340 kN m^{-2} at 22 °C, and thereafter only rises to 380 kN m^{-2} at 35 °C[10]. In contrast, fast myotomal fibers of various Antarctic fish produce 230 kN m^{-2} at −1 °C, and 260 kN m^{-2} at 10 °C[5,11]. The results obtained from the marlin are consistent with it being a relatively eurythermal animal, capable of maintaining force production over the wide range of temperatures it experiences during its diurnal vertical migrations. This appears however to be at the cost of a 2-fold decrease in 'economy' (force generated/ATP hydrolyzed) for each 10 °C rise in temperature.

Experimentally determined parameters such as Po and V_{max} can be shown to be dependent upon particular rate constants in cross bridge theory[12]. It might therefore be informative to see if the results presented are explicable on the basis of Huxley's model. Po is proportional to $f_1/(f_1+g_1)$, where f_1 and g_1 are the cross bridge attachment rate and isometric detachment rate respectively. To be consistent with the results obtained here, this relation should remain approximately constant over the physiological temperature range. The rate of isometric cross bridge turnover on the other hand is proportional to $(f_1 \cdot g_1)/(f_1+g_1)$. Isometric ATPase activity is a measure of cross bridge turnover, and is highly temperature dependent in the case of the marlin. Taking the simplest hypothesis, that the rates of attachment and detachment are both temperature dependent, and have identical Q_{10}'s, then the above equations predict to Po would be independent of temperature, and the rate of isometric cross bridge turnover would have the same Q_{10} as f_1 and g_1. The results are therefore consistent with a model in which the rates of attachment and detachment both have a Q_{10} or around 2, and the small temperature dependence observed for Po can be explained by a small difference in Q_{10} between f_1 and g_1.

Acknowledgments. This work was supported by grant GR3/4936 from the Natural Environment Research Council, and a Small Grant in Science award from the Nuffield Trust which supported travel to Hawaii. We are grateful to the Pacific Gamefish Foundation for provision of facilities, and to its Scientific Director, Dr Charles Daxboeck for his enthusiastic support.

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0014-4754/85/121532-02$1.50 + 0.20/0

Diurnal change in stature: effects of sleep deprivation in young men and middle-aged men

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Summary. Sleep deprivation was associated with decreased stature and it blunted the normal 24-h rhythm in young and in middle-aged men. Loss in stature was regained during the first recovery night of sleep. The 24-h rhythm in height is not an endogenous circadian rhythm but depends upon the periods of recumbency over the sleep/wake cycle.
Key words. Sleep deprivation; diurnal rhythm; height, stature.

Over 200 years ago, Montbeillard found that his son's height varied according to whether he was rested or tired, and that the loss in stature by day was recovered following rest[2]. Others found the same[3–5], and that most of the decrease took place in the first hours after rising[6–8]. Diurnal variation in height may be due to variation in the water content of the nucleus pulposus[9,10], and some suggest that loss of muscle tone and associated postural changes contribute to the diurnal change in stature[11].

We undertook this study because diurnal change in stature has not been investigated using modern techniques, and because we were able to take advantage of two unrelated research projects in which volunteers were sleep-deprived (in order to study changes in blood and urine).

Methods. Study I. 12 healthy men aged 19–28 years (mean 22) were resident in the sleep laboratory for five days and nights. The first night was a baseline night with sleep, followed by 63 h of continuous sleep deprivation, which ended on the fourth evening of the study with a recovery night of sleep, followed the next evening by a second recovery night. On baseline and recovery nights, subjects were in bed from 23.00 h to 08.00 h. No subject took part in strenuous physical exercise and all were under constant surveillance.

Measurements of overall standing height, and cervical, thoracic and lumbar lengths were carried out at 08.00 h and 23.00 h of each day, beginning at 23.00 h on the first day and ending at 08.00 h on the last day. A wall-mounted Harpenden Stadiometer was used to measure stature and back length to the nearest mm. Head height was measured to the nearest mm using a craniometer. From these measurements, vertebral lengths were calculated (fig. 1). To ensure that the same vertebral point was measured at each time point, marks were made on each subject's back at C7, T12 and S2. At each measurement time, subjects were positioned standing as tall as possible[7,12], and all measurements were recorded by the same observer.

Study II. Six healthy men, aged 44–50 years (mean 47), were

Analysis of variance on measures of young men. a) Over baseline and recovery periods, showing diurnal change. b) over baseline and sleep deprivation periods showing effect of sleep deprivation treatment. c) the interaction between diurnal change and sleep deprivation

Measure	a) Diurnal change df 1,11	b) Sleep deprivation treatment df 2,22	c) Interaction df 2,22
Stature	F 88.51, $p < 0.001$	F 40.75, $p < 0.001$	F 25.04, $p < 0.001$
Cervical	NS	NS	F 8.15, $p < 0.01$
Thoracic	F 7.34, $p < 0.025$	NS	NS
Lumbar	F 15.26, $p < 0.01$	NS	F 3.64, $p < 0.05$

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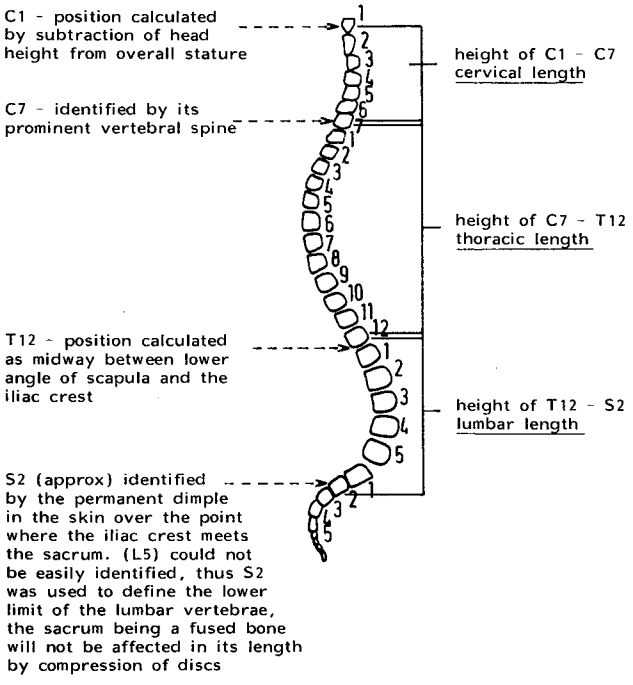

Figure 1. Definition and measurement of vertebral lengths.

studied in the sleep laboratory for 24 h on two separate occasions 7 weeks apart: one night they slept normally and on another they were deprived of sleep. The sleep and sleep deprivation conditions were in balanced order over the subjects. Stature and vertebral lengths were measured as in study I, beginning at 08.00 h when the subjects arrived at the laboratory, every 3 h thereafter until 23.00 h, and again at 08.00 h after either a night of sleep or of sleep deprivation.

Data analysis. We used measures of change in stature and vertebral length i.e. any increase or decrease in length from the first measurement of the study (23.00 h in study I and 08.00 h in study II). Thus, subject 1 (study I) was 1763 mm at 23.00 h on the baseline night, and the following morning was 1780 mm: the overnight change score was +17 mm. In study II, changes from the 08.00 h measurement at the start were calculated at each three-hourly period during the day, and the overnight change from 23.00 h to 08.00 h. Analysis of data used the BMDP statistical package of the Health Sciences Computing Facility, University of California, L.A. To determine the effect of time of day (diurnal change) and of treatment (sleep deprivation), analysis of variance with repeated measures was carried out. If a significant treatment effect was found, correlated t-tests (2-tailed) were performed between pairs of conditions.

Results. Study I, young men. Mean changes in stature are shown in figure 2. Analysis of variance using change scores revealed a significant diurnal change in stature, thoracic length and lumbar length: the loss of height by day was regained during the following night of sleep (see table). Comparison of the baseline and sleep deprivation periods by analysis of variance revealed that sleep deprivation had significantly reduced stature but reductions in the different sections of the back failed to reach statistical significance. Significant interactions were found between time of day and treatment (table), because sleep deprivation largely eliminated the normal pattern of diurnal change.

On the baseline night of sleep, stature increased, whereas during the night without sleep stature decreased below the bedtime value, the effects of the two nights being significantly different ($t = 8.17$, $df = 11$, $p < 0.001$). The reduction in stature was sustained through the second sleep deprivation night (change from baseline: $t = 9.98$, $df = 11$, $p < 0.001$). A comparison of the

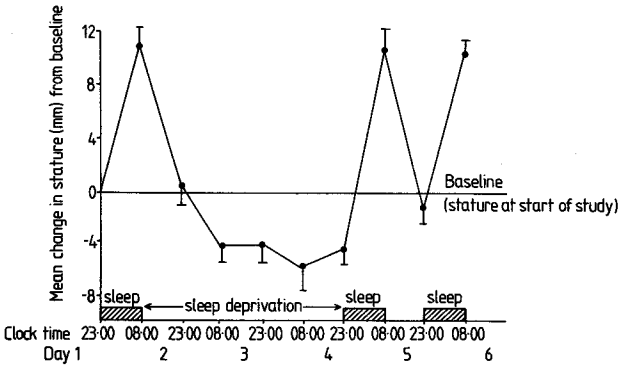

Figure 2. Mean change in stature (±SEM) of 12 healthy young men on 6 days including 63 h of sleep deprivation. During the sleep deprivation period stature decreased to its lowest and the overnight change on both of the sleep deprivation nights was significantly different from the change on the baseline night ($p < 0.001$). The loss in stature was regained during the first recovery night of sleep.

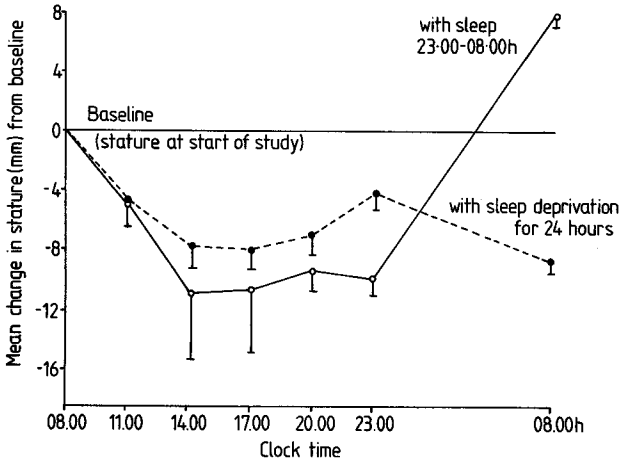

Figure 3. Mean change in stature (±SEM) of six healthy middle-aged men during 24 h on two occasions, one with sleep and another with sleep deprivation. The overnight change on the two occasions was significantly different ($p < 0.001$).

change in stature following the baseline night with the change following the first recovery night showed no significant difference ($t = 0.18$, $df = 11$, NS). Thus loss in stature with sleep deprivation was regained in one night of sleep. The two measurements taken during the final 24 h of the study showed loss occurring by day to be regained during sleep.

Study II, middle-aged men. Mean changes in stature during 24 h with and without sleep are shown in figure 3. Analysis of variance revealed no significant difference between the two days in measures of stature and back lengths taken every 3 h during the day. However, analysis of variance on overnight changes (23.00 h–08.00 h), showed that sleep deprivation had a significant effect on stature, ($F = 26.65$, $df = 1,5$, $p < 0.01$), though not in the subdivisions of the back. The significant interactions between time of day and sleep deprivation treatment for all measures shows that sleep deprivation altered the overnight pattern of change in stature ($F = 335.23$, $df = 1,5$, $p < 0.001$) though not in the subdivisions of the back.

Discussion. We confirmed that height decreases during the day, mostly in the morning. Whether sleep or mere recumbency is the more important for recovery remains to be investigated. Nachemson and Morris[13] compared the in vivo intradiscal pressure in sitting, standing and reclining subjects, and found that when sitting the lower lumbar spine is subjected to 10–15 kg/cm^2.

This pressure is reduced by 30% when standing, and by 50% in the reclining position. In cadavers and anesthetized patients with fully relaxed muscles, resting pressures are low compared with resting but awake subjects, for when a subject is awake the spinal muscle tone produces compressive force on the discs[10], whereas in sleep muscle tone decreases, especially during REM sleep. These factors are borne out by study I, with continuing loss in stature during deprivation of sleep. Not until subjects slept, and their muscle tone diminished, was accumulated loss regained. Precision of measurement is less in the subdivisions of the vertebral column, causing difficulty in establishing any pattern of change in cervical, thoracic and lumbar regions. Discrepancy between overall change in stature and sum of the changes in back lengths could indicate compression in the leg, through apposition of the bones of the leg and foot[15]. A small gain in stature has been shown following a rest without sleep[7], when pressure on cartilage would be reduced, but it would appear that full return of stature lost by day is dependent on sleep.

1 Acknowledgments. The first author was a Medical Research Council scholar; the second was supported by the Scottish Hospital Endowments Research Trust.
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0014-4754/85/121533-03$1.50 + 0.20/0

Freezing-tolerance in the woodroach *Cryptocercus punctulatus* (Scudder)

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Summary. Winter-acclimated *Cryptocercus punctulatus* are able to withstand ice crystal formation within their bodies (freeze-tolerant), and contain hemolymph plasma ice nucleating factors (INF's) throughout the year. In addition, ribitol, a sugar alcohol accumulates in their hemolymph during winter. This represents a new report of INF's occurring in the Dictyoptera, and the presence of ribitol in the hemolymph of the Insecta.
Key words. Freeze-tolerance; ribitol; *Cryptocercus punctulatus* (Scudder).

Wood cockroaches *(Cryptocercus punctulatus)* are primitive insects which inhabit downed, decaying logs in scattered mountainous regions of North America. Much like termites, they consume wood and utilize cellulose as a food source with the aid of symbiotic gut protozoans[1,2]. Mated pairs remain together in the same log for 4–5 years, sharing in the care (brooding) of their young which mature in 6–7 years and may live for 10 years[3]. Since these insects are found at relatively high elevations, studies were conducted to evaluate the ability of these insects to survive cold temperatures.

Insect overwintering biology has been of interest for many years. Information on insect cold-tolerance and cryobiology has increased since Chino[4] reported the occurrence of glycerol and sorbitol in cold-acclimated *Bombyx mori* eggs. Most early studies focused on the production and effects of glycerol and other polyols in insect hemolymph. These materials usually function as antifreeze agents by lowering the hemolymph supercooling point providing insects with protection from freezing.

Zachariassen and Hammel[5] first described ice nucleating factors (INF's) from the hemolymph of freeze-tolerant beetles. These INF's «seed» hemolymph ice crystal formation at high subzero temperatures (circa −6 °C).INF's from two insect species have been purified and partially characterized as being proteins or lipoproteins[6,7]. Nucleating factors override the colligative properties of other compounds such as sugars, polyols, or salts which would normally depress hemolymph supercooling points. It has been proposed that seeding extracellular ice at a high subzero temperature promotes water movement from cells as water freezes in the extracellular spaces. The resulting cellular dehydration is thought to reduce the possibility of intracellular ice crystal formation, which would cause extensive cell damage. To date, INF's have been reported to occur in only three insect orders: Diptera, Coleoptera, and Hymenoptera[8,9]. However, on the basis of hemolymph supercooling point determinations (above −10 °C) the freeze-tolerant cockroach *Parcoblatta pennsylvanica*[10] appears to have hemolymph ice nucleators. This report suggests their occurrence in *P. pennsylvanica*, but no confirmation of their presence was provided.

Although INF's normally occur in hemolymph during the winter, there are reports that they may be found in insects during the summer. There is no clear explanation for the occurrence of INF's in summer-acclimated insects, but they may be present under circumstances where summer night temperatures drop below freezing[11,12], or the 'INF's' may have multiple functions as suggested by Duman et al.[7].

Cryptocercus punctulatus collected in November 1983 were found to be freeze-tolerant. Both whole insects and hemolymph plasma samples supercooled to similar points, ranging between −5.5 and −5.6 °C (table 1). The supercooling point was observed as a sudden rise in temperature (as measured by a 40-gauge copper-constantan thermocouple and a Leeds and Northrup Speedomax 250 recorder) due to the release of the latent heat of fusion of the solution as the temperature was slowly lowered (−0.3 °C/min). Cold-acclimated *C. punctulatus* frozen for relatively short time intervals invariably recover upon warming to room temperature. We have found 76% survival (N = 94) among individuals held up to 205 days at −10 °C when observed 3 days post-thaw.