.03     | 0.04   | 0.08   | 0.30*| 0.06    | 0.03   | 0.02   | 0.21*| 0.01     |
| NOISE      | 0.01   | 0.03   | 0.04 | 0.01     | 0.02   | 0.01   | 0.01 | 0.00     | 0.01   | 0.03   | 0.44*| 0.40*    | 0.00   | 0.01   | 0.04 | 0.03     |

---

**a** Values for physiological correlations are Pearson's correlation coefficients ($r^2$).

* Indicates a correlation that explains 10% or more of the variance in the physiological parameter.

**b** Values for behavioral correlations are correlation ratios ($eta^2$).
Table 9: One-way analysis of variance multiple range tests on the physiological parameters for each behavioral parameter.

<table>
<thead>
<tr>
<th>Behavioral parameter</th>
<th>Growly</th>
<th>Snarly</th>
<th>Guen</th>
<th>Mandalene</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TA</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB</td>
<td>21.83±6</td>
<td>34.28±9*</td>
<td>56.47±28</td>
<td>53.86±201</td>
</tr>
<tr>
<td>TS</td>
<td>4.82±105</td>
<td>24.38±25</td>
<td>65.47±128</td>
<td>32.81±156</td>
</tr>
<tr>
<td>HR</td>
<td>2.38±406*</td>
<td>36.2±46</td>
<td>36.7±435 6</td>
<td>1.2±8 3475 6</td>
</tr>
<tr>
<td>SHR</td>
<td>3.02±486</td>
<td>26.06±45</td>
<td>74.20±835</td>
<td>70.23±86</td>
</tr>
<tr>
<td><strong>TB</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TS</td>
<td>24.86±175</td>
<td>71.26±853</td>
<td>67.41±853</td>
<td>28.57±641</td>
</tr>
<tr>
<td>HR</td>
<td>0.15±5378</td>
<td>74.63±378</td>
<td>64.31±387</td>
<td>0.1±625 8 7</td>
</tr>
<tr>
<td>SHR</td>
<td>2.13±641</td>
<td>50.38±817</td>
<td>64.93±817</td>
<td>4.56±712</td>
</tr>
<tr>
<td><strong>TS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>0.40±627</td>
<td>54.26±87</td>
<td>46.72±80</td>
<td>52.30±876</td>
</tr>
<tr>
<td><strong>HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>2.07±654</td>
<td>42.86±57</td>
<td>56.72±208</td>
<td>45.70±236</td>
</tr>
<tr>
<td><strong>CHR</strong></td>
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<td></td>
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</tr>
<tr>
<td>SHR</td>
<td>0.04±676</td>
<td>42.80±36</td>
<td>80.58±236</td>
<td>80.84±736</td>
</tr>
<tr>
<td>** Pre**</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>SHR</td>
<td>0.27±674</td>
<td>61.48±63</td>
<td>0.3±6267</td>
<td>4.07±623</td>
</tr>
<tr>
<td><strong>HP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>5.03±721</td>
<td>31.27±84</td>
<td>13.6±72</td>
<td>69.7±2132</td>
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<tr>
<td><strong>HR</strong></td>
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<td></td>
</tr>
<tr>
<td>SHR</td>
<td>7.45±318</td>
<td>32.18±46</td>
<td>4.16±72</td>
<td>3.24±182</td>
</tr>
<tr>
<td><strong>HR</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>2.01±738</td>
<td>32.01±38</td>
<td>2.1±678</td>
<td>2.31±678</td>
</tr>
<tr>
<td><strong>MISC</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>1.07±160</td>
<td>71.50±38</td>
<td>16.5±78</td>
<td>1.7±576</td>
</tr>
<tr>
<td><strong>VOC</strong></td>
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</tr>
<tr>
<td>SHR</td>
<td>4.01±823</td>
<td>40.06±28</td>
<td>0.5±28</td>
<td>0.5±1824</td>
</tr>
<tr>
<td><strong>FFP</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>6.40±723</td>
<td>40.06±28</td>
<td>40.1±28</td>
<td>1.0±298</td>
</tr>
<tr>
<td><strong>KFP</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>3.08±127</td>
<td>0.85±62</td>
<td>20.4±65</td>
<td>20.4±565</td>
</tr>
<tr>
<td><strong>NOISE</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHR</td>
<td>3.10±247</td>
<td>02.04±65</td>
<td>10.5±66</td>
<td>10.5±26</td>
</tr>
</tbody>
</table>

*Each entry gives the order (from lowest to highest) of the behavioral codes for the specified physiological parameter. Spacing indicates groups that are distinguishable at p<0.05 level with Student-Newman-Keuls multiple range tests.
*Indicates those comparisons that segregate into groups (p<0.05).
and GBP, Table 9), but the ordination of behavioral codes does not generally agree between bears.

When the physiological parameters from all of the bears are combined, multivariate discriminant analyses can predict the overall activity (OA) for 81% of the cases ($n = 636$). The ability to predict OA increases if the grizzlies and polar bears are treated as different groups (Table 10). The remaining discriminant analyses were done for each bear separately (Table 10).

When the physiological parameters from baseline observations were separated from those of repellent observations, they are better at predicting the overall activity in every case except Magdalene's baseline physiology (Table 10). Similarly, recoding OA = 8 (lying quietly) increases the ability to predict the overall activity from the physiological parameters (except in Magdalene where OA = 8 was recoded to OA = 4, Table 10).

The ability to predict the other behavioral parameters with the physiology varies (Table 11). Transitions in posture and activity have high (75%) prediction rates in all the bears, but vocalizations and hind foot positions are predicted that well only in the grizzlies. The only other behavioral parameters that were predicted from the physiology for more than 75% of the cases were Magdalene's head orientation and ear position (Table 11).

**Repellent Tests**

The effects of the repellent tests on the bears were analyzed from 2 perspectives. First, the baseline physiology and behavior were compared to the repellent physiology and behavior. In this case, I sampled the data at 10-minute intervals to compensate for the
Table 10: Prediction rates of overall activity from discriminant analyses of physiology.

<table>
<thead>
<tr>
<th>Discriminant variables*</th>
<th>Bear(s)</th>
<th>% predicted</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td>TB, TS, HR, SHR, SA, TAM</td>
<td>All</td>
<td>67.3</td>
<td>1431</td>
</tr>
<tr>
<td></td>
<td>Grizzly bears</td>
<td>57.6</td>
<td>708</td>
</tr>
<tr>
<td></td>
<td>Polar bears</td>
<td>77.7</td>
<td>723</td>
</tr>
<tr>
<td></td>
<td>Growly</td>
<td>54.3</td>
<td>372</td>
</tr>
<tr>
<td></td>
<td>Snarly</td>
<td>72.8</td>
<td>493</td>
</tr>
<tr>
<td></td>
<td>Guen</td>
<td>83.1</td>
<td>602</td>
</tr>
<tr>
<td></td>
<td>Magdalene</td>
<td>68.8</td>
<td>140</td>
</tr>
<tr>
<td>TB, TS, HR, SHR, SA, TAM, MâHR</td>
<td>All</td>
<td>80.7</td>
<td>636</td>
</tr>
<tr>
<td></td>
<td>Grizzly bears</td>
<td>82.7</td>
<td>330</td>
</tr>
<tr>
<td></td>
<td>Polar bears</td>
<td>84.3</td>
<td>306</td>
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<tr>
<td></td>
<td>Growly</td>
<td>52.6</td>
<td>215</td>
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<tr>
<td></td>
<td>Snarly</td>
<td>88.3</td>
<td>247</td>
</tr>
<tr>
<td></td>
<td>Guen</td>
<td>88.8</td>
<td>224</td>
</tr>
<tr>
<td></td>
<td>Magdalene</td>
<td>90.2</td>
<td>82</td>
</tr>
<tr>
<td>TB, TS, HR, SHR, SA</td>
<td>Growly</td>
<td>44.0</td>
<td>479</td>
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<tr>
<td></td>
<td>Snarly</td>
<td>63.7</td>
<td>493</td>
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<tr>
<td></td>
<td>Guen</td>
<td>81.6</td>
<td>602</td>
</tr>
<tr>
<td></td>
<td>Magdalene</td>
<td>63.0</td>
<td>606</td>
</tr>
<tr>
<td>TB, TS, HR, SHR, SA, TAM</td>
<td>Baseline data only</td>
<td>Growly</td>
<td>54.4</td>
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<td></td>
<td>Snarly</td>
<td>74.4</td>
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<td></td>
<td>Guen</td>
<td>83.4</td>
<td>241</td>
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<td></td>
<td>Magdalene</td>
<td>34.0</td>
<td>235</td>
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<tr>
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<td>Repellents data only</td>
<td>Growly</td>
<td>44.7</td>
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<tr>
<td></td>
<td>Snarly</td>
<td>80.1</td>
<td>266</td>
</tr>
<tr>
<td></td>
<td>Guen</td>
<td>83.7</td>
<td>361</td>
</tr>
<tr>
<td></td>
<td>Magdalene</td>
<td>70.3</td>
<td>118</td>
</tr>
<tr>
<td>TB, TS, HR, SHR, SA, TAM</td>
<td>OA=8 recoded to OA=4 (light activity).</td>
<td>Growly</td>
<td>66.0</td>
</tr>
<tr>
<td></td>
<td>Snarly</td>
<td>75.2</td>
<td>140</td>
</tr>
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<td></td>
<td>Guen</td>
<td>85.7</td>
<td>602</td>
</tr>
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<td></td>
<td>Magdalene</td>
<td>87.9</td>
<td>140</td>
</tr>
<tr>
<td>TB, TS, HR, SHR, SA, TAM</td>
<td>OA=8 recoded to OA=2 (lying quietly).</td>
<td>Growly</td>
<td>66.0</td>
</tr>
<tr>
<td></td>
<td>Snarly</td>
<td>81.5</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>Guen</td>
<td>89.0</td>
<td>583</td>
</tr>
<tr>
<td></td>
<td>Magdalene</td>
<td>78.6</td>
<td>140</td>
</tr>
</tbody>
</table>

* TB=Body temperature, TS=Sub-cutaneous temperature, HR=Heart rate, SHR=Standard deviation of HR, SA=Sinus arrhythmia, TAM=Ambient temperature, and MâHR=Maximum or minimum HR.
Table 11: Prediction rates of behavioral parameters from discriminant analyses of physiology.*

<table>
<thead>
<tr>
<th>Behavioral parameter</th>
<th>Growly % predicted</th>
<th>Snarly % predicted</th>
<th>Guen % predicted</th>
<th>Magdalene % predicted</th>
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</thead>
<tbody>
<tr>
<td>Transitions in posture</td>
<td>83.7</td>
<td>79.5</td>
<td>94.4</td>
<td>94.3</td>
</tr>
<tr>
<td>Transitions in activity</td>
<td>76.0</td>
<td>87.4</td>
<td>86.1</td>
<td>91.4</td>
</tr>
<tr>
<td>Gross body position</td>
<td>55.4</td>
<td>65.9</td>
<td>65.2</td>
<td>54.8</td>
</tr>
<tr>
<td>Head position</td>
<td>42.8</td>
<td>51.9</td>
<td>37.7</td>
<td>48.6</td>
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<tr>
<td>Head orientation</td>
<td>56.3</td>
<td>60.2</td>
<td>71.8</td>
<td>76.3</td>
</tr>
<tr>
<td>Ear position</td>
<td>58.2</td>
<td>62.0</td>
<td>68.6</td>
<td>75.4</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>53.2</td>
<td>71.0</td>
<td>69.1</td>
<td>63.9</td>
</tr>
<tr>
<td>Vocalizations</td>
<td>91.0</td>
<td>82.5</td>
<td>69.5</td>
<td>----</td>
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<tr>
<td>Front foot positions</td>
<td>63.6</td>
<td>56.4</td>
<td>59.7</td>
<td>48.6</td>
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<td>Hind foot positions</td>
<td>91.2</td>
<td>79.5</td>
<td>34.3</td>
<td>55.7</td>
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<tr>
<td>Start time of behavior</td>
<td>54.2</td>
<td>41.0</td>
<td>44.6</td>
<td>54.3</td>
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<tr>
<td>Test condition</td>
<td>44.0</td>
<td>58.0</td>
<td>65.8</td>
<td>52.1</td>
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</tbody>
</table>

* Physiological parameters used in these analyses were; TB, TS, HR, SHR, SA, TAM.
continuous recording during repellent tests. Secondly, the behavioral and physiological parameters immediately prior to a test or control were compared with the same parameters immediately after a test or control.

Heart rate was the only parameter that was significantly different (higher in repellents) for all the bears (Mann-Whitney U-tests, Table 12). Sub-cutaneous temperature was significantly different in the grizzlies and in Guen. However, Snarly's TS was higher for the repellents, while Growly's and Guen's were lower during the repellents. The body temperature is significantly higher in the repellent observations for Snarly and Guen, and SHR is significantly higher in Snarly (Table 12).

The ear position (EP) was the only behavioral parameter that was significantly different for all the bears between baseline and repellent observations (Table 13). Seven of the behavioral parameters were different for 3 bears (OA, GBP, HP, HO, MISC, FFP, and HFP). Transitions in posture (TP), vocalizations (VOC), and external noises (NOISE) were different for 2 bears and none of the bears showed a significant change in transitions in activity (TA). Growly's behavior was significantly different for fewer of the parameters than the other bears.

The correlation between peaks in heart rate and individual repellent trials is especially striking in the polar bears (Fig. 6, C and D). Guen's HR exceeded 130 bpm at every test disturbance. The amount of time the bears spent in heavy activity also increased dramatically in the repellent trials. In many cases the trial
Table 12: Mann-Whitney U-tests comparing baseline physiology with repellent physiology.\textsuperscript{a}

<table>
<thead>
<tr>
<th>Bear</th>
<th>U</th>
<th>sig.</th>
<th>N\textsubscript{1}</th>
<th>N\textsubscript{2}</th>
<th>Direction of change</th>
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</thead>
<tbody>
<tr>
<td><strong>Body temperature</strong></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Growly</td>
<td>1006</td>
<td>0.068</td>
<td>58</td>
<td>44</td>
<td>-</td>
</tr>
<tr>
<td>Snarly</td>
<td>9470</td>
<td>0.002*</td>
<td>80</td>
<td>307</td>
<td>+</td>
</tr>
<tr>
<td>Guen</td>
<td>2360</td>
<td>0.000*</td>
<td>209</td>
<td>281</td>
<td>+</td>
</tr>
<tr>
<td>Magdalene</td>
<td>27199</td>
<td>0.651</td>
<td>208</td>
<td>268</td>
<td>+</td>
</tr>
<tr>
<td><strong>Skin temperature</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>1454</td>
<td>0.002*</td>
<td>53</td>
<td>29</td>
<td>-</td>
</tr>
<tr>
<td>Snarly</td>
<td>9466</td>
<td>0.003*</td>
<td>80</td>
<td>301</td>
<td>+</td>
</tr>
<tr>
<td>Guen</td>
<td>16206</td>
<td>0.000*</td>
<td>209</td>
<td>282</td>
<td>-</td>
</tr>
<tr>
<td>Magdalene</td>
<td>26605</td>
<td>0.445</td>
<td>207</td>
<td>268</td>
<td>-</td>
</tr>
<tr>
<td><strong>Heart rate</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Growly</td>
<td>1471</td>
<td>0.002*</td>
<td>86</td>
<td>50</td>
<td>+</td>
</tr>
<tr>
<td>Snarly</td>
<td>18622</td>
<td>0.013*</td>
<td>197</td>
<td>220</td>
<td>+</td>
</tr>
<tr>
<td>Guen</td>
<td>17505</td>
<td>0.000*</td>
<td>239</td>
<td>317</td>
<td>+</td>
</tr>
<tr>
<td>Magdalene</td>
<td>27754</td>
<td>0.000*</td>
<td>226</td>
<td>307</td>
<td>+</td>
</tr>
<tr>
<td><strong>Standard deviation of heart rate</strong></td>
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<td></td>
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<tr>
<td>Growly</td>
<td>1676</td>
<td>0.131</td>
<td>83</td>
<td>48</td>
<td>+</td>
</tr>
<tr>
<td>Snarly</td>
<td>18467</td>
<td>0.009*</td>
<td>197</td>
<td>220</td>
<td>-</td>
</tr>
<tr>
<td>Guen</td>
<td>34979</td>
<td>0.121</td>
<td>239</td>
<td>317</td>
<td>+</td>
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<tr>
<td>Magdalene</td>
<td>34094</td>
<td>0.734</td>
<td>226</td>
<td>307</td>
<td>-</td>
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</tbody>
</table>

\textsuperscript{a} Data for these comparisons were sampled from the total in order to avoid the bias caused by continuous recording when a test was performed. * indicates p\leq0.05
Table 13: $\chi^2$ test results on behavioral differences between baseline and repellents observations.\(^a\)

<table>
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<tbody>
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<td>OA</td>
<td>8.4 4 0.08</td>
<td>27.1 4 &lt;0.001*</td>
<td>17.6 4 0.003*</td>
<td>65.3 6 &lt;0.001*</td>
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</tr>
<tr>
<td>TP</td>
<td>12.9 7 0.08</td>
<td>20.7 8 0.009*</td>
<td>7.8 6 0.26</td>
<td>18.4 7 0.01*</td>
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<tr>
<td>TA</td>
<td>10.9 5 0.06</td>
<td>9.4 5 0.10</td>
<td>8.6 6 0.20</td>
<td>12.0 7 0.10</td>
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<tr>
<td>GBP</td>
<td>16.7 6 0.01*</td>
<td>10.3 6 0.12</td>
<td>35.8 4 &lt;0.001*</td>
<td>21.9 6 0.002*</td>
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<tr>
<td>HP</td>
<td>31.9 7 &lt;0.001*</td>
<td>18.3 7 0.01*</td>
<td>131.1 6 &lt;0.001*</td>
<td>6.6 7 0.47</td>
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<tr>
<td>HO</td>
<td>20.6 6 0.004*</td>
<td>19.1 7 0.009*</td>
<td>32.2 5 &lt;0.001*</td>
<td>13.7 8 0.09</td>
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<tr>
<td>EP</td>
<td>21.0 6 0.003*</td>
<td>45.9 5 &lt;0.001*</td>
<td>25.8 4 &lt;0.001*</td>
<td>20.0 5 0.002*</td>
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<tr>
<td>MISC</td>
<td>9.2 4 0.06</td>
<td>41.6 8 &lt;0.001*</td>
<td>33.0 6 &lt;0.001*</td>
<td>36.4 6 &lt;0.001*</td>
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<tr>
<td>VOC</td>
<td>8.6 5 0.13</td>
<td>16.1 4 &lt;0.001*</td>
<td>19.2 4 &lt;0.001*</td>
<td>4.4 5 0.49</td>
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<tr>
<td>FFP</td>
<td>10.8 6 0.07</td>
<td>33.8 6 &lt;0.001*</td>
<td>117.7 3 &lt;0.001*</td>
<td>20.9 8 0.009*</td>
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<tr>
<td>HFP</td>
<td>5.8 4 0.21</td>
<td>15.3 6 0.02*</td>
<td>51.4 5 &lt;0.001*</td>
<td>46.3 6 &lt;0.001*</td>
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<tr>
<td>NOISE</td>
<td>5.1 4 0.28</td>
<td>4.7 5 0.45</td>
<td>46.1 7 &lt;0.001*</td>
<td>16.1 8 0.04*</td>
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</tbody>
</table>

\(^a\) Data for these comparisons were sampled from the total in order to avoid the bias caused by continuous recording when a test was performed.

* $p<0.05$
initiated heavy activity. The HR occasionally peaked at a trial without concurrent heavy activity (e.g., Snarly, Day 6 at 15:04, Fig. 6B).

There were differences between bears when the physiological parameters for 30 minutes prior to tests, controls, or feeding disturbances were compared to the same parameters for the 30 minutes beginning with the test disturbance (Table 14). Heart rate increased significantly for each bear during tests. Standard deviation of heart rate also increased for Snarly during tests (Table 14). The heart rate of both polar bears also increased significantly during controls, but there was no difference in the polar bears' HR between post-test and post-control periods. Magdalene's TB was higher after controls than after tests, and Guen's TS was lower. Finally, Snarly's TB was lower after feeding than before. No other changes in TB or TS occurred.

There were also significant behavioral differences between the 30 minutes prior to testing and the 30 minutes after testing (Table 15). The overall activity and gross body position were significantly different after tests in all the bears. TA and TP were different in Snarly, Guen, and Magdalene. Overall activity and gross body position also changed significantly in the polar bears during controls, as did GBP in Growly. Finally, the only difference between the post-test and post-control periods was Guen's overall activity.

All of the chemicals except Bear Trail consistently repelled the bears, but with varying intensities (strong, moderate, or weak, Table 16). The best repellent was Halt, a dog repellent designed to stop an attacking dog. Each time it was tested, the bear charged until it was sprayed, the bear then turned and ran to the farthest corner of the
Figure 6. Repellents physiology. TB is solid line, TS is dotted line, and HR is dashed line. Vertical bars along the top of the graphs represent periods of heavy activity. Horizontal lines indicate periods when the bear was eating. Vertical arrows represent test disturbances when the assistant entered the cell area (Table 3).

$T_1 = S_{Growl}$  $S_1 = \text{Thunderflash}$  $C_1 = \text{Onion juice}$

$T_2 = S_{Hiss}$  $S_2 = \text{Bells}$  $C_2 = \text{Windex}$

$T_3 = S_{Bark}$  $S_3 = \text{Boat horn}$  $C_3 = \text{Mustard}$

$T_4 = S_{Shout}$  $S_4 = \text{Sound 911}$  $C_4 = \text{Halt}$

$T_5 = G_{Growl}$  $S_5 = \text{Dog whistle}$  $C_5 = \text{Dog Stopper}$

$T_6 = G_{Bark}$  $S_6 = \text{ref's whistle}$  $C_6 = \text{Git}$

$T_7 = 1977PB$  $S_7 = \text{Trucktone horn}$  $C_7 = \text{Chaperone}$

$T_8 = \text{GUEN}$  $S_8 = \text{Cap-chur gun}$  $C_8 = \text{Bear Trail}$

$T_9 = \text{ORCA}$  $S_C = \text{Control}$  $C_C = \text{Chemical control}$

$T_C = \text{Control}$

$S_01 = \text{Strobe light}$

$S_02 = \text{Loom}$

$C = \text{Control (Stand at door)}$

$F = \text{Feeding}$
C. GUEN REPELLENTS

TEMPERATURE (°C)

HEART RATE (BPM)

TIME OF DAY

700 1200 1700
DAY 6

700 1200 1700
DAY 7

700 1200 1700
DAY 8

700 1200 1700
DAY 9

700 1200 1700
DAY 10

700 1200 1700
DAY 11

700 1200 1700
DAY 12
Table 14: Mann-Whitney U-tests comparing physiology under different test conditions.

<table>
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</thead>
<tbody>
<tr>
<td><strong>Pre-test vs Post-test</strong></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TB</td>
<td>529 0.161</td>
<td>64 186 +</td>
<td>2489 0.705</td>
<td>55 93 +</td>
<td>1294 0.217</td>
<td>91 311 -</td>
<td>2533 0.721</td>
<td>52 101 +</td>
</tr>
<tr>
<td>TS</td>
<td>375 0.555</td>
<td>65 120 -</td>
<td>2597 0.867</td>
<td>60 88 -</td>
<td>2869 0.440</td>
<td>10 124 +</td>
<td>259 0.824</td>
<td>52 102 +</td>
</tr>
<tr>
<td>HR</td>
<td>11269 0.005*</td>
<td>112 267 +</td>
<td>2592 0.000*</td>
<td>55 171 +</td>
<td>853 0.000*</td>
<td>91 311 +</td>
<td>4321 0.000*</td>
<td>96 254 +</td>
</tr>
<tr>
<td>SHR</td>
<td>12397 0.133</td>
<td>108 255 +</td>
<td>3048 0.043*</td>
<td>55 171 +</td>
<td>12947 0.217</td>
<td>91 311 -</td>
<td>1175 0.643</td>
<td>96 253 +</td>
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<tr>
<td><strong>Pre-test vs Pre-control</strong></td>
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<tr>
<td>TB</td>
<td>1030 0.570</td>
<td>64 35 +</td>
<td>610 0.287</td>
<td>55 26 +</td>
<td>366 0.594</td>
<td>18 17 -</td>
<td>141 0.070</td>
<td>52 23 +</td>
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<tr>
<td>TS</td>
<td>1611 0.239</td>
<td>65 50 -</td>
<td>676 0.475</td>
<td>60 25 +</td>
<td>388 0.670</td>
<td>19 17 -</td>
<td>535 0.469</td>
<td>52 23 -</td>
</tr>
<tr>
<td>HR</td>
<td>2721 0.083*</td>
<td>112 58 +</td>
<td>422 0.000*</td>
<td>55 31 +</td>
<td>1225 0.402</td>
<td>91 30 -</td>
<td>1434 0.002*</td>
<td>96 44 +</td>
</tr>
<tr>
<td>SHR</td>
<td>2080 0.752</td>
<td>108 55 -</td>
<td>824 0.798</td>
<td>55 31 +</td>
<td>1200 0.694</td>
<td>91 30 +</td>
<td>1909 0.480</td>
<td>96 43 -</td>
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<tr>
<td>TB</td>
<td>1700 0.803</td>
<td>35 100 +</td>
<td>393 0.872</td>
<td>26 31 +</td>
<td>230 0.664</td>
<td>17 30 +</td>
<td>120 0.205</td>
<td>23 45 +</td>
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<tr>
<td>TS</td>
<td>1650 0.683</td>
<td>50 69 -</td>
<td>376 0.699</td>
<td>25 32 +</td>
<td>253 0.820</td>
<td>17 31 -</td>
<td>371 0.057</td>
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<tr>
<td>HR</td>
<td>3857 0.872</td>
<td>58 135 +</td>
<td>1260 0.868</td>
<td>31 83 +</td>
<td>692 0.000*</td>
<td>30 91 +</td>
<td>1354 0.000*</td>
<td>44 177 +</td>
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<tr>
<td>SHR</td>
<td>3625 0.817</td>
<td>55 131 +</td>
<td>1099 0.233</td>
<td>31 83 +</td>
<td>1057 0.065</td>
<td>30 91 -</td>
<td>2110 0.590</td>
<td>43 110 +</td>
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<tr>
<td><strong>Post-test vs Post-control</strong></td>
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<td>TB</td>
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<td>1530 0.163</td>
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<td>1332 0.000*</td>
<td>101 45 +</td>
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<tr>
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<td>1213 0.247</td>
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<td>1421 0.025</td>
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<tr>
<td>HR</td>
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<td>267 135 +</td>
<td>5180 0.000*</td>
<td>171 83 +</td>
<td>13651 0.596</td>
<td>311 91 +</td>
<td>13077 0.572</td>
<td>254 178 +</td>
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<td>SHR</td>
<td>14326 0.022*</td>
<td>255 135 +</td>
<td>7033 0.908</td>
<td>171 83 +</td>
<td>12711 0.140</td>
<td>311 91 -</td>
<td>12473 0.411</td>
<td>253 104 +</td>
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<tr>
<td><strong>Pre-feeding vs Post-feeding</strong></td>
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<td>TB</td>
<td>35 0.253</td>
<td>10 10 -</td>
<td>262 0.017*</td>
<td>26 32 -</td>
<td>insufficient data</td>
<td></td>
<td>18 0.731</td>
<td>6 7 -</td>
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<td>TS</td>
<td>28 0.660</td>
<td>6 11 -</td>
<td>326 0.157</td>
<td>26 32 -</td>
<td>insufficient data</td>
<td></td>
<td>21 1.0</td>
<td>6 7 0</td>
</tr>
<tr>
<td>HR</td>
<td>58 0.001*</td>
<td>15 22 +</td>
<td>2058 0.242</td>
<td>65 73 +</td>
<td>insufficient data</td>
<td></td>
<td>6 0.003*</td>
<td>6 11 +</td>
</tr>
<tr>
<td>SHR</td>
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<td>15 22 -</td>
<td>2319 0.019</td>
<td>65 73 +</td>
<td>insufficient data</td>
<td></td>
<td>15 0.078</td>
<td>6 11 +</td>
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* P < 0.05
Table 15: $X^2$ test results on behavioral differences under different test conditions.

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<tr>
<th></th>
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<tbody>
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<td>Pre-test vs post-test</td>
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<td></td>
<td></td>
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</tr>
<tr>
<td>OA</td>
<td>123.4 6 &lt; 0.001*</td>
<td>41.6 6 &lt; 0.001*</td>
<td>40.6 6 &lt; 0.001*</td>
<td>65.8 6 &lt; 0.001*</td>
</tr>
<tr>
<td>TP</td>
<td>8.2 7 0.32</td>
<td>36.0 6 &lt; 0.001*</td>
<td>30.2 7 &lt; 0.001*</td>
<td>43.0 7 &lt; 0.001*</td>
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<tr>
<td>TA</td>
<td>8.4 5 0.14</td>
<td>12.9 6 0.047*</td>
<td>32.4 7 &lt; 0.001*</td>
<td>17.1 6 0.01*</td>
</tr>
<tr>
<td>GBP</td>
<td>36.9 7 &lt; 0.001*</td>
<td>21.5 5 &lt; 0.001*</td>
<td>37.4 4 &lt; 0.001*</td>
<td>130.7 6 &lt; 0.001*</td>
</tr>
<tr>
<td>Pre-test vs pre-control</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>11.3 6 0.08</td>
<td>14.7 5 0.01*</td>
<td>2.0 4 0.73</td>
<td>15.6 6 0.02*</td>
</tr>
<tr>
<td>TP</td>
<td>9.6 7 0.21</td>
<td>24.9 7 &lt; 0.001*</td>
<td>9.1 6 0.17</td>
<td>12.0 5 0.04*</td>
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<tr>
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<td>3.2 6 0.79</td>
<td>8.6 6 0.20</td>
<td>13.0 4 0.01*</td>
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<tr>
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<td>12.0 4 0.02*</td>
<td>7.4 4 0.12</td>
<td>11.8 6 0.07</td>
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<tr>
<td>Pre-control vs post-control</td>
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<td></td>
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<tr>
<td>OA</td>
<td>11.3 6 0.08</td>
<td>6.2 5 0.29</td>
<td>179.0 3 &lt; 0.001*</td>
<td>16.5 6 0.01*</td>
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<tr>
<td>TP</td>
<td>5.1 8 0.75</td>
<td>9.5 7 0.22</td>
<td>9.3 5 0.10</td>
<td>7.4 7 0.39</td>
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<tr>
<td>TA</td>
<td>2.9 5 0.71</td>
<td>4.8 7 0.68</td>
<td>4.9 5 0.43</td>
<td>7.9 6 0.25</td>
</tr>
<tr>
<td>GBP</td>
<td>34.9 6 &lt; 0.001*</td>
<td>3.8 5 0.59</td>
<td>33.1 4 &lt; 0.001*</td>
<td>14.0 6 0.04*</td>
</tr>
<tr>
<td>Post-test vs post-control</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>OA</td>
<td>8.2 6 0.23</td>
<td>9.7 6 0.15</td>
<td>102.4 6 &lt; 0.001*</td>
<td>13.4 6 0.04*</td>
</tr>
<tr>
<td>TP</td>
<td>11.4 8 0.18</td>
<td>12.9 7 0.08</td>
<td>7.4 7 0.39</td>
<td>2.6 7 0.92</td>
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<td>TA</td>
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<td>GBP</td>
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<td>4.6 5 0.47</td>
<td>4.9 4 0.30</td>
<td>6.1 6 0.41</td>
</tr>
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</table>

p<0.05
Table 16: Behavioral reactions to repellent stimuli.

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Growly</th>
<th>Snarlly</th>
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<tbody>
<tr>
<td></td>
<td>S* M W N</td>
<td>S M W N</td>
</tr>
<tr>
<td>Taped sounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human growling (SGrowl)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Human hissing (SHiss)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Human barking (SBark)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Human shouting (SShout)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Grizzly growling (GGrowl)</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>Grizzly barking (GBark)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Polar bear (1977PB)</td>
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<td></td>
</tr>
<tr>
<td>Polar bear (GUEM)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Killer whale (ORCA)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control (hold up speaker)</td>
<td>0,0</td>
<td>+</td>
</tr>
<tr>
<td>Other sounds</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thunderflash</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bells</td>
<td>+</td>
<td>0,0</td>
</tr>
<tr>
<td>Control (bells)</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Boat horn</td>
<td>-</td>
<td>-,-</td>
</tr>
<tr>
<td>Control (boat horn)</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Sound 911</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Dog whistle</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Referee's whistle</td>
<td>+,-</td>
<td></td>
</tr>
<tr>
<td>Control (whistle)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trucktone horn</td>
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<td></td>
</tr>
<tr>
<td>Control (Trucktone horn)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cap-chur gun</td>
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<tr>
<td>Chemicals</td>
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<tr>
<td>Onion juice</td>
<td>-</td>
<td></td>
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<tr>
<td>Windex (ammonia)</td>
<td>-</td>
<td></td>
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<tr>
<td>Mustard</td>
<td>-</td>
<td></td>
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<tr>
<td>Halt (dog rep.)</td>
<td>-</td>
<td>-,-</td>
</tr>
<tr>
<td>Dog Stopper (dog rep.)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Git (dog rep.)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Chaperone (dog rep.)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Bear Trail</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Control (water)</td>
<td>-,+</td>
<td>-,-,-</td>
</tr>
<tr>
<td>Other</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Strobe light</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Loom</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Control (stand at door)</td>
<td>0,0</td>
<td>+</td>
</tr>
</tbody>
</table>

*a + indicates approach, - indicates repel, +- indicates ambivalent reaction, 0 indicates no reaction. Symbols separated by commas indicate multiple trials of the same stimulus.

*S=Strong reaction, M=Moderate reaction, W=Weak reaction, N=No reaction.
Table 16: Behavioral reactions to repellent stimuli. (cont.)

<table>
<thead>
<tr>
<th>Stimuli</th>
<th>Guen</th>
<th>Magdalene</th>
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<tbody>
<tr>
<td></td>
<td>S*</td>
<td>M</td>
</tr>
<tr>
<td><strong>Taped sounds</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human growling (SGrowl)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Human hissing (SHiss)</td>
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</tr>
<tr>
<td>Human barking (SBark)</td>
<td>+-</td>
<td>-</td>
</tr>
<tr>
<td>Human shouting (SShout)</td>
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<tr>
<td>Grizzly growling (GGrowl)</td>
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<td>-</td>
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<tr>
<td>Grizzly barking (GBark)</td>
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<td>-</td>
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<tr>
<td>Polar bear (1977PB)</td>
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<tr>
<td>Polar bear (GUEN)</td>
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<tr>
<td>Killer whale (ORCA)</td>
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<td>-</td>
</tr>
<tr>
<td>Control (hold up speaker)</td>
<td>+-</td>
<td>+</td>
</tr>
<tr>
<td><strong>Other sounds</strong></td>
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</tr>
<tr>
<td>Thunderflash</td>
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<tr>
<td>Bells</td>
<td>+-</td>
<td>-</td>
</tr>
<tr>
<td>Control (bells)</td>
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</tr>
<tr>
<td>Boat horn</td>
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<tr>
<td>Control (boat horn)</td>
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<td>-</td>
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<tr>
<td>Sound 911</td>
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<td>Dog whistle</td>
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<tr>
<td>Referee's whistle</td>
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<td>Control (whistle)</td>
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<tr>
<td>Trucktone horn</td>
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<td>Control (Trucktone horn)</td>
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<td>Cap-chur gun</td>
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<td><strong>Chemicals</strong></td>
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<td>Onion juice</td>
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<td>Windex (ammonia)</td>
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<td>Mustard</td>
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<td>Halt (dog rep.)</td>
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<td>Dog Stopper (dog rep.)</td>
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<td>Git (dog rep.)</td>
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<tr>
<td>Chaperone (dog rep.)</td>
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<tr>
<td>Bear Trail</td>
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<tr>
<td>Control (water)</td>
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<tr>
<td><strong>Other</strong></td>
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<tr>
<td>Strobe light</td>
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<tr>
<td>Loom</td>
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<td></td>
</tr>
<tr>
<td>Control (stand at door)</td>
<td>+</td>
<td></td>
</tr>
</tbody>
</table>

*a: + indicates approach, - indicates repel, +- indicates ambivalent reaction, 0 indicates no reaction. Symbols separated by commas indicate multiple trials of the same stimulus. 
*S=Strong reaction, M=Moderate reaction, W=Weak reaction, N=No reaction.

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corner of the cell where it rubbed its eyes and blinked vigorously. In one case, Snarly went to the water well and "washed his face" with his paws.

Sounds were good repellents only if they were extremely loud and sharp (Thunderflash, Cap-chur gun, and boat horn). The other sounds such as bells, whistles, and all the recorded sounds were either attractive or induced caution instead of fear in the animals. The only other stimulus that consistently repelled all the animals was the loom stimulus. In each case, the bear started to charge and immediately turned when suddenly presented with the face of a 1 x 1.5 m piece of plywood. The repellency of the loom response, however, lasted for less than 30 seconds. None of the behavioral effects of any of the repellent stimuli lasted for more than 5 minutes.

In contrast to the repellent stimuli, the control tests rarely repelled the subject. Those controls that did repel the animals were where water was shot in the bears' faces. The bears either approached or showed no response to the other control tests.

The classified behavioral reactions agree well with the physiological responses to the repellents (Fig. 6). It is difficult to discern the physiological reactions in Growly, but the other bears were investigated for specific repellent stimuli. Snarly's HR peaked at every test and control that was concurrent with heavy activity. There were 4 cases unaccompanied by heavy activity, Control (Boat horn), Sound 911, Windex and Git (see Appendix B for a description of the repellents). The HR did peak in all but the Boat horn control. In that case there was no reaction. Every test and control resulted in heavy activity and elevated HR in Guen. In Magdalene, the only tests that did not result
in a peak in HR (GUEN (polar bear sounds) ORCA, Tape control, Dog whistle, and Control) were classified as no reaction. Once in all the tests, there was a single Control test (Fig. 6D, Day 11, 16:34) where the behavioral reaction was classified as 'none' and the HR peaked.
Chapter IV
DISCUSSION, LABORATORY STUDIES

The observations took an average of 29 days rather than the 18 days scheduled because the 2 wire electrodes on the heart rate transmitters broke easily and several re-implantations were necessary. The efficiency of performing behavioral-physiological observations and repellent tests would improve greatly by solving the electrode problem.

There were also differences in the readability of the records obtained from the different heart rate transmitters. Growly's transmitter was very sensitive to muscular activity (Skutt et al. 1973). Because many records of high HR were not countable when Growly was active, his average HR was lower than it should have been. The other HR transmitters (J. Stuart Enterprizes, Grass Valley, CA) gave readable records when the electrodes were functioning.

The temperature transmitters also had some inadequacies. The thermocouples were insulated by the size of the transmitter and its protective coating so there was a time lag between a change in TB or TS and recording the change. The calibrations indicate that the equilibration time was 4-5 minutes in the TS transmitters and 10 minutes in the TB transmitters.

The large number of recordings of the physiological parameters \( n = 4, 258 \) represents a significant increase for the total physiological measurements in the literature. The overall averages that I obtained compare well with those reported in the literature (Table 17). The
Table 17: Values of physiological parameters reported in the literature.

<table>
<thead>
<tr>
<th>X</th>
<th>Range</th>
<th>Species and weight (kg)</th>
<th>Comment</th>
<th>Source</th>
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<td>Body temperature (°C)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>36.71</td>
<td>34.92-38.45</td>
<td>Griz. (200)</td>
<td>Growly</td>
<td>This study</td>
</tr>
<tr>
<td>38.64</td>
<td>37.87-39.71</td>
<td>Griz. (160)</td>
<td>Snarly</td>
<td>This study</td>
</tr>
<tr>
<td>38.23</td>
<td>37.50-39.02</td>
<td>P.B. (160)</td>
<td>Guen</td>
<td>This study</td>
</tr>
<tr>
<td>36.55</td>
<td>35.65-37.96</td>
<td>P.B. (200)</td>
<td>Magdalene</td>
<td>This study</td>
</tr>
<tr>
<td>37.5</td>
<td>-----</td>
<td>P.B. (10)</td>
<td>in air</td>
<td>Blix and Lentfer 1979</td>
</tr>
<tr>
<td>30.0</td>
<td>-----</td>
<td>P.B. (10)</td>
<td>in ice water</td>
<td>Blix and Lentfer 1979</td>
</tr>
<tr>
<td></td>
<td>37.3-39.0</td>
<td>P.B.</td>
<td></td>
<td>Baldwin 1973</td>
</tr>
<tr>
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<td>36.8-38.8</td>
<td>P.B. (280)</td>
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<td>Øritsland 1970</td>
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<tr>
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<td>37.0-38.0</td>
<td>P.B. (25)</td>
<td></td>
<td>Hock 1968</td>
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<tr>
<td></td>
<td>37.4-40.5</td>
<td>P.B. (80)</td>
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<td>Hock 1968</td>
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analysis of variance on the physiological parameters indicates that polar bears' HR is lower than grizzlies', but that TB, and TS are more dependent on individual differences than species differences.

The differences in average HR are easily explained by differences in activity between the polar bears and the grizzlies. Both grizzlies spent much time pacing, pounding on the cell door, or vigorously pouncing on objects in the cell. They were curious and played with small objects. In contrast, the polar bears spent most of their time sleeping or lying quietly.

Trends in the physiology are obvious (Figs. 5 and 6). Longer periods of continuous observations are easier to read than short observations. The system of observations used on Snarly and the polar bears allows comparison of the physiology between baseline and repellent observations. The short, trial-oriented observations for Growly's repellents are very difficult to interpret because of the lack of continuity between trials.

Duration of activities also affects the physiological parameters. Body temperature changes relatively slowly. Activities that place a large physical demand on the heart and hence increase HR may not be sustained long enough to create a measurable change in TB or TS. Unless the behavioral reactions are observed, such a combination of factors could result in an erroneous assumption that psychological factors rather than increased activity increased the heart rate.

Certain behaviors consistently increased the physiological parameters (Table 7). Neither the Pearson's correlations ($r^2$) nor the correlation ratios (Eta$^2$) allows for the prediction of the behavior from the physiological parameters. The relationships between behavior
and physiology are complex. Furthermore, there are large differences between bears in which behavior results in the highest and lowest values of the physiological parameters (Table 9).

It is possible to predict the values of most of the behavioral parameters relatively accurately with discriminant analysis. Some care must be taken in interpreting the calculated prediction rates of the various behavioral parameters. There is a trade-off between the best prediction rate, the sample size, and the experimental goals.

The SPSS program used the overall probability of obtaining the particular behavioral code (regardless of the physiology) to help decide how a particular physiological record should be classified. Consequently, for a behavioral code like TP (transitions in posture) where most of the values were '0' (no change), high prediction rates may be misleading. For example, 568 of 602 observations of Guen's TP were coded '0'. When the computer used that figure to help predict the values of TP, it classified 563 (94%) of the cases correctly. However, of the remaining 39 cases where Guen did change posture, only 5 (13%) were classified correctly. Even though the overall correct prediction rate of 94% for Guen's TP is real, the more interesting cases for TP suffer the majority of the error.

Choosing which physiological parameters to use in the analysis also affects the prediction rate. Several combinations of the telemetry parameters were used to predict the overall activity (OA) of each bear (Table 10). Because the SPSS program cannot use cases that are missing any of the discriminant variables, the sample changes composition when variables are added or deleted. Variables such as
MMHR which can add or delete particular kinds of cases due to the nature of the coding should be handled with care.

On the other hand, the behavioral categories can be re-coded to enhance the prediction rate obtained from the discriminant functions. For example, the code '8' for OA meant that the bear was shifting slightly in its place. Many times '8' was coded for movements that occurred while the bear was sleeping. The cases where OA was '8' were first re-coded to '2' (lying quietly) and then to '4' (light activity) and reanalyzed for each bear (Table 10). In each case the prediction rate increased over the original coding and was best when '8' was re-coded to '2'. Physiologically, '8' and '2' are redundant codes. Thus by manipulating the variables the best compromise between high prediction rates and descriptive value can be obtained.

It was hoped that by monitoring the bears' physiological reaction to possible repellent stimuli that the behavioral reactions could be understood better. Because of the similarity between the physiological parameters when the bear was aggressive and when it was fearful, and the complicating effects of activity changes at the time of testing, the amount of useful information added to the behavioral observations with respect to repellent tests was limited.

The differences in the physiology and behavior between baseline and repellent observations (Tables 12 and 13), show that the periodic disturbances of repellent tests significantly affected the bears' activity. Because the data used in this analysis was sampled to exclude the period when the test stimulus was given, the differences in behavior and physiology are overall reactions to general disturbance.
When the behavior and physiology immediately before tests and controls were compared with the behavior and physiology following tests and controls (Tables 14 and 15), the tests affected all the bears' heart rates, but only the polar bears were affected by controls. Because the polar bears reacted similarly to controls, there was no difference in HR between post-test and post-control periods as in the grizzlies.

There were striking changes in heart rate during individual trials, but many of the control tests resulted in similar heart rate peaks. The bears nearly always reacted to the assistant by approaching or by charging the door. Thus, when the stimulus was delivered, the bears were already reacting maximally. Most of the cases where the bears did not react were controls. The notable exceptions involved 2 stimuli. Twice when small bells were tested on Growly, he slept through the test. The bells were of the type that are sold to hikers in Glacier and Yellowstone national parks to warn bears of their approach. In these tests the assistant stood at the door of the cell and rang the bells. Growly was not more than 6 m away and never woke up! The idea that small bells on ones shoes will warn grizzlies before approaching too close clearly needs re-evaluation. The dog whistle tests on Snarly and Magdalene also elicited no reactions.

The behavioral observations indicate that laboratory tests of repellents can be performed effectively. The strong repellent effects of 'Halt' dog repellent and of loud, sharp sounds are clear. Most of the reactions of the bears to stimuli can be classified easily. The laboratory situation facilitates testing many stimuli, but the number of individual animals remains small due to the time constraints of
implanting transmitters. Further studies should be done to sample individuals in a broad base of sex and age classes. Because the physiological parameters do not add different information to the behavioral observations, further repellent tests need not include measuring the physiology.
Chapter V
MATERIALS AND METHODS, FIELD STUDIES

Field tests of possible repellents were made on free-ranging polar bears at Gordon Point near Churchill, Manitoba, from 11 October to 12 November, 1978.

Description of Study Area

Observations were made from Klein Tower, located 40 km east of Churchill, Manitoba, (58°45' N. Lat., 94°04' W. Long.). The tower is on Gordon Point, 6 km east of the end of the improved road in Churchill. Gordon Point is a long spit of land that extends north into Hudson Bay (Fig. 7). Klein Tower is 6 m high and commands an excellent view of the surrounding area. The area has little relief, and the vegetation consists of low shrubs, grasses, sedges, and small forbs and lichens. The several lakes in the area (Fig. 8) were frozen for the duration of the field observations. Hudson Bay remained clear of ice until about 28 October when it began to freeze up gradually. By 12 November, shore-fast ice extended offshore for several kilometers.

Materials and Methods

Because my scientific permit did not allow me to spray chemicals into the faces of free-ranging polar bears, the field tests were limited to acoustic repellents and passive chemical deterrents.

On 11 October, 11 sites were set up 100-500 m from the tower (see Fig. 8). They were divided into the East Unit (5 sites), the West Unit (5 sites), and the single acoustic site (AS). The sites were marked with blaze-orange flagging on small posts that were driven into
Figure 7. Map of Cape Churchill area.
Figure 8. Map of the study area. The baited sites are labelled 1-5E (east unit), 1-5W (west unit), AS (acoustic site). The 2 baited sites labelled NWT were used for a concurrent study by the Northwest Territories.
the ground nearby. At each site, about 100 ml of a mixture of mashed sardines and cooking oil was poured over a conspicuous rock. The sites were rebaited periodically as safety allowed. In addition to my 11 sites, there were 2 more sites in the area baited with sardine mash/cooking oil (Fig. 8). These additional sites were being used for a concurrent study conducted by the Northwest Territories (NWT).

All the sites were baited but otherwise undisturbed for 2 weeks. At that time, a loudspeaker was placed 5 m from the bait at the acoustic site.

The remaining 10 bait stations were sprayed with various commercial dog repellents and household chemicals so that the uncontaminated sardine mash bait was surrounded by the test chemical (see Appendix B for a description of the chemicals). Enough chemical was used to wet the area around the bait. Once repellent tests began, each site was rebaited with the sardine mash and the appropriate chemical according to a predetermined schedule (Table 10). Ammonia and Pine Sol were tested later at sites where other chemicals were used earlier in the observation period.

Continuous observations of all animals within view were made from dawn to dusk every day from 11 October to 12 November (except 4 Nov.). Bears were categorized as adults, subadults, or family groups. An adult was any bear estimated to weigh 200 kg or more. Subadults weighed less than 200 kg and were not accompanied by another adult. They were probably 1.5 to 4.5 years old. Family groups were treated experimentally as a single unit and included any group with one adult (assumed female) and one or more cubs that were significantly smaller than the adult. Several bears in the area had been captured and marked.
Table 18: Chemical deterents baiting schedule.\textsuperscript{a}

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\textsuperscript{a} Deterrents are described in detail in Appendix B.

* C=Control, Chap=Chaperone, BT=Bear Trail, Amm=Ammonia, and PS=Pine Sol.

** No data was taken on 4 Nov.
with conspicuous numbers for a Canadian Wildlife Service study. Weights and sexes were known for those animals. Except for a few extremely large adults that were assumed to be males, the sexes of the remaining unmarked individuals were not determined (see Appendix C for a list of the bears visiting the sites). When a bear approached the sites, its identity (if possible), behavior, and the length of time that it spent at the baited sites were recorded.

At the acoustic site, the subject was allowed to remain at the bait for 10 seconds. After that time, the acoustic stimulus was played through the remote speaker with a cassette tape recorder (Hitachi Model TRK-5190H) in the tower. The duration of the stimulus varied with the type of sound and the length of the tape (see Appendix B for a description of the sounds tested). If the initial sound did not repel the bear, a second sound was tested after waiting from 2 to 5 minutes.

A hand held, freon-powered boat horn (Airchimes Horns, Lynco Ltd., Vancouver) was also tested. The boat horn failed in the low ambient temperatures and could not be triggered remotely. Consequently, the boat horn was hand-tested whenever a bear approached the tower, or when I was carrying it while rebaiting sites. A test consisted of pointing the horn at the animal until it was aware of me, then blasting the horn once or twice for 3 to 5 seconds each time. Control tests were similar except that I did not blast the horn.
Chapter VI

RESULTS, FIELD STUDIES

In the 4 weeks of observations from Klein Tower, 36 different polar bears were observed in the area. Eleven of these bears were of known sex and had been marked with numbers by the CWS. Five more bears had unique characteristics and could be recognized from day to day. These 16 identifiable bears visited the area 51 times, while 65 visits were made by unmarked animals or family groups. Though the unmarked animals could be followed within a single day, their identity was not maintained from one day to the next. By assuming a constant ratio between the number of visits and the number of bears making those visits, the number of unmarked animals visiting the area was estimated by the equation:

\[
\frac{\text{# of marked animals}}{\text{# of visits by marked animals}} = \frac{\text{# of unmarked animals}}{\text{# of visits by unmarked animals}}.
\]

This estimate indicates that only 20 different unmarked bears visited the area, or that a total of 36 bears made 116 visits to the observation area.

After the first week, the number of bears visiting the area each day increased (Fig. 9). There were 23 visits in the second week, and 44 and 38 visits in the third and fourth weeks respectively. Stable, shore-fast ice on Hudson Bay increased dramatically over 7 and 8 November and many bears were observed on the ice far from the shore. The number of bears visiting the observation area dropped quickly at
Figure 9. Number of bears visiting the observation area.
That time until the last bear in the area was seen walking onto the ice on the morning of 11 November.

Subadults accounted for 75.4% of all visits. With just 2 exceptions, the adult bears (17.5% of visits) and family groups (7.1%) visited the observation area only after the second week. Subadults, on the other hand, visited the area from 13 October to 11 November, after the last adults had moved onto the ice.

The wind was usually from the north. On the 3 most active days (29, 31 Oct. and 6 Nov.), however, it blew across the observation area to the nearest shoreline on Hudson Bay (ESE wind). There were usually more bears along the shoreline, but on the days that the wind blew the odors of the baits toward shore, more bears visited the observation area.

The activity schedules of the bears were also analysed within daily periods by compiling half-hourly observations of the number and activity of the bears over the 31 days of observation (Fig. 10). The bears were classified as either active or inactive. All behaviors performed while lying down were classified as inactive (sleeping, watching, licking paws, etc.) while walking, trotting, sitting, standing, etc. were classified as active.

Subadults were active 91% of the time while the adults and family groups were active 78% and 70% of the time. The differences in the amounts of time active are significant ($X^2 = 11.21, d.f. = 2, p = 0.005$). Adults visited baited sites less often than subadults. Adults appeared to walk more slowly and determinedly and spent less time investigating their surroundings than did the subadults. The adults generally
Figure 10. Diurnal activity of bears at the observation area.
seemed lethargic. Family groups were somewhat less active than single adults. The adult females with cubs acted similar to single adults except that they spent more time resting with the cubs. Subadults constantly wandered back and forth between bait sites. They frequently avoided other bears or stopped to investigate the area.

In addition to differences in total time active, the different groups of bears differed in the diurnal activity patterns (Fig. 10). Subadult activity gradually built up through the morning to its highest level at noon, then tapered off in the evening. During the observation period, sunset advanced more than one hour so that by October 31, observations ceased by 16:15. Therefore, the reduction in activity was not as pronounced as that shown in Figure 10. Furthermore, only subadult bears were active at night. Inactive animals were probably present at night as well, but they were not observed.

The family groups also showed a single peak in activity which roughly corresponded to the peak of the subadults. In contrast to the single peak of activity for subadults and family groups, the unaccompanied adults showed a bimodal distribution of activity. The morning peak occurred from 8:00 to 9:00, while the afternoon peak was at 13:30. The difference between the activity cycles may allow family groups and subadults to reduce the number of potentially dangerous interactions with single adults.

**Passive Chemical Deterrents**

There were a total of 294 visits by bears to the 10 chemical deterrent/bait sites. Of 294 visits, 248 (84%) were by subadults, while 20 (7%) and 26 (9%) of the visits were by single adults and family groups respectively (Table 19). When the number of visits to
Table 19: Summary of bear activity.

<table>
<thead>
<tr>
<th>Day to day activity:</th>
<th>Number of visits</th>
<th>Per cent of total</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex/age class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subadults</td>
<td>86</td>
<td>75</td>
</tr>
<tr>
<td>Adults</td>
<td>20</td>
<td>18</td>
</tr>
<tr>
<td>Family groups</td>
<td>8</td>
<td>7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>114</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Diurnal activity:</th>
<th>Bear hours of activity</th>
<th>Per cent of total bear hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>sex/age class</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subadults</td>
<td>203 Active (91%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>20 Inactive (9%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>223 Total</strong></td>
<td><strong>78</strong></td>
</tr>
<tr>
<td>Adults</td>
<td>34 Active (78%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10 Inactive (22%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>44 Total</strong></td>
<td><strong>15</strong></td>
</tr>
<tr>
<td>Family groups</td>
<td>13 Active (70%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>6 Inactive (30%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>19 Total</strong></td>
<td><strong>7</strong></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>250 Active (88%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>36 Inactive (12%)</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>286 Total</strong></td>
<td></td>
</tr>
</tbody>
</table>

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the bait sites by each group was compared with the total number of bear-hours that each group was observed, there was a significant difference \((X^2 = 11.1, \text{ d.f.} = 2, p = 0.006)\). Unaccompanied adult bears visited the bait sites much less often than would be predicted by their number of bear-hours of observation.

A maximum of 63 different bears visited the bait sites. By using the same method to estimate the number of unidentifiable bears as in the last section, 27 different bears visited the bait sites. One subadult female, no. 6, made 77 visits to the bait sites, while another subadult of unknown sex, SURE (identified by a large Scratch Under the Right Eye), visited the sites 63 times. These 2 bears totalled 140 visits, or 48% of all the visits to the bait sites. Two other subadult bears, LOLE (Line Over Left Eye), and no. 10 (female), visited the sites 28 (9.5%) and 19 (6.5%) times respectively. The remaining 107 visits were divided fairly evenly among the other 23 bears.

There were few cases where the presence of the chemical at the bait station caused obvious behavioral reactions or unusual behaviors. Typically a bear walked around the area until it passed downwind of a site then it turned and walked upwind with its neck stretched forward and slightly above horizontal until it reached the site. Sometimes the bear simply followed one of the many trails made in the snow by bears travelling between sites and around the area. When the bear arrived at the site, it usually spent a few seconds sniffing the ground around the area before licking the rock that was baited. In the case of treated baits, the bear licked the uncontaminated bait before licking the repellent.
The bear typically remained in the same orientation that it had approached the site and stood with its head down licking the rock for a varying amount of time. During longer visits at a bait station, the bears paused and looked up frequently. Occasionally a bear spent a long time at a site and sat or lay down while licking the rock. In these cases, the bear usually oriented itself so that it could see other animals in the area. When it left a site, the bear usually continued in the same direction it had been travelling before stopping.

Bears were repelled from chemically contaminated bait sites just 5 times out of the 29\(^\frac{1}{4}\) visits (2.6\%) (Table 20). Pine Sol was the deterrent in each case and two different subadults of unknown sex were involved, SURE and BE (Big Ears). BE approached site \#1 on 8 November. After 9 seconds of typical licking behavior, BE quickly raised its head up and backed away. BE then turned and trotted away from the site. At 10 m from the site, BE nosed-dived into the snow and rubbed its nose and chest on the ground before getting up and walking on. The remaining four cases of repellency involved SURE on 9 November. SURE approached the sites and stayed from 12 to 187 seconds before being repelled. In the most vigorous case, SURE jumped away from the site and trotted four steps then stopped and shook its head several times making vigorous licking movements in the air. See Table 21 for a description of the other successful repels.

Bears also responded to the test chemicals by head shaking, rolling-in-the-snow, and 'nose-diving' (Table 21). Head shaking was a vigorous rotational shaking of the head. Rolling-in-the-snow and nose-diving were somewhat similar. To roll in the snow the bear lay down,
Table 20: Summary of visits and duration of visits at chemical deterrent sites.

<table>
<thead>
<tr>
<th>Bait</th>
<th>Sex/age class</th>
<th>Time at bait (sec)</th>
<th>Mann-Whitney test&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Number of reps</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Subadults</td>
<td>Adults</td>
<td>Family groups</td>
<td>Total</td>
</tr>
<tr>
<td>Control</td>
<td>35</td>
<td>0</td>
<td>0</td>
<td>35</td>
</tr>
<tr>
<td>Halt</td>
<td>34</td>
<td>3</td>
<td>6</td>
<td>43</td>
</tr>
<tr>
<td>Chaperone</td>
<td>34</td>
<td>7</td>
<td>5</td>
<td>46</td>
</tr>
<tr>
<td>Bear Trail</td>
<td>31</td>
<td>2</td>
<td>4</td>
<td>37</td>
</tr>
<tr>
<td>Git</td>
<td>20</td>
<td>0</td>
<td>3</td>
<td>23</td>
</tr>
<tr>
<td>Scram</td>
<td>35</td>
<td>0</td>
<td>5</td>
<td>40</td>
</tr>
<tr>
<td>Pine Sol</td>
<td>30</td>
<td>3</td>
<td>2</td>
<td>35</td>
</tr>
<tr>
<td>Ammonia</td>
<td>29</td>
<td>5</td>
<td>1</td>
<td>35</td>
</tr>
<tr>
<td>Total</td>
<td>248</td>
<td>20</td>
<td>26</td>
<td>294</td>
</tr>
</tbody>
</table>

<sup>a</sup>In Mann-Whitney U-test, N<sub>1</sub>=35 and N<sub>2</sub>= the number of times the treated site was visited.
*<sup>p</sup>< 0.05
Table 21: Obvious behavioral reactions to chemical deterrents.

<table>
<thead>
<tr>
<th>Time</th>
<th>Bait (site)</th>
<th>Duration of visit (sec)</th>
<th>Bear</th>
<th>Behavior</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nov. 8</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1120</td>
<td>Ammonia (3W)</td>
<td>45</td>
<td>#6</td>
<td>At 193 s, she turned and faced the wind, then nose-dived into the snow and rolled over. She returned to the bait. She nose-dived again half-way to site LW.</td>
</tr>
<tr>
<td>1153</td>
<td>Ammonia (1W)</td>
<td>187</td>
<td>#6</td>
<td>Snapped behind her for no apparent reason. She left 1W and rolled in the snow. After walking 30 m she nose-dived again and rolled over twice.</td>
</tr>
<tr>
<td>1211</td>
<td>Pine Sol (2E)</td>
<td>277</td>
<td>#6</td>
<td>When she left the site, she stopped after 10 m and rolled in the snow.</td>
</tr>
<tr>
<td>1527*</td>
<td>Pine Sol (4E)</td>
<td>9</td>
<td></td>
<td>Big Ears. At 9 s, BE quickly raised up, turned left and trotted SW. At 10 m from 4E, BE nose-dived into the snow.</td>
</tr>
<tr>
<td>Nov. 9</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0801</td>
<td>Ammonia (1W)</td>
<td>13</td>
<td>#6</td>
<td>Rolled in the snow after leaving site.</td>
</tr>
<tr>
<td>1008*</td>
<td>Pine Sol (4E)</td>
<td>187</td>
<td>SURE</td>
<td>Left site suddenly, trotted NNE for 5 m then shook head vigorously and nose-dived into snow and onto its left side. Got up quickly and walked to site 3E.</td>
</tr>
<tr>
<td>1013</td>
<td>Pine Sol (2E)</td>
<td>95</td>
<td>SURE</td>
<td>Looked up and walked toward 3E. Stopped to shake head hard once.</td>
</tr>
<tr>
<td>1028</td>
<td>Ammonia (3W)</td>
<td>185</td>
<td>SURE</td>
<td>On leaving, SURE rubbed its nose with its right foot then shook its head twice before walking to 4W.</td>
</tr>
<tr>
<td>1039</td>
<td>Ammonia (3W)</td>
<td>29</td>
<td>SURE</td>
<td>Revisit. Shook its head on leaving.</td>
</tr>
<tr>
<td>1043*</td>
<td>Pine Sol (2W)</td>
<td>170</td>
<td>SURE</td>
<td>Jumped away from site. After trotting ¼ steps, SURE shook its head several times while making vigorous licking movements in the air. SURE then shook its head ¼ more times before walking on to site 1W.</td>
</tr>
<tr>
<td>1100*</td>
<td>Pine Sol (4E)</td>
<td>28</td>
<td>SURE</td>
<td>SURE raised up quickly and backed away from the site holding its right front foot up.</td>
</tr>
<tr>
<td>1104*</td>
<td>Pine Sol (2E)</td>
<td>45</td>
<td>SURE</td>
<td>Revisit. At 12 s, SURE snuffed and raised its head, shook its head twice, then backed away from the site.</td>
</tr>
<tr>
<td>1106</td>
<td>Pine Sol (2E)</td>
<td>28</td>
<td>SURE</td>
<td>Rolled in the snow on the way to 1E.</td>
</tr>
<tr>
<td>1108</td>
<td>Ammonia (1E)</td>
<td>45</td>
<td>SURE</td>
<td>Rolled in the snow on the way to the West Unit.</td>
</tr>
<tr>
<td>1114</td>
<td>Ammonia (3W)</td>
<td>106</td>
<td>SURE</td>
<td>Nose-dived into snow on way to 2W.</td>
</tr>
<tr>
<td>1120</td>
<td>Ammonia (1W)</td>
<td>191</td>
<td>SURE</td>
<td>Left site, then rubbed its neck and chest in deep snow.</td>
</tr>
</tbody>
</table>

*Denotes repel.
either by flopping onto its side or by nose-diving. Then the bear
rolled from its side to its back repeatedly while rubbing its face in
the snow. The bears rarely rolled over completely.

Nose-diving occurred when the bear was standing or walking. The
bear rapidly extended its nose forward and down to the ground. Then
it suddenly flopped to the ground by pushing ahead with its hind feet
and letting its front feet trail alongside its body. Sometimes the
bear continued to stand with its hind feet and pushed itself along the
ground, while other times it lay down completely and then rolled in the
snow. Though these behaviors were directly related to tasting and
perhaps ingesting the repellent, they were usually performed while
walking between sites rather than while at a bait site.

There were few dramatically repellent cases, but the bears spent
much less time at the experimental sites than at the control sites.
Though not dramatic, the shorter time spent at the chemically treated
sites indicates that the bears were repelled. Of the bears that could
be identified (12 of 35 visits), there was no difference between the
lengths of time spent at the control sites by subadult males and
subadult females (Mann-Whitney U-test; U = 11, n_1 = 5, n_2 = 7,
\( p = 0.172 \)), so all the controls were lumped and used as a single unit
to compare with the lengths of visits at the experimental sites.
Although neither unaccompanied adults nor family groups visited the
control sites, the times they spent at the experimental sites did not
differ from the corresponding times for subadults. All bears spent
significantly less time at the experimental sites than at control
sites (Table 20).
Acoustic Repellents

Eleven different bears visited the acoustic site for a total of 55 trials. Fourteen of the trials were controls where no sounds were played to the animals. The stimulus for 16 of the tests was a recording of an adult female polar bear in a culvert trap that was recorded in October 1977 (1977PB), while another 9 tests were with a recording of a human shouting (SShout). These 2 recordings made up 61% of the tests. The other 6 acoustic stimuli (GUEN, Radio, GBark, Orca, Shiss, SBark) were used for the remaining 16 trials. See Appendix B for a list and description of the stimuli.

The 55 trials were divided between unaccompanied adults (2 trials), family groups (1 trial), and subadults (52 trials). As in the passive chemical deterrents, the single adults visited the acoustic site significantly less than would be expected from the number of bear-hours of observation of adults ($X^2 = 7.98$, d.f. = 2, $p = 0.025$). In addition, the subadults visited the acoustic site more than expected. One particular subadult, SURE, visited the site 22 (40%) of the 55 total visits. This particular bear frequented the observation area for the last 13 days of observations and made many visits to all of the sites.

The reactions of the bears to the acoustic stimuli were classified into four categories; repel, orient, no effect, and approach. Each bear's reaction was classified as repel if the bear stopped licking the bait and then moved away from the bait while the sound was playing. A test was still classified as a repel if the bear returned to the bait as soon as the stimulus ended. Orient signified that the bear shifted its position enough to face the speaker but did not leave the bait. The bear usually stopped eating and stood over the bait looking toward
the speaker with its ears directed forward and its neck slightly lower than horizontal with its nose near the ground. The bears frequently extended their upper lips, but I could not tell if they also hissed. In the lab tests, the bears nearly always hissed when they extended their upper lip as a sign of agitation. The categories no effect and approach are self-explanatory.

There were a total of 17 repels (41.5%), 19 orients (46.3%), 4 no effects (9.8%) and 1 approach (2.4%). The single approach was a startling reaction. The stimulus was SShout. When the tape began, the unidentified subadult looked up quickly and trotted to the speaker. The bear turned the speaker on its back and stuck its nose into the face of the speaker until the stimulus ended. When the tape finished, the bear returned to the bait and remained for several minutes. All four tests that elicited no apparent response involved SURE.

When the data from different acoustic stimuli were considered individually, some were more effective than others, (Table 22). The only stimulus that was 100% effective (n = 2) was the Radio. Both 1977PB and GBark (adult male grizzly 'barking' vigorously) were 50% effective (n = 16, n = 4). The remaining 5 stimuli were not better than 33.3% effective at repelling bears. The lengths of time that the bears stayed at the site for each stimulus and each category of reaction were compared with the times for the controls. With just 2 exceptions (out of 15 comparisons) there were no differences in the lengths of time spent at a test site and the time spent at a control. The 2 exceptions were bears that were repelled by 1977PB (Mann-Whitney U-test; U = 25, n₁ = 8, n₂ = 14, p<0.05) and those repelled by SShout.
Table 22: Results of acoustic site trials

<table>
<thead>
<tr>
<th>Stimuli*</th>
<th>Repel</th>
<th>Orient</th>
<th>No effect</th>
<th>Approach</th>
<th>Total</th>
<th>% Repel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14 (306)</td>
<td>14 (306)</td>
</tr>
<tr>
<td>1977PB</td>
<td>8 (62)</td>
<td>7 (175)</td>
<td>1 (263)</td>
<td>0</td>
<td>16</td>
<td>50</td>
</tr>
<tr>
<td>SShout</td>
<td>3 (17)</td>
<td>5 (123)</td>
<td>0</td>
<td>1 (255)</td>
<td>9</td>
<td>33.3</td>
</tr>
<tr>
<td>GBark</td>
<td>2 (56)</td>
<td>2 (598)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>50</td>
</tr>
<tr>
<td>ORCA</td>
<td>1</td>
<td>3 (236)</td>
<td>0</td>
<td>0</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>RADIO</td>
<td>2 (24)</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>2</td>
<td>100</td>
</tr>
<tr>
<td>GUEN</td>
<td>0</td>
<td>0</td>
<td>1 (316)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>SHisS</td>
<td>1 (15)</td>
<td>2</td>
<td>1 (1310)</td>
<td>0</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>SBark</td>
<td>0</td>
<td>0</td>
<td>1 (1310)</td>
<td>0</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>17</td>
<td>19</td>
<td>4</td>
<td>1</td>
<td>55</td>
<td>42% 46% 10% 2%</td>
</tr>
</tbody>
</table>

* Described in Appendix B.
\(U = 5, n_1 = 3, n_2 = 14, p = 0.05\). They left the acoustic site in much less time than when bears visited the controls.

Finally, all the bears that were tested with the same stimulus in three or more trials were examined to determine if they habituated to the stimulus. Bear #6 encountered the stimuli 1977PB and SShout 3 times each, while SURE encountered 1977PB 5 times and GBark 4 times. There was no tendency for the stimuli to be less effective in the later trials. The case of SURE encountering GBark suggests that the bear may have habituated; the first 2 trials repelled SURE, while in the last 2 trials SURE oriented toward the speaker. More trials would be necessary to verify this result, however. Furthermore, the three bears that were tested more than three times total were also examined over all the stimuli. SURE participated in 17 trials overall, while #6 and #10 were tested 8 and 6 times respectively. The tests were ranked chronologically and categorized as either repel or non-repel. There was no tendency for the repels to cluster toward the earlier trials (Mann-Whitney U-tests; SURE \(U = 14, n_1 = 3, n_2 = 14, p > 0.1\); #6 \(U = 10, n_1 = 3, n_2 = 5, p > 0.6\); #10 \(U = 4, n_1 = 3, n_2 = 3, p > 0.6\)).

**Boat Horn**

The boat horn was tested 41 times, including 10 control tests. All but three of the tests were performed from the balcony of the tower, 6 m above the ground. Tests were performed on an estimated 15 different bears (using the estimating procedure described above). There were 33 (80.5\%) tests on subadults and 4 (9.75\%) tests each on single adults and family groups. There was no difference between the number of tests done on the different groups of bears and the number
of bear-hours each group was observed ($X^2 = 1.32, p = 0.26$), nor was
one group repelled more often than another group ($X^2 = 1.78, p = 0.41$).

When a test was performed, the bear was already aware of my
presence on the balcony. Consequently, all of the animals were
oriented toward the tower. The bears ranged from 5 m to 50 m away
from the tower for the trials (average, 20 m). When the horn blasted,
the animal nearly always startled before reacting further. If the
animal did not turn and move off faster than a walk, the horn was
blasted a second time. Nine of the 31 tests involved more than one
horn blast. The animals that were repelled, trotted or ran various
distances before continuing on their way. These bears usually extended
their upper lips and hissed.

In tests classified as *no repel* the bears continued what they
were doing before the test at approximately the same intensity. In
some cases they were approaching the tower to investigate the area
underneath it. In those *no repel* cases, the bears either stopped at a
short distance and watched, or continued until under the tower.

The boat horn repelled the bears 25 (80.6%) of the 31 experimental
trials, while bears were repelled from control tests 5 (50%) times
(Table 23). The number of repels from the boat horn was significantly
greater than those from the controls ($X^2 = 11.6, \text{d.f.} = 1, p<0.001$).
In contrast, there was no difference in the intensity of the reactions
(measured by the distance the bear ran) between bears that were
repelled from the boat horn and those that were repelled from controls
(Mann-Whitney U-test; $U = 109, n_1 = 5, n_2 = 31, p = 0.24$). Finally, as
in the case of the acoustic repellents, there was no tendency for the
Table 23: Results of boat horn trials.

<table>
<thead>
<tr>
<th>Result</th>
<th>Subadult</th>
<th>Adult</th>
<th>Family group</th>
<th>Total(%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Repel</td>
<td>3</td>
<td>0</td>
<td>2</td>
<td>5 (50)</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td></td>
<td></td>
<td>5 (50)</td>
</tr>
<tr>
<td>No effect</td>
<td>4</td>
<td>1</td>
<td>0</td>
<td>5 (50)</td>
</tr>
<tr>
<td>Total</td>
<td>7</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Repel</td>
<td>19</td>
<td>3</td>
<td>3</td>
<td>25 (81)</td>
</tr>
<tr>
<td>Test</td>
<td>No effect</td>
<td>6</td>
<td>0</td>
<td>6 (19)</td>
</tr>
<tr>
<td>Total</td>
<td>25</td>
<td>3</td>
<td>3</td>
<td>31</td>
</tr>
<tr>
<td>Grand total</td>
<td>32</td>
<td>4</td>
<td>5</td>
<td>41</td>
</tr>
</tbody>
</table>

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boat horn to be more effective on earlier trials in any of the bears that were tested several times.
Chapter VII
DISCUSSION, FIELD STUDIES

Each fall, large numbers of polar bears congregate along the north and east shores of Cape Churchill (Stirling et al. 1977). Observations at Klein Tower began before a significant number of bears were in the area and continued until the bears had left the coastline and walked onto the ice that had formed on Hudson Bay. The height of the tower and the general lack of obscuring vegetation allowed continuous observations of individuals during daylight hours. Both the ease of observations and the large number of bears visiting the area attest to its suitability for conducting field tests of possible bear repellents. In general, the bears entered the area from the direction of Hudson Bay. The fact that the three days with the most bear visits were days in which the wind blew across the study area to the nearest shoreline indicates that the odors coming from the baits, chemicals and observation tower attracted the bears from up to a kilometer away.

When polar bears concentrate on Cape Churchill, the large adults dominate the Cape areas and force most of the subadults from the area. In addition, the adults are usually fat from hunting the previous winter and spring whereas the subadults have depleted their fat reserves and are hungry (Bukowsky and Kearney 1978). Klein Tower is not close to the preferred beach areas near Cape Churchill and many more subadults than adults visited the area. Seventy-five percent of all the visits by bears to the area were by subadults and 78% of the total number of visits.
bear-hours of observation were spent watching subadults. This 3 to 1 ratio of subadults to other bears was also reflected in the boat horn trials where bait was not used.

In contrast, subadults accounted for 84.4% of all the visits to the chemical repellent/bait sites and 95% of the acoustic trials (also a baited site). Though this discrepancy could be accounted for by the assumption that subadults are hungrier, that is only part of the answer.

The test sites were selected to maximize the ability of the observer to see details of the bears' behavior and to maximize the number of tests possible. At the same time, it was necessary to keep a reasonable distance between the sites to minimize interference from other sites which may have attracted other bears. The arrangement and closeness of the sites resulted in many multiple visits by individuals. After a few days, the sites were also connected with trails in the snow from the bears themselves and from my efforts to keep the baits and test chemicals as fresh as possible. Frequently one bear would visit all 11 sites in one circuit.

The problem of bears visiting the sites repeatedly is best illustrated with 2 subadults, SURE and #6. These 2 bears accounted for 47.6% of all the visits to the chemical sites and 60.0% of all the acoustic trials. SURE visited the area on 13 days and #6 visited the area on 17 days. Both bears made circuits of the sites, visiting each in its turn, sometimes 2 circuits in one day, despite being faced with repeated harassment by sounds and chemicals while attempting to lick up the bait.
With these 2 bears in mind, it is more likely that the preponderance of subadults in the chemical and acoustic tests was due to a few bears making exceptionally large numbers of visits rather than all of the subadults being hungrier. Notwithstanding, SURE and FF could have been motivated by hunger.

A further confounding factor of the sites being close together was that there were often many bears in the area at one time, so that when one bear was visiting the acoustic site or was near the tower, the sound of the tape or boat horn was broadcast to all the bears in the area. Consequently, bears being tested for the first time with acoustic repellents may not have been naive bears.

The presence of other bears in the area also may have increased caution in some of the individuals and affected their behavior at the sites. I observed 21 instances (of the 29 trials visits to the sites) where one individual or family group was supplanted at a site by another. In 11 of those cases, large adults supplanted subadults or family groups by walking toward the site. The family groups (4 instances) yielded to the unaccompanied adult before it was within 20 m of them whereas the subadults often waited until the adult was quite close. Although a subadult did supplant a family group once and subadults displaced each other, they tended to avoid large individuals. In contrast to the adults and the subadult displacing a family group, I observed one female with 2 cubs displace a large male from a site and shortly thereafter return to the site and chase off a subadult. Although Stirling (1974) found that females with cubs were not subordinate when threatened, my observations indicate that they are cautious and tend to avoid situations that are potentially dangerous.
At first consideration, the 5 dramatic reactions of 2 subadult bears out of 294 visits to treated bait sites seems negligible, but there are several aspects of the tests that are worthy of discussion. The bears did discriminate between the bait and the chemicals. Often a bear sniffed around the baited rock for some time, but they always began licking where there was bait but no chemical. Furthermore, the few repels and the other behavioral manifestations of licking the baits indicate that some of the chemicals tested (Pine Sol and Ammonia) were indeed noxious to the bears and the significantly less time spent at the treated sites can be considered one measure of the aversive conditioning of the bears. On the other hand, it could be that the chemicals at the baits were not the primary force in reducing the amount of time spent at a site. Black-tailed deer can effectively be inhibited from eating food from bowls surrounded by the scents of predators (coyote and mountain lion) (Muller-Schwarze 1972). The visual and olfactory presence of numerous other bears and humans could have a similar effect on a polar bear at a bait.

The results of the acoustic trials indicate that though some sounds can be effective repellents, the results cannot be generalized to all bears or circumstances. No unaccompanied adults and only one family group were tested. The family group was repelled by 1977PB. All the other tests were on subadults. Turning on the radio while the bear was at the bait was the most effective repellent (100%, n = 2), but the 2 recordings of bears vigorously growling and hissing or 'barking' (1977PB and GBark) worked fairly well too (50% each, n = 16 and n = 4 respectively). Interestingly enough, the bears that were repelled by 1977PB (n = 8) and SShout (n = 3) were the only bears that
spent significantly less time at the test site when compared with the controls. On the other hand, SShout elicited the only approach in 55 trials.

The general lack of repellency is probably partly due to the nature of the test. When a bear approached the site and the stimulus was played, the bear nearly always reacted. Only $4 (9.8\%)$ of the 55 trials elicited no obvious response, but $19 (46.3\%)$ were classified as orient. When the test sound started, the bears nearly always startled and turned to face the sound. Often the bears sniffed the air or stood on their hind feet and looked around. It was obvious in many cases that the bear was looking out beyond the small speaker that was on the ground and that the bear was uncertain of the threat. There was no visual stimulus that could easily be recognized as the source of the threat, and once the bear had satisfied itself that there was no immediate danger it would return to the bait. Further tests need to complete the illusion of a threatening situation. This could be done by having the observer as part of the stimulus, using models of bears, or something as simple as putting the speaker in shrubs so that when the bear orients it cannot easily confirm that nothing is there.

Most promising of all the tests were those of the boat horn. In 31 tests, $25 (80.6\%)$ were effective in repelling the bear. Furthermore, the age/sex classes were tested proportionately to the number of bear-hours of observation for each group and no group was repelled more effectively than another. In contrast to the sounds in the acoustic trials, the boat horn produces a very loud and directional sound. Another factor that was probably important in the effectiveness of the tests is that I was part of the stimulus and the stimulus was delivered
from 6 m off the ground on the balcony of the tower. Although 5 (50%) of the control tests were repellent, the difference between the controls and the experimentals was significant ($x^2 = 11.64$, d.f. = 1, p<0.001).

When the bears were repelled by the boat horn, they ran only 5 to 40 m ($\bar{x} = 20$ m) before they slowed to a walk. Twenty meters is not a great distance for a bear. If the victim of a bear attack wanted to be safe, he/she would have to act immediately to increase the distance without inducing a further attack.

Another aspect of the boat horn trials as well as the acoustic stimuli is the problem of habituation. A frightening stimulus that is not followed by an appropriate or painful reinforcing stimulus might soon become meaningless to the bears. Reacting appropriately to a biologically significant sound such as an aggressive bear should always be advantageous to a bear, and one would expect that habituation would be less likely in the tests where bear sounds are used. None of the animals that were tested more than twice showed a tendency to be repelled more often in the earlier trials. My observations indicate, however, that the bears may indeed show habituation to the stimuli by reacting less quickly or strongly to the sounds when they are repelled.

Perhaps more alarming was the virtual disregard of some bears to all my efforts to repel them. One particular unidentified subadult visited the area near the tower on 7 November. After testing the boat horn twice at a range of 5 m, I tried it twice more to no avail. When that failed, I threw things at the bear which only seemed to enrage it. As a last resort, I dropped a Thunderflash in the snow near the bear, and the explosion finally scared the bear off. Because the Thunderflash is an explosive device, it can injur a bear. In addition, such
explosive devices cannot be used in national parks. Therefore, the instances when I could not repel the bear except with the Thunderflash indicate that a small percentage of the animals cannot be repelled.
Chapter VIII
SUMMARY AND CONCLUSIONS

The purpose of this study was to develop and evaluate techniques to monitor behavioral and physiological responses of grizzly and polar bears and to relate the physiological parameters to the bears' behavior. Continuous monitoring of the heart rate, body temperature, and subcutaneous temperature of bears requires implanted transmitters. Despite difficulties with the heart rate transmitters and transmitter-related inaccuracies in measuring the body temperature and subcutaneous temperature, the behavior of captive grizzly and polar bears can be predicted well by using the physiological parameters in discriminant analyses. Overall activity, as well as relatively detailed aspects of behavior like ear position or vocalizations, can be predicted by analyzing the physiological parameters.

The predictions of behavior from the physiology in this study used only parameters that could be measured with radio-telemetry. With this method it is possible to predict an animal's behavior accurately without having to observe the animal. Such an ability should be very valuable in studies of animals that are difficult to observe. For example, with improvements in physiological telemetry equipment, one could instrument free-ranging polar bears and determine activity budgets of the bears in the winter when they are exceedingly difficult to observe. For burrowing or nocturnal animals, such a 'remote' observation method may be the only alternative to captive animal studies. Initially it is necessary to observe the behavior of the
animal while simultaneously recording the physiological parameters. Discriminant functions used in subsequent studies that do not include behavioral observations are determined from these baseline studies. Thus, these studies are never completely divorced from direct observations. On the other hand, because the prediction rates for the grizzlies and polar bears compared well with those for the individual bears, direct observations of a few individuals can furnish discriminant functions that would be appropriate for the entire species. More studies should be done to determine how sex, age, and size affect the prediction ability of the physiological parameters.

The prediction of behavior through discriminant analysis of physiological parameters requires that the parameters measured vary with the behavior of the animal. Though the physiological parameters measured can be correlated with each other, they should also change differently from each other during different behaviors in order to maximize the discrimination between behaviors. The accuracy of the prediction also depends on the reliability of the transmitters. Heart rate transmitters must be immune to disturbances during heavy activity that make the heart rate record impossible to read. The temperature transmitters must be improved to minimize their latency. Finally, for field studies, the range of all the transmitters must be increased.

The correlations between physiology and behavior were integrated into laboratory tests of repellent stimuli. The changes in physiology and behavior that took place between baseline and repellent observations indicate that periodic disturbances significantly increase activity. Such changes affect the energy requirements of the animals and suggest that grizzlies and polar bears may be very sensitive to relatively
minor disturbances. The bears' sensitivity to disturbances should be studied more, but these results should be considered when land use and development programs encroach on bear habitats. Relatively minor disturbances like occasional human traffic may significantly increase the energy requirements of the bears.

Body temperature and sub-cutaneous temperature did not show consistent changes when the bears were subjected to repellent tests. The lack of change is partly due to the fact that the transmitters were slow to react to changes in the temperatures. The heart rate consistently increased when tests were performed. Unfortunately, the bears' heart rate also increased when controls were run. Because the activity of the bear nearly always changed dramatically when tests were run, the heart rate record added very little information to the behavioral observations.

The unambiguous behavioral reactions to repellent tests in the laboratory show the validity of captive animal studies of repellents. Laboratory studies allow testing of many stimuli in a relatively short time. Without implanting physiological transmitters, a series of 25 tests would take 14 days using the same schedule of observations as used in this study. The average length of observations in this study was 29 days. Many tests can be performed on a bear in a short time, but the number of bears tested remains small. Laboratory studies must be complimented with field studies.

The Churchill, Manitoba, area is an ideal place to perform field trials on polar bears. A relatively small number of different stimuli were tested on many different bears and some bears were tested several
times with the same stimulus. The behavior of free-ranging bears is not affected by the constraints of captivity.

The stimulus that repelled polar bears in the field (Boat horn) also repelled the polar and grizzly bears in the laboratory. This agreement between the results of laboratory and field studies gives more support to the validity of the laboratory tests. Further tests should be done on more repellent stimuli. Laboratory and field studies should be planned to compliment each other. The sample sizes of tests for individual repellent stimuli must be increased in order to answer questions about habituation. The chemicals (especially Halt) evoke their repellent effects by causing intense pain and should be resistant to habituation. Likewise, aggressive bear sounds should be resistant to habituation because of the risk involved in not reacting appropriately to such sounds. Different age and sex classes of individuals must be bested to investigate the generality of the results found here. Areas must be sought where relatively large numbers of black bears and grizzlies can be tested in the field.

The results of 'Halt' dog repellent in the laboratory and the Boat horn in both the laboratory and the field indicate that effective repellents can be developed. The stimuli that were effective usually relied on startling the animal initially (Loom, Cap-chur gun, and Boat horn). Part of the battle in averting a bear's attack is to get the bear to stop or turn away. Once the bear is repelled, it must be prevented from returning before the victim reaches safety. None of the repellent reactions in the laboratory lasted more than 5 minutes and the bears in the field ran an average of 20 m when repelled by the Boat horn. Though the stimuli repelled the bears, neither 5 minutes
nor 20 m is much of a margin of safety. Warning the bears before getting too close is a good strategy for preventing encounters, but the bells that are currently sold to hikers for that purpose do not work.

The passive chemical deterrents in the field indicate that such chemicals do not prevent the bears from visiting the area, but the bears did spend less time at individual sites. The chemical's effectiveness may increase as the bears make more visits to the sites and never attain the expected reward (bait). I did not observe such a learning process, but the baits themselves were never contaminated so the bears did not necessarily lick the repellent. In a study on the efficacy of commercial dog repellents, Ortho Scram was 42-65% effective in preventing a dog from using a treated dog house, but a product like Chaperone was ineffective (Huebner and Morton 1964). Tests on dogs which would be easier and cheaper might prove valuable in selecting different stimuli for testing on bears.

Finally, there must be a concurrent program to develop delivery systems. The chemicals tested were sprayed at the animals and needed to contact the bears' eyes to be effective. The effective range of Halt was about 2 m—clearly unacceptable if one is trying to stop a charging bear in the wild. Such a spray should deliver a large stream of repellent at least 5 m accurately. Freezing conditions renders pressurized aerosols ineffective. Both the chemical sprays and the freon-powered horns are affected by temperature. Because attacks are often sudden and unexpected, the repellent must be simple, durable, and easy to use. The small plastic horn part of Sound 911 was easily
damaged by an assistant performing a test. The victim of an attack would not likely have the presence of mind to be careful with the horn.

The best repellent may prove to be a device that combines the best repellent stimuli. It could be a combination horn, chemical, and 'loom' stimulus. The horn would be used on bears that were farther away than 5 m. If the bear approached or was encountered closer than that, the chemical would be effective. When the bear got too close, a loom stimulus might finally persuade it to stop. Unfortunately, the field studies also indicate that no repellent will work on some individuals.

Preventing encounters between bears and people by adjusting land use and development practices to the ecology and behavior of bears is the best way to prevent injuries. However, encounters between bears and people will continue to occur. This study shows that safe, effective repellents can be developed for bears. More importantly, it provides effective techniques for the systematic study of bear repellents.
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Appendix A: Calibrations of temperature transmitters.

Each temperature transmitter was calibrated by putting it into a constant temperature water bath until the transmitter stabilized. The pulse rate for three or four temperatures was obtained and a regression line was fitted to the points. I tested linear, logarithmic, exponential, and power functions for the best fit (determined by Pearson's correlation coefficients). On obtaining the best regression, the telemetered pulse rate was transformed into temperatures (°C) and rounded to 2 significant digits.

Growly calibrations

Body temperature:

<table>
<thead>
<tr>
<th>Beats/min.</th>
<th>TB</th>
<th>Logarithmic equation</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>16.00</td>
<td>$\text{TE} = 58.320 + 20.206 \ln X$</td>
</tr>
<tr>
<td>56</td>
<td>23.00</td>
<td>$r = .9995$</td>
</tr>
<tr>
<td>92</td>
<td>33.60</td>
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<tr>
<td>168</td>
<td>44.90</td>
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Sub-cutaneous temperature:

<table>
<thead>
<tr>
<th>Beats/min.</th>
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<th>Logarithmic equation</th>
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</thead>
<tbody>
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<tr>
<td>27</td>
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<tr>
<td>62</td>
<td>42.80</td>
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Snarly calibrations

Body temperature:

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<tr>
<th>Interpulse interval (sec)</th>
<th>TB</th>
<th>Exponential equation</th>
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<tbody>
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<td>.940</td>
<td>27.60</td>
<td>$\text{TB} = 152.694 e^{-1.820}$</td>
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<tr>
<td>.710</td>
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<td>.720</td>
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<td>.570</td>
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Snarly calibrations (cont.)

Sub-cutaneous temperature:

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<td>.300</td>
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Gwen calibrations

Body temperature:

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<td>822</td>
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Sub-cutaneous temperature:

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<td>$TS = 111066.935 e^{-1.194X}$</td>
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<tr>
<td>862</td>
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<tr>
<td>694</td>
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Magdalene calibrations

Body temperature:

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<td>1001</td>
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Sub-cutaneous temperature:

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<th>Int. int. (msec)</th>
<th>TS</th>
<th>Power function</th>
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<tr>
<td>694</td>
<td>44.80</td>
<td></td>
</tr>
</tbody>
</table>
Appendix B: Descriptions of repellent stimuli.

Taped sounds

**Human growling (SGrowl):** A 21 s recording of my assistant, Sheridan Stone, imitating a grizzly bear's growl. Sheridan has a deep, resonant voice. There are 7 separate growls from 1 to 5 s in duration (1,1,3, 5,5,2,3, s). They are separated by very short pauses.

**Human hissing (SHiss):** A 21 s recording of my assistant hissing. The hissing is a 'shh' sound rather than a 'sss' sound. Each hiss is 1 or 2 s long with a very short breathing space between them. The tape has 2 s of quiet followed by 14 hisses (1,1,1,2,2,1,1,1,2,2,2,1,1, 1 s). Although my assistant hissed as loud as possible, he could not match the volume of air expelled by the bears when they hiss, nor were there the normally associated breathing and growling sounds.

**Human barking (SBark):** A 27 s recording of my assistant imitating a grizzly barking. The barks sound more like very energetic grunts. There are 17 barks, separated by short breathing spaces. Most of the barks are very staccato grunts. Two of the barks in the middle of the tape trail off and last about 2 s each.

**Human shouting (SShout):** A 21 s recording of Sheridan Stone shouting as if he had met a bear on a trail. "Hey bear! Get out'a here! Get out'a here bear! Hey! Hey! (5 s pause) Hey! Bear! Go on bear, go on! Hey! Fey! Get out'a here, get out'a here, go on!" The tape begins very loud and abruptly. There are pauses between shouts and each succeeding shout is loud and sharp.

**Grizzly growling (GGrowl):** A 29 s recording of Growly growling. The recording consists of 5 low growls of 5,6,7,3, and 3 s duration. The
first and fourth growls end in a heavy exhalation that sounds like a hiss. The growls are not loud and they fade in and out.

**Grizzly barking (GBark):** A 41 s recording of Growly 'barking'.

Barking is a vigorous growl that crescendos rapidly to a loud grunt-like bark. There are 15 barks on the recording. They are connected with growling so that it is difficult to tell when one ends and the next begins.

**Polar bear sounds (1977PE):** This is a 27 s recording of an adult female polar bear that was being held in a culvert trap. She had a cub-of-the-year with her in the trap. The tape begins very abruptly with a 3 s hiss. The hiss is followed by 1 s of growling, a pause, 7 s of heavy breathing, 4 s of growling that ends in vigorous chuffing (like very rapidly repeated 'f' sounds), a short (1 s) vigorous hiss and finally, 4 s of growling. The growling is a very deep sound and rolls like low thunder.

**Polar bear sounds (GUEN):** A 44 s recording of Guen growling and hissing.

The recording begins with a very loud and sharp hiss (2 s). The hiss is followed by a deep growl (4 s), 12 s of panting, another loud hiss-breathing-hiss (6 s), deep growl (2 s), and finally, a last loud hiss followed by loud panting. This tape was recorded while Guen was in the experimental cell at the laboratory, she was vigorously charging the recorder.

**Killer whale sounds (ORCA):** This stimulus consisted of playing approximately 20 s of a recording of killer whale sounds. The recording has various sounds on it. Most of the sounds are high pitched whistles and squeaks that sound like the noise produced by pushing the air out of a balloon while pinching the mouthpiece. There are also clicks and pops.
that are rapidly repeated. The entire tape has background water noises from the hydrophone being underwater.

**Other sounds**

**Thunderflash**: This is a very loud firecracker. It is no longer available, but a similar product, 'Polar Bear Scaring Device', is available from Hand Chemical Industries Ltd., Milton, Ontario. Purchase of the devices requires approval from the Bureau of Explosives in Ottawa. For the test, the Thunderflash was dropped inside the cage away from the animal.

**Bells**: Examples of bells sold to hikers in Glacier and Yellowstone National Parks. They were small cowbells and a jingle bell. They are sold to hikers to attach to their boots to warn bears of the peoples' approach.

**Boat horn**: A freon-powered signal horn from Lynco Ltd., Canada. The sound is very loud and piercing. It reaches full volume instantly. The output is 98 dB at 30 cm and 62 dB at 20 m (tested with Sound Level Meter Type 450B, H. H. Scott Inc., Maynard, Mass.). It is small enough to be hand-carried.

**Sound 911**: A pocket-sized freon-powered horn from Falcon Safety Products. The sound is higher pitched than the boat horn but is also very loud. Its output is 96 dB at 30 cm and 58 dB at 20 m.

**Dog whistle**: An Acme Silent Dog Whistle. It is for training dogs. The whistle was tested with the assistant blowing it as hard as she could and by attaching it to the electric compressor for the Trucktone horn.

**Referee's whistle**: Available at most sporting goods stores.
Trucktone horn: Battery powered air horn for trucks that was mounted on a plywood base. It has a deep resonant sound that began and ended gradually. Not suitable for hand use.

Cap-chur gun: Fired a Cap-chur dart gun without a dart. It fires a .22 calibre blank cartridge to create gas pressure to fire the dart. The barrel of the gun was aimed away from the bear when it was fired.

Chemicals

Onion juice: Solution of 1/3 onion juice and 2/3 water was shot in the animals face with a 30 ml syringe.

Ammonia (Windex): Household window cleaner with ammonia. It was also sprayed with a 30 ml syringe.

Ammonia: For field trials, full strength "Parson's Ammonia" was poured around baits. Parson's Ammonia. Ingredients: Ammonium hydroxide solution, Ethoxylated alkyl alcohol, Perfume, Color, Clarifying agent, Salts (inert), contains 0% Phosphorus per recommended use.

Pine Sol: Household disinfectant used in field trials only. Full strength solution was poured around baits. Ingredients: Active, Pine oil 30.0%, Isopropanol 10.9%, Soap 10.0%. Inert 49.1%. Contains no phosphorus. Caution: If swallowed, do not induce vomiting, this may be harmful. Keep out of eyes.

Mustard: A solution was prepared by boiling dry mustard in water. The solution was sprayed at the bears with a 30 ml syringe.

Halt: Commercial dog repellent, designed to stop an attacking dog (Animal Repellents Inc., Griffin, GA). EPA Reg No. 7754-1 EPA Est. 7754-NY-1. In aerosol can. Ingredients: Active, Capsaicin .35% (derived from Oleoresin of Capsicum). Inert ingredients 99.65%.
**Dog Stopper:** Commercial dog repellent designed to stop an attacking dog (Whitmire Research Lab. Inc., St. Louis, MO). It is a foam that is shot as a stream from an aerosol can. USDA Reg. No. 499-141. Ingredients: Active, Triethanolamine Salt of Lauryl Sulphate 2.8%, Diethanolamide Condensate of Coconut Oil .7%, Inert 96.5%.

**Git:** Commercial dog repellent designed to keep dogs from frequenting a particular area (Animal Repellents Inc., Griffin, GA). Sprayed from an aerosol can. EPA Reg. No. 7754-9, EPA Est. 7754-NY-1. Ingredients: Methyl Nonly Ketone 1.9%, related compounds .1%, Inert 98.0%.

**Ortho Scram:** Commercial dog repellent designed to keep dogs out of gardens (Chevron Chemical Co., San Francisco, CA). Sprayed from aerosol can. Used in field trials only. EPA Reg. No. 239-2057-ZB, EPA Est. 11525-CA-1. Ingredients: Active, Bone oil .5%, Allyl Isothiocyanate .3%, Paradichlorobenzene 1.0%, Oil of Sassafras (artificial) .5%, Inert 97.7%.

**Bear Trail:** A secret formula for training dogs to track bears (National Scent Co.). To the human nose it smells vaguely like a grizzly bear.

**Other**

**Strobe light:** A slow repeating strobe light (1 flash/sec) for scaring wildlife (Telonics, Tempe, AZ).

**Loom:** Assistant suddenly presents the face of a 1.0 x 1.5 m piece of plywood. After the initial test, the stimulus was given repeatedly for 3 or 4 times.
Appendix C: Identifiable bears visiting the observation during field trials.

<table>
<thead>
<tr>
<th>Name</th>
<th>Sex</th>
<th>Age class</th>
<th>Weight (kg)</th>
<th>Identifying marks</th>
</tr>
</thead>
<tbody>
<tr>
<td>#1&lt;sup&gt;a&lt;/sup&gt;</td>
<td>M</td>
<td>Subadult</td>
<td>223</td>
<td>Numbers painted on sides</td>
</tr>
<tr>
<td>#2</td>
<td>M</td>
<td>S</td>
<td>168</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
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<tr>
<td>#3</td>
<td>M</td>
<td>S</td>
<td>196</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
<td>#4</td>
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<td>S</td>
<td>196</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
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</tr>
<tr>
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<td>S</td>
<td>128</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
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<td>S</td>
<td>146</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
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<td>A</td>
<td>255</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
<td>#27</td>
<td>M</td>
<td>Yearling</td>
<td>101</td>
<td>&quot;   &quot;   &quot;   &quot;   &quot;   &quot;</td>
</tr>
<tr>
<td>#8R&lt;sup&gt;b&lt;/sup&gt;</td>
<td>F</td>
<td>S</td>
<td>195</td>
<td>Number painted on rump</td>
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<tr>
<td>Henry&lt;sup&gt;c&lt;/sup&gt;</td>
<td>M</td>
<td>A</td>
<td>450</td>
<td>Very large, pear shaped</td>
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<tr>
<td>SURE</td>
<td>?</td>
<td>S</td>
<td>130</td>
<td>Scratch Under Right Eye</td>
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<tr>
<td>LOLE</td>
<td>?</td>
<td>S</td>
<td>130</td>
<td>Line Over Left Eye</td>
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<tr>
<td>BE</td>
<td>?</td>
<td>S</td>
<td>100</td>
<td>Big Ears</td>
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<tr>
<td>DULE</td>
<td>?</td>
<td>S</td>
<td>130</td>
<td>Dot Under Left Eye</td>
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<tr>
<td>MOLE</td>
<td>M?</td>
<td>A</td>
<td>400</td>
<td>Large dot on right cheek</td>
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</tbody>
</table>

<sup>a</sup> Information for #1-#27 from Paul Latour, CWS.
<sup>c</sup> Remaining bears' weights were estimated.