Døgnrytme og svømning ydeevne

Greg Atkinson¹ and Andrew Thompson²

¹Health and Social Care Institute, Teesside University
²Research Institute for Sport and Exercise Sciences, Liverpool John Moores University
How can chronobiology help the swimmer?

- Circadian rhythms relevant to swimming
- Can we ‘cure’ circadian variation?
  - Warm-ups?
  - Bright light?
  - Melatonin?
- Can we ‘cure’ jet-lag?
  - US Soccer study
How can chronobiology help the swimmer?

• Circadian rhythms relevant to swimming
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  – Warm-ups?
  – Bright light?
  – Melatonin?
• Can we ‘cure’ jet-lag?
  – US Soccer study
Swimming performances in the noisy real world

Heats vs Finals (Beijing)?
e.g. 400 m Freestyle

<table>
<thead>
<tr>
<th>Name</th>
<th>Final</th>
<th>Heat</th>
</tr>
</thead>
<tbody>
<tr>
<td>Park Taehwan, South Korea</td>
<td>03:41.9</td>
<td>03:43.4</td>
</tr>
<tr>
<td>Lin Zhang, China</td>
<td>03:42.4</td>
<td>03:43.3</td>
</tr>
<tr>
<td>Larsen Jensen, United States</td>
<td>03:42.8</td>
<td>03:43.1</td>
</tr>
<tr>
<td>Peter Vanderkaay, United States</td>
<td>03:43.1</td>
<td>03:44.2</td>
</tr>
<tr>
<td>Oussama Mellouli, Tunisia</td>
<td>03:43.4</td>
<td>03:44.5</td>
</tr>
<tr>
<td>Grant Hackett, Australia</td>
<td>03:43.8</td>
<td>03:44.0</td>
</tr>
<tr>
<td>Yuriy Prilukov, Russia</td>
<td>03:44.0</td>
<td>03:44.8</td>
</tr>
<tr>
<td>Nikita Lobintsev, Russia</td>
<td>03:48.3</td>
<td>03:43.4</td>
</tr>
</tbody>
</table>
Controlled swimming time trials in the pool

Controlling for sleep prior to each test time

How can chronobiology help the swimmer?

- Circadian rhythms relevant to swimming
- Can we ‘cure’ circadian variation?
  - Warm-ups?
  - Bright light?
  - Melatonin?
- Can we ‘cure’ jet-lag?
  - US Soccer study
The circadian system

- Body clock
- Melatonin
- Pineal gland
- Retino-Hypothalamic tract
- Vision
- Light rhythm
- Activity rhythm
- Outputs
- Intergeniculate leaflet

Waterhouse et al., *Keeping in time with your body clock*, Oxford University Press
“Curing” morning impairment with a warm-up?

“Curing” morning impairment with caffeine?

Mora-Rodríguez et al. (2012) PLoS ONE 7(4): e33807
The circadian system

Body clock

- Intergeniculate leaflet
- Activity rhythm

- Melatonin
  - Pineal gland
  - Retino-Hypothalamic tract
  - Light rhythm
  - Vision

Waterhouse et al., *Keeping in time with your body clock*, Oxford University Press
A ‘phase-response curve’ for exercise?

Timing of morning exercise in the 3-day “taper” phase before a morning performance?

The circadian system

Body clock

Intergeniculate leaflet
Activity rhythm

Melatonin
Retino-Hypothalamic tract
Light rhythm
Vision

Pineal gland

Waterhouse et al., Keeping in time with your body clock, Oxford University Press
Phase-response curve for light

Waterhouse et al. *Neurosci Let* 1998; **245**: 97-100
Evening bright light delays the body temperature rise

Endurance exercise in the heat: Pre-cooling methods

- Air temperature and humidity
- Convection
- Radiation
- Sky thermal radiation
- Respiratory evaporation
- Blood flow to the skin
- Solar radiation
- Metabolic heat production
- Conduction
- Thermal radiation from the ground
- Reflected solar radiation
- Sweat evaporation
## Evening bright light and sleep quality

<table>
<thead>
<tr>
<th>Variables</th>
<th>No light</th>
<th>Light</th>
<th>No blue light</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assumed sleep duration (min)</td>
<td>390.62</td>
<td>390.33</td>
<td>389.75</td>
<td>0.98</td>
</tr>
<tr>
<td>Actual sleep duration (min)</td>
<td>359.12</td>
<td>358.33</td>
<td>356.50</td>
<td>0.95</td>
</tr>
<tr>
<td>Wake time after sleep onset (min)</td>
<td>31.00</td>
<td>31.33</td>
<td>33.12</td>
<td>0.95</td>
</tr>
<tr>
<td>Actual sleep duration (%)</td>
<td>91.99</td>
<td>91.85</td>
<td>91.50</td>
<td>0.96</td>
</tr>
<tr>
<td>Wake time after sleep onset (%)</td>
<td>8.01</td>
<td>8.15</td>
<td>8.50</td>
<td>0.96</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>89.06</td>
<td>88.70</td>
<td>88.09</td>
<td>0.89</td>
</tr>
<tr>
<td>Sleep latency (min)</td>
<td>12.87</td>
<td>14.00</td>
<td>15.00</td>
<td>0.85</td>
</tr>
<tr>
<td>Sleep quality - VAS</td>
<td>6.80</td>
<td>6.70</td>
<td>6.33</td>
<td>0.92</td>
</tr>
</tbody>
</table>
Phase-response curve for light

Waterhouse *et al.* *Neurosci Let* 1998; **245**: 97-100
Dawn simulation and 4-km time trial

<table>
<thead>
<tr>
<th>Condition</th>
<th>Time Taken (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>600</td>
</tr>
<tr>
<td>Dawn Simulation</td>
<td>350</td>
</tr>
</tbody>
</table>

**Individual Performances**

**Mean**
The circadian system

Body clock

Intergeniculate leaflet
Activity rhythm

Retino-Hypothalamic tract
Light rhythm

Melatonin

Pineal gland

Vision

Waterhouse et al., *Keeping in time with your body clock*, Oxford University Press
Synthesis of melatonin

Schematic cross-sectional diagram of the brain to show location of the pineal gland.
Secretion onset of melatonin prior to sleep

Thijssen et al. FASEB, In Press
## Dietary melatonin?

### Melatonin Content in Different Species

<table>
<thead>
<tr>
<th>Species</th>
<th>Tissue</th>
<th>Melatonin [ng/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(A) Edible plants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lycopersicon esculentum (tomato)</td>
<td>fruit</td>
<td>0.5</td>
</tr>
<tr>
<td>Raphanus sativus (red radish)</td>
<td>root tuber</td>
<td>0.6</td>
</tr>
<tr>
<td>Brassica campestris (Japanese radish)</td>
<td>stem, leaves</td>
<td>0.6</td>
</tr>
<tr>
<td>Brassica nigra (black mustard)</td>
<td>seed</td>
<td>129</td>
</tr>
<tr>
<td>Brassica hirta (white mustard)</td>
<td>seed</td>
<td>189</td>
</tr>
<tr>
<td>Prunus cerasus (tart cherry, Montmorency)</td>
<td>fruit</td>
<td>15–18</td>
</tr>
<tr>
<td>Prunus amygdalus (almond)</td>
<td>seed</td>
<td>39</td>
</tr>
<tr>
<td>Pimpinellia anisum (anise)</td>
<td>seed</td>
<td>7</td>
</tr>
<tr>
<td>Foeniculum vulgare (fennel)</td>
<td>seed</td>
<td>28</td>
</tr>
<tr>
<td>Helianthus annuus (sunflower)</td>
<td>seed</td>
<td>29</td>
</tr>
<tr>
<td>Oryza sativa (rice)</td>
<td>seed</td>
<td>1</td>
</tr>
<tr>
<td>Zea mays (Indian corn)</td>
<td>seed</td>
<td>1.3</td>
</tr>
<tr>
<td>Avena sativa (oat)</td>
<td>seed</td>
<td>1.8</td>
</tr>
<tr>
<td>Festuca arundinacea (tall fescue)</td>
<td>seed</td>
<td>15</td>
</tr>
<tr>
<td>Eletraria cardamomum (green cardamom)</td>
<td>seed</td>
<td>5</td>
</tr>
<tr>
<td>Zingiber officinalis (ginger)</td>
<td>tuber</td>
<td>0.5</td>
</tr>
<tr>
<td>Musa paradisiaca (banana)</td>
<td>fruit</td>
<td>0.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Species</th>
<th>Tissue</th>
<th>Melatonin [ng/g]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>(B) Officinal plants</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Melissa officinalis (balm mint)</td>
<td>young plant</td>
<td>16</td>
</tr>
<tr>
<td>Scutellaria baicalensis (huang-qin)</td>
<td>plant</td>
<td>&gt; 2,000 – &gt; 7,000</td>
</tr>
<tr>
<td>Pimpinella peregrina (-)</td>
<td>dried root</td>
<td>38</td>
</tr>
<tr>
<td>Hypericum perforatum (St. Johns wort)</td>
<td>leaf</td>
<td>1,750</td>
</tr>
<tr>
<td>Hypericum perforatum (St. Johns wort)</td>
<td>flower</td>
<td>&gt; 2,400 – &gt; 4,000</td>
</tr>
<tr>
<td>Lippia citriodora (lemon verbena)</td>
<td>young plant</td>
<td>22</td>
</tr>
<tr>
<td>Tanacetum parthenium (feverfew)</td>
<td>leaf (fresh/dried)</td>
<td>&gt; 1,300/7,000</td>
</tr>
</tbody>
</table>
# Tart Cherry and sleep quality

<table>
<thead>
<tr>
<th>Variable</th>
<th>Tart cherry trial</th>
<th>Placebo trial</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total sleep (min)</td>
<td>420.3 ± 67.2</td>
<td>398.2 ± 97.3</td>
<td>P = 0.232</td>
</tr>
<tr>
<td>Sleep efficiency (%)</td>
<td>79.0 ± 13.6</td>
<td>76.1 ± 20.1</td>
<td>P = 0.410</td>
</tr>
<tr>
<td>Sleep latency (min)</td>
<td>46.5 ± 59.5</td>
<td>39.5 ± 41.5</td>
<td>P = 0.567</td>
</tr>
<tr>
<td>Sleep bouts</td>
<td>31 ± 8</td>
<td>32 ± 9</td>
<td>P = 0.534</td>
</tr>
<tr>
<td>Wake bouts</td>
<td>31 ± 9</td>
<td>32 ± 9</td>
<td>P = 0.599</td>
</tr>
<tr>
<td>Mean sleep bout (sec)</td>
<td>893.7 ± 371.5</td>
<td>850.8 ± 506.0</td>
<td>P = 0.644</td>
</tr>
<tr>
<td>Mean wake bout (sec)</td>
<td>109.8 ± 65.3</td>
<td>175.8 ± 118.1</td>
<td>P = 0.119</td>
</tr>
</tbody>
</table>
Phase response curve for ingested melatonin

Circadian time (h)

Delay

Advance

Approx 4am
Melatonin acutely impairs alertness and performance

### Hypothermic effects of melatonin

#### Study name | Mean | Standard error | Variance | Lower limit | Upper limit | Z-Value | p-Value
--- | --- | --- | --- | --- | --- | --- | ---
5. Dawson et al. 1996 | 0.155 | 0.025 | 0.001 | 0.106 | 0.204 | 6.175 | 0.000
6. Dawson et al. 1996 | 0.175 | 0.025 | 0.001 | 0.126 | 0.224 | 6.971 | 0.000
7. Dawson et al. 1996 | 0.225 | 0.025 | 0.001 | 0.176 | 0.274 | 8.963 | 0.000
8. Dawson et al. 1996 | 0.300 | 0.025 | 0.001 | 0.251 | 0.349 | 11.951 | 0.000
9. Deacon & Arendt 1994 | 0.260 | 0.067 | 0.005 | 0.128 | 0.392 | 3.870 | 0.000
10. Deacon & Arendt 1995 | 0.180 | 0.030 | 0.001 | 0.121 | 0.239 | 5.958 | 0.000
11. Deacon & Arendt 1995 | 0.300 | 0.030 | 0.001 | 0.241 | 0.359 | 9.930 | 0.000
12. Deacon & Arendt 1995 | 0.300 | 0.030 | 0.001 | 0.291 | 0.409 | 11.585 | 0.000
17. Gilbert et al. 1999 | 0.170 | 0.020 | 0.000 | 0.131 | 0.209 | 8.542 | 0.000
21. Krauchi et al. 1997 | 0.135 | 0.050 | 0.003 | 0.037 | 0.233 | 2.689 | 0.007
22. McLellan et al. 1999 | 0.100 | 0.047 | 0.002 | 0.007 | 0.193 | 2.113 | 0.035
23. McLellan et al. 1999 | 0.050 | 0.047 | 0.002 | -0.043 | 0.143 | 1.056 | 0.291
24. McLellan et al. 2000 | 0.100 | 0.054 | 0.003 | -0.005 | 0.205 | 1.863 | 0.062
25. Reid et al. 1996 | 0.310 | 0.050 | 0.003 | 0.212 | 0.408 | 6.200 | 0.000
26. Satoh & Mishima 2000.1 | 0.058 | 0.058 | 0.003 | 0.086 | 0.314 | 3.450 | 0.001
27. Satoh & Mishima 2000.2 | 0.058 | 0.058 | 0.003 | 0.126 | 0.354 | 4.140 | 0.000
28. Satoh & Mishima 2000.3 | 0.058 | 0.058 | 0.003 | 0.086 | 0.314 | 3.450 | 0.001
21. Van Den Heuvel et al. 1999 | 0.030 | 0.030 | 0.001 | 0.051 | 0.169 | 3.660 | 0.000
22. Van Den Heuvel et al. 1999 | 0.040 | 0.040 | 0.002 | 0.082 | 0.238 | 4.005 | 0.000
23. Van Den Heuvel et al. 1999 | 0.040 | 0.040 | 0.002 | 0.102 | 0.258 | 4.505 | 0.000

### Mean and 95% CI

- **Mean**: 0.201
- **Standard error**: 0.008
- **Variance**: 0.000
- **Lower limit**: 0.187
- **Upper limit**: 0.216
- **Z-Value**: 26.763
- **p-Value**: 0.000

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**Marrin et al. In preparation**
Endurance exercise and thermoregulation: pre-cooling methods

Air temperature and humidity

Convection

Radiation

Sky thermal radiation

Respiratory evaporation

Blood flow to the skin

Metabolic heat production

Sweat evaporation

Conduction

Thermal radiation from the ground

Solar radiation

Reflected solar radiation
How can chronobiology help the swimmer?

• Circadian rhythms relevant to swimming
• Can we ‘cure’ circadian variation?
  – Warm-ups?
  – Bright light?
  – Melatonin?
• Can we ‘cure’ jet-lag?
  – US Soccer study
RANDOMISED CONTROLLED TRIAL OF A BRIGHT LIGHT INTERVENTION FOR REDUCING SYMPTOMS OF JET-LAG IN WORLD-CLASS FEMALE SOCCER PLAYERS: A PILOT STUDY

A. Thompson¹, A. M. Batterham², H. Jones¹, W. Gregson¹, D. Scott³ and G. Atkinson²

¹Research Institute for Sport and Exercise Sciences, Liverpool John Moores University, Liverpool, UK

²Health and Social Care Institute, Teesside University, Middlesbrough, UK

³US Soccer Federation, Chicago, USA
Summary

• Good evidence for endogenous circadian variation in swimming performance

• Variation not completely ameliorated by warm-up interventions – caffeine?

• Timing of circadian rhythm might be manipulated by careful timing of reliable and safe synchronisers to circadian system
  – Bright light
  – Exercise
  – Dietary melatonin?
Recommendations for optimizing morning performance

• It seems sensible to be exposed to bright light and take some exercise in the morning during the taper phase ............

• Minimal exposure to **evening** bright light and exercise in taper phase

• Experimentation:
  – Sleep deprivation (prior evening heats + early waking)?
  – Timing of pre-race meals?
  – Individual differences (chronotype)?
  – Melatonin in afternoon?
Is the circadian variation robust?

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day 1 a.m.</th>
<th>Day 1 p.m.</th>
<th>Day 2 a.m.</th>
<th>Day 2 p.m.</th>
<th>Day 3 a.m.</th>
<th>Day 3 p.m.</th>
<th>Inter-daily variation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance (s)</td>
<td>84.4 (6.2)</td>
<td>83.8 (6.2)</td>
<td>84.2 (6.1)</td>
<td>84.1 (6.1)</td>
<td>84.2 (6.2)</td>
<td>84.3 (6.2)</td>
<td>*÷ 1.00</td>
</tr>
<tr>
<td>S.R. strokes · min⁻¹</td>
<td>28.4 (3.9)</td>
<td>27.9 (3.9)</td>
<td>29.4 (4.2)</td>
<td>28.6 (3.8)</td>
<td>28.8 (4.3)</td>
<td>28.3 (3.9)</td>
<td>*÷ 1.13</td>
</tr>
<tr>
<td>Heart rate (b · min⁻¹)</td>
<td>164 (9)</td>
<td>164 (8)</td>
<td>161 (10)</td>
<td>162 (8)</td>
<td>168 (7)</td>
<td>165 (6)</td>
<td>*÷ 1.03</td>
</tr>
<tr>
<td>RPE</td>
<td>13 (0)</td>
<td>11 (1)*a</td>
<td>12 (0)</td>
<td>12 (0)</td>
<td>13 (1)</td>
<td>11 (0)*a</td>
<td>*÷ 1.22</td>
</tr>
<tr>
<td>VE (l · min⁻¹)</td>
<td>81.2 (32.4)</td>
<td>79.0 (28.0)</td>
<td>77.1 (32.8)</td>
<td>80.9 (33.4)</td>
<td>84.6 (30.9)</td>
<td>82.1 (23.2)</td>
<td>*÷ 1.45</td>
</tr>
<tr>
<td>VO₂ (l · min⁻¹)</td>
<td>3.18 (0.50)</td>
<td>3.42 (0.63)</td>
<td>3.24 (0.69)</td>
<td>3.55 (0.60)</td>
<td>3.52 (0.57)</td>
<td>3.43 (0.32)</td>
<td>*÷ 1.34</td>
</tr>
<tr>
<td>VCO₂ (l · min⁻¹)</td>
<td>3.16 (0.68)</td>
<td>2.80 (1.15)*a</td>
<td>3.22 (0.95)</td>
<td>3.52 (0.84)</td>
<td>3.57 (0.88)</td>
<td>3.48 (0.62)</td>
<td>*÷ 2.77</td>
</tr>
<tr>
<td>RER</td>
<td>0.99 (0.12)</td>
<td>0.99 (0.11)</td>
<td>0.99 (0.10)</td>
<td>0.99 (0.10)</td>
<td>0.98 (0.15)</td>
<td>1.01 (0.13)</td>
<td>*÷ 1.14</td>
</tr>
<tr>
<td>Temperature (°C)</td>
<td>36.7 (0.4)</td>
<td>37.0 (0.2)</td>
<td>36.6 (0.2)</td>
<td>37.0 (0.2)*ar</td>
<td>36.5 (0.3)</td>
<td>37.1 (0.3)*ar</td>
<td>*÷ 1.02</td>
</tr>
<tr>
<td>Lactate (mM)</td>
<td>6.3 (2.5)</td>
<td>6.0 (1.5)</td>
<td>5.3 (1.8)</td>
<td>4.9 (1.0)</td>
<td>5.6 (1.3)</td>
<td>5.4 (1.7)</td>
<td>*÷ 1.62</td>
</tr>
<tr>
<td>Glucose (mM)</td>
<td>7.0 (1.3)</td>
<td>6.3 (0.6)</td>
<td>7.1 (1.8)</td>
<td>6.1 (1.7)*ar</td>
<td>7.0 (1.6)</td>
<td>6.2 (1.8)*a</td>
<td>*÷ 1.16</td>
</tr>
</tbody>
</table>

* significant difference between morning and evening trials (P<0.05), a= absolute data, r= relative data

Synchronisers of the human circadian system
Measuring endogenous component: 2. Temporal isolation

“Mammoth Cave”, Kentucky

Temporal Isolation Lab, Liverpool
Swim bench performance

Is the circadian variation resistant to change?

THE EXTRAORDINARY NEW YORK TIMES BESTSELLER

THE MELATONIN MIRACLE

Nature’s Age-Reversing, Disease-Fighting, Sex-Enhancing Hormone

Based on the Authors’ Groundbreaking Research
Published by The National Academy of Science

Walter Pierpaoli, M.D., Ph.D.,
and William Regelson, M.D.,
with Carol Colman

SHERWYN’S HEALTH FOOD SHOP

YES WE HAVE MELATONIN!

Allstate

Street scene with people walking and a sign that says "SHERWYN'S HEALTH FOOD SHOP YES WE HAVE MELATONIN!"
Effects of daytime ingestion of melatonin on short-term athletic performance

G. ATKINSON*, H. JONES, B. J. EDWARDS, and J. M. WATERHOUSE

Research Institute for Sport and Exercise Science, Liverpool John Moores University, 15–21 Webster Street, Liverpool L3 2ET, UK
Effects of melatonin on choice reaction time

Effects of melatonin on 4-km cycling performance

Melatonin is not an ergogenic aid when ingested immediately before short-term performance and may in fact hinder performance.

But..........................
Pre-cooling and prolonged exercise performance

Drust et al., *Eur J Appl Physiol* 2000;81:11-17
Effects of melatonin on the thermoregulatory responses to intermittent exercise

Abstract: We examined the effects of a single 2.5-mg dose of melatonin on the thermoregulatory and circulatory responses to intermittent exercise at a room temperature of 27.2 ± 0.4°C (mean ± S.D.), a relative humidity of 55 ± 3% (mean ± S.D.), and a light intensity of 200–300 lux. In a double-blind cross-over study, six male participants ingested either melatonin or placebo at 11:45 hr. Participants then rested in a semi-supine position for 75 min and completed an intermittent running protocol for 66 min at alternating intensities of 40, 60 and 80% of maximal oxygen uptake. Rectal and mean skin temperature, heart rate, blood pressure, skin blood flow, subjective alertness and sleepiness, ratings of perceived exertion (RPE) and thermal strain were recorded. No effects of melatonin were found on these variables measured during the resting period ($P > 0.10$). During exercise, melatonin was found to moderate the increase in rectal temperature by approximately 0.25°C ($P = 0.050$) and magnify the increase in skin blood flow ($P = 0.047$). Postexercise systolic blood pressure was 7.8 ± 2.5 mmHg (mean ± S.D.) lower than before the exercise in the melatonin trial and...
Dependent variables

- Rectal temperature
- Mean skin temperature
- Heart rate
- Blood pressure
- Blood flow
- Perceived exertion and alertness

Effects of melatonin on core temperature during exercise

Effects of melatonin on skin blood flow during exercise

Summary

• We have a body clock which controls circadian rhythms
• Light alters the timing of the body clock depending on the time it is administered
• Evening light can delay the morning rise in body temperature – useful for pre-cooling?
• Light may be useful for alleviating jet-lag (timing crucial)
• Melatonin can also alter circadian timing and can help sleep in some individuals
• Immediate hypnotic effects of exercise may hinder short-term performances
• Hypothermic effects of exercise may be useful for ‘pre-cooling’ athletes
Melatonin and exercise metabolism

Melatonin and exercise metabolism

Melatonin alters the growth hormone response to exercise

Meeking et al., Eur J Endocrin 1999;141:22-26
Melatonin alters immune response to exercise

Melatonin is an anti-oxidant

Reiter et al., Life Sci 1997;60:2255-2271
Pinealectomy leads to altered exercise response

Measuring endogenous component: Constant routines

Edwards et al., *Chronobiol Int* 2002; 19: 579-597
Measuring endogenous component: Constant routines

Edwards et al., Chronobiol Int 2002; 19: 579-597
Circadian Rhythm in Melatonin

Arendt, (2005)
Circadian Rhythm in Body Temperature

![Graph showing circadian rhythm in body temperature]

Bright Light Therapy

Bright light therapy can:

Reduce depression scores in SAD patients (Terman, 1990).

Delay the body clock when delivered before temperature nadir

Advance the body clock when delivered after temperature nadir (Minors et al., 1991).

Improve cognitive performance (Phipps-Nelson et al., 2003).
Method

- 5 physically active subjects (4 M, 1F) (24 ± 7 years) classed as late chronotypes.
- 2 conditions (with or without dawn simulation).
- Set sleep and wake-up times to allow 8 h of prior sleep.
- Dawn simulation initiated 30 min prior to awakening (0.001 – 300 lux).
- 3 cognitive tests at 15, 30 and 75 min post-waking.
- 4 km self-paced cycling time trial at 60 min post-waking.
Measured Outcomes

• Salivary melatonin (60 min and 5 min before sleep & 0, 15, 30, 45, 60 & 75 min after awakening).
• Core body temperature (intestinal).
• Skin Temperature (iButtons).
• KSS scores at 1, 5, 15, 30, 45, 60, and 75 min.
• Cognitive testing – Responses, correct and mean reaction time.
• 4 km time trial – Time, RPE, Watts.
• Data analysed with two factor repeated measures general linear models. Paired t-tests.
Results – Cognitive Performance

- Total Additions – Work Preference Series
  - Control
  - Dawn Simulation

- Mean Reaction Time (sec) – Determination Unit Test
  - Cognitive Testing Session
  - Control
  - Dawn Simulation
Results – Core Body Temperature

Core Body Temperature (°C)

Stage of Testing

- Control
- Dawn Simulation

1.5h Pre, 1h Pre, 30 min Pre, 20 min Pre, 10 min Pre, Waking, 5 min Post, 15 min Post, 30 min Post, Post TT, 60 min Post, 75 Post
The underlying circadian system
Dawn simulation

Control
Dawn Sim

Time point:
- 1hr Pre-sleep
- Pre-sleep
- Waking
- 15 min Post
- 30 min Post
- Post TT
- 60 min Post
- 75 min Post

Melatonin (pg.ml\(^{-1}\))

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