Chronobiological Consequences of Long Haul Flights, Travel Fatigue, and Jet Lag

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Travel fatigue is associated with long haul flights, and jet lag is experienced when flights entail transmeridian travel. Symptoms are linked with disturbance of the body’s circadian rhythms. Exercise performance may be affected until the body clock is adjusted to the new time zone. Methods of speeding up the adjustment include pharmacological and behavioral methods. Emphasis is placed on behavioral strategies and appropriate use of exposure to light. Care is needed in the timing of exercise training, particularly having traveled eastwards. A holistic strategy incorporates planning for the journey, for the flight itself, and for the days immediately following.

Key Words: biological rhythms, body clock, exercise performance, time zones

Nowadays sports participants travel across the world on a regular basis for purposes of training or competing. For example, for the great majority of participants in the Sydney 2000 Olympic Games and their medical support staff, it will be necessary to travel to Sydney by plane. This presents two common problems. The first, "travel fatigue," arises because of the difficulties associated with undertaking a long journey and adapting one's lifestyle to it. The second, which affects those who travel long distances in a westerly or easterly direction, is "jet lag." Both can be debilitating and, at the very least, distract the athlete from the Games themselves. The subjective consequences of travel should be rectified, irrespective of whether these are effects on actual sports performance (which can never realistically be measured).

This article aims to explain the nature and causes of these two problems and to offer advice about how to reduce their negative effects.

Travel Fatigue

Travel fatigue is caused in part by the worry associated with preparations for the flights, the flights themselves, and becoming attuned to the new environment. Major fatigue factors during flight include (i) boredom with the long journey, (ii) prolonged period in a cramped posture, (iii) sleep deprivation, and (iv) exposure to dry cabin air. (Some also need to deal with climatological changes, but this concern is beyond the scope of the present article.)

Before the Flight to Sydney

Preparations for the flight generally take place weeks or even months before the journey itself. They include (i) ensuring passport validity, (ii) meeting any visa requirements, (iii) seeking out and acting upon any health advice (including required inoculations), and (iv) securing sufficient funds for the trip. Medical personnel should survey health risks associated with the country of destination, including quality air and water, and the variety and quality of food. Many of these preparations can be made well in advance to avoid last-minute delays.

Part of these preparations include arranging the flight or flights, and it is here that choices often have to be made. These include (i) whether or not there should be a stopover en route and, if so, how long it should last; (ii) whether to fly by day or by night (though, with long distances and transitions across several time zones, the meaning of "night" and "day" can change during the course of the flight). For the Olympic competitors, these choices depend in part on how the individual plans to adjust to local time in Australia,
Whether in Sydney itself or in a training camp environment within the country, the appropriate choice of strategy can only be made after considering "jet lag" (see below).

**During the Flight to Sydney**

During the flight itself, there are several problems associated with the actual cabin environment. The cabin is a cramped area. During a long flight, there is very limited opportunity for movement, let alone exercise. Being immobile for extended periods increases the risk of developing muscle cramp and even deep-vein thrombosis. Such conditions have been linked with air travel of longer than 4 hours. The median post-flight period for incurring venous thromboembolism is 4 days (4). Passengers are advised to walk around the cabin and to perform stretching exercises when possible. In addition, or alternatively, isometric exercises in the seat can do much to boost a sluggish circulation.

Because the cabin air is very dry; a further problem can arise when lips become sore and the passenger develops general dehydration. Sore lips can be guarded against with lip salve, and dehydration can be prevented by increasing fluid intake. However, alcoholic drinks, which act as diuretics, and even tea, which promotes sweating, are not ideal, since they tend to cause further dehydration. Spring water, soft drinks, and fruit juices are more suitable for maintaining hydration. This can be calculated from principles of dry respiratory heat loss. Fluid loss could amount to 400 ml during a flight from Europe or South Africa to Australia. In rehydrating to replace this amount, an additional 200 ml should be included to account for urine production.

There is always a problem of what to do on a long flight, and many travelers "solve" this problem by sleeping or napping throughout the flight. This is not the best solution if the journey is across several time zones, as is likely to be the case for the Sydney Olympian athletes. Naps or sleep should take place at times coincident with night in Sydney rather than with night on "home" time. If it is daytime in Sydney, therefore, attempt to stay awake by playing cards or make use of the in-flight entertainment. A good piece of advice is to leave behind "home time" upon boarding the plane; instead, use the destination time to determine when things should be done. If there is a brief stopover en route, a sensible strategy is to alter one's watch to the local time in this intermediate destination and then, on re-embarking, change it again to be in line with the final destination.

**Arrival in Sydney**

Upon arrival in Sydney, there remains the problems of collecting baggage, clearing customs and finding transport to the final destination. These matters take time and can cause aggravation, particularly if there are problems resulting in delays. The best advice in this situation is to keep calm. When the final destination is reached, the natural tendency is to sleep because of fatigue. This is a good idea if it is night on Sydney time, but this is often not the case. If it is morning, then a nap of 1–2 hours may be recuperative and could be followed by an invigorating shower. A nap in the afternoon is not advised because it would operate against a phase advance of the body clock, making sleeping more difficult when it comes to nighttime.

If local time differs from home time by only up to 2–3 hours (e.g. athletes traveling from Singapore or Malaysia to the east coast of Australia), then there should not be a problem in staying awake until bedtime (Sydney time) and then getting a refreshing night's sleep. This will ensure that by the next day, the effects of travel fatigue will have worn off, and the athlete can concentrate on the preparation for the competition itself. This time difference will apply often to those teams who have flown first to the Far East and allowed themselves time to adjust to this time zone. They may even have been able to participate in competitions. By contrast, if there has been a time-zone transition of 4 or more hours, particularly if it is in excess of 8 hours, then a full sleep during the night on Sydney time will not be possible. The athlete will then begin the next day feeling unrefreshed and unable to train as effectively as he/she had hoped. This is one of the symptoms of "jet lag."
Jet Lag

This is the term commonly applied to an assemblage of symptoms that includes:

- feeling tired in the daytime (by new local time), and yet being unable to sleep at night;
- feeling less able to concentrate or to motivate oneself for training;
- increased incidence of headaches and irritability;
- loss of appetite and general bowel irregularities.

These symptoms are not necessarily all experienced to the same extent by all individuals. They tend to be more intense as the number of time zones crossed increases, and after time zone transitions to the east rather than to the west. In addition to these subjective symptoms, there is objective evidence that mental and physical performance deteriorate, and that sleep is shorter and more fractionated than normal. Studies upon athletes and sportspersons indicate that they too give poorer performances, with a loss of motivation and an increase in perceived effort during training sessions (5).

The symptoms are, however, transient and, as a rule, last about one day per time zone crossed; it is only when the symptoms have abated fully that the athlete’s performance—both in training and competition—returns to its peak. Until jet lag has disappeared completely, individuals are advised to reduce the severity of their training schedules, and both they and the coaches should not be surprised by what appears to be under-achievement. The extent to which performance might be affected depends on the nature of the sport.

The problems encountered cannot be attributed to differences in climate or culture between Australia and the individual’s home country; as they are likely to be of a similar severity for Africans, Europeans, North Americans and South Americans. However, they are likely to be similar but less severe for New Zealanders, Japanese and travelers from the Philippines. For the latter, they are due rather to a body clock that is slow to adjust to the new time zone. To understand how this accounts for the difficulties described above, it is necessary to discuss the role normally played by the body clock, its position in the body, and some of its properties. (For more about the physiology of jet lag, see Appendix A.)

Summary

Some of the main points to bear in mind are:

**Flight Schedule.** If arrival time is in the morning or early afternoon, then a nap on arrival is acceptable, but it must not be too long. If arrival is in the late afternoon or evening, then the desire to sleep should be resisted until bedtime in the new time zone.

**General Strategy.** According to the number of time zones crossed, a decision must be taken as to whether an advance or delay of the body clock is to be promoted. In those cases where the flight is eastward through 9–11 time zones, this decision will be influenced by the exposure to natural light that is likely to occur as a result of the flight schedule. Once this decision has been taken, then stick to it.

**Sleep and Training.** Minimize the use of drugs for promoting the new schedule of sleep and activity try to adjust behavioraly. For the first few days after the flight, avoid heavy training sessions, particularly early in the morning.

References


Appendix A: The Physiology of Jet Lag

The Rhythmic Body

In the body there are daily changes in core temperature, with higher values in the daytime and lower values at night. Similarly timed rhythms are found in many other variables, including heart rate and mental performance, and in many components of muscular performance. By contrast, for many hormones—melatonin, for instance—the observed rhythm is the inverse, with nocturnal concentrations being higher than those in the daytime. In addition, the perceived exertion associated with mental or physical tasks is higher at night. That is, the athlete is better able to perform in the daytime than at night (7).

These results might indicate that the body is responding to all the rhythms in the environment of a day-orientated society, with opportunity at night for sleep and recuperation. Such an explanation is only partially correct, however, as can be deduced from studies of an individual during a "constant routine." Here the subject is required: (i) to stay awake and be sedentary for at least 24 hours in an environment of constant temperature, humidity, and lighting; and (ii) to engage in similar activities throughout (generally reading or listening to music), and to take identical meals at regularly-spaced intervals. Under such conditions, any rhythmicity due to the environment and lifestyle has been removed, and yet the rhythm of core temperature (and other variables that have been studied) is still present, even though its amplitude is decreased (Figure 1). Three deductions can be made from this result:

1. The rhythm that remains must arise within the body. It is described as an endogenous rhythm, and its generation is attributed to some form of "body clock."

Figure 1 — Mean circadian changes in rectal temperature measured hourly in 8 subjects living a normal existence (full line), and in the same subjects given a constant routine of being woken at 04:00 and spending the subsequent 24 hr awake in a constant light and taking hourly small identical snacks (dashed line; based on ref. 7).
2. Some effect of the environment and lifestyle is present, as can be deduced from the finding that the two temperature curves differ. This component of the rhythm is termed "exogenous." For body temperature, it is raised by light, and mental and physical activities during daytime waking, and is decreased by darkness, sleep and inactivity during the night.

3. In subjects living a conventional lifestyle, these two components are in phase. During the daytime, the body temperature is raised by the body clock, acting in synchrony with the environment and lifestyle. During the night, the clock, environment and lifestyle all act to reduce core temperature.

The Site of the Body Clock and Some of Its Properties

Humans have paired nuclei in the base of the hypothalamus, the suprachiasmatic nuclei (SCN) i.e. the site of the body clock in mammals. Thus, slices of brain containing the SCN show rhythmicity in neuronal firing rates and in neurotransmitter release when the slices are cultured in vitro in constant conditions. No other region of the brain shows autonomous activity in such circumstances. The findings of recent studies in genetics and molecular biology have produced a fairly complete picture about how this region of the brain produces this rhythmicity.

When individuals are studied in an environment where there are no time cues—in an underground cave, for example—rhythms continue. This confirms their endogenous origins, but the period of such rhythms is closer to 25 than 24 hours. For this reason, the rhythms are called circadian ("about a day").

Adjustment of the Body Clock

Such circadian rhythmicity implies that the body clock needs to be continually adjusted for it to remain synchronized to a solar (i.e. 24-h) day. Synchrony is achieved by "zeitgebers" (German for "time-giver"), rhythms resulting, directly or indirectly, from the environment. In different mammals, rhythms of the light/dark cycle, of food availability/unavailability, of activity/inactivity, and of social influences, act singly or in combination. In humans, the position is not yet fully resolved, but some combination of these "zeitgebers" is normally present.

Light

Important among possible "zeitgebers" in humans is the light/dark cycle. The effect of light depends on the time at which it is presented. Originally, it was shown that: (i) pulses of bright light (that is, light of an intensity found outdoors rather than domestically) that are centered in the 6-h "window" immediately after the trough of the body temperature rhythm (the trough normally being 03h00-05h00) produce a phase advance; (ii) pulses centered in a window 6 h before the temperature minimum produce a phase delay; and (iii) those centered away from the trough by more than a few hours have little effect. More recent work has shown that light pulses that are weaker (and similar in intensity to domestic lighting) also affect the clock and can produce smaller phase shifts (1; 9). This is important since most humans have very little exposure to natural daylight.

Melatonin

Melatonin ingestion has been shown to adjust the phase of the body clock (3). Again, according to the time of ingestion, it can phase advance, phase delay or have no effect upon the body clock. The results are the inverse of the effects of light, and so ingesting melatonin in the afternoon and evening tends to advance the body clock, while ingestion in the morning tends to delay it. The mechanism by which this is achieved is unknown, but receptors for melatonin are present in the SCN. Also, light inhibits melatonin secretion, the amount of inhibition being dependent on light intensity, and this makes their phase-shifting effects on the body clock reinforce each other. Thus, bright light in the early morning, just after the temperature minimum, advances the phase of the body clock directly. It is also effective indirectly as it suppresses melatonin secretion and so prevents the phase-delays effect that melatonin would have exerted at this time.
Meals
Other "zeitgebers" have been proposed to act in humans, such as feeding-fasting and physical activity-inactivity cycles. The "feeding hypothesis" proposes that a high-protein breakfast raises plasma-tyrosine levels, and that this promotes the synthesis and release of noradrenaline and dopamine, which would activate the body's arousal system. It is also proposed that a high-carbohydrate evening meal raises plasma-tryptophan levels, thereby promoting the synthesis and release of serotonin, a neurotransmitter with an important role in sleep regulation and a precursor of melatonin. According to this hypothesis, adjustment of the body clock to a new time zone would be promoted by the appropriate timing and composition of meals. This hypothesis has not yet been tested satisfactorily in humans. Those tests that have been carried out suggest that any effect is small.

Physical Activity
If hamsters act as models for humans, then physical activity should promote adjustment of the body clock, the effect appearing to depend upon the amount of "excitement" caused rather than, say, the temperature or metabolic changes produced. Results with humans have not yet proved conclusive, though whether this is because such a mechanism is inoperative in humans, the amount of activity needs to be greater than has been used in studies so far, or subjects are not sufficiently "excited" by exercise remains to be established.

When light acts as a "zeitgeber", it is believed that the information passes directly to the SCN via a direct pathway, the retinohypothalamic tract. Even though it is still being actively researched, it seems that the retina contains a subgroup of receptors whose visual pigment is based on Vitamin B2 rather than the more conventional Vitamin A-based options. Another input pathway to the SCN is via the intergeniculate leaflet and is probably important for non-photic (activity) "zeitgeber inputs in hamsters; it is not yet established how important this pathway is in humans. As described above, receptors for the hormone melatonin have been found in the SCN, and this might enable melatonin to act as an "internal zeitgeber".

The Role of the Body Clock
Humans are diurnal creatures, not only by virtue of their responses to the environment but also because of the drive imparted to the whole body by the body clock. The body clock achieves this by producing daily rhythms in core temperature, plasma-hormone concentrations, the outflow of the sympathetic nervous system and the sleep centers of the brain, all of which exert effects throughout the body.

The effect of the clock is twofold. First, it enables the "ergotropic" actions of the body (those involving physical and mental activity and their associated biochemical and cardiovascular changes - the functions which are so vital to athletes) to be promoted in the daytime, and for the "trophotropic" actions (those involving recovery and restitution during a period of inactivity) to be promoted at night. The second role is to enable preparations to be made for the switches from the active to the sleeping phase, and vice versa. Individuals have to prepare for going to sleep and for waking up. Such profound neurophysiological changes cannot be brought about rapidly, but require instead an ordered reduction or increase in activity of a whole series of biochemical and physiological functions - and this takes time.

The need for "zeitgebers" is not merely to overcome the limitations of an "inaccurate" body clock. They also enable the body to be in synchrony with an environment where the rhythms, except near the equator, change with the passage of the year.

Fundamental to achieving these roles is the need for a robust clock, that is, one where the timing is slow to respond. For example, a clock that rapidly adjusted to changes would compromise the phasing of the circadian rhythms of an animal during an eclipse, or of an individual who woke transiently in the night or took a nap (or hid in a dark place) in the daytime. The observation that the body clock is slow to adjust to changes in lifestyle makes sound ecological sense, therefore. But such an intransigence becomes the bane of those who have to work at night or undergo timezone transitions since, before adjustment of the body clock to the changed sleep-wake pattern or local time has taken place, the normal synchrony between the endogenous and exogenous components of the circadian rhythms will be lost. In other words, these individuals will suffer a whole series of negative subjective and objective effects, known respectively as "shift workers' malaise" and "jet lag."
Prevention of Jet Lag

The main aim, certainly in the longer term, must be to attempt to promote adjustment of the body clock to the new time zone. Several methods have been suggested, differing in their practicality, the scientific evidence in support of them, and in potential side effects. They include nutritional, environmental, and behavioral measures. In effect, they amount to strengthening the "zeitgebers" that normally adjust the body clock. Attention here will be directed to the two methods that seem to be most effective, namely melatonin and bright light.

When attempting to promote adjustment of the body clock, it is essential to understand that this process can take place by advancing or delaying the body clock, and that each alternative requires a different timing of treatment. For timezone transitions of up to 8 h to the east (in practice, journeys to Sydney from eastern Europe and places to the east of this area), a phase advance of the body clock should be promoted; and for timezone transitions to the west (journeys from South America and the USA), a phase delay. For journeys to the east through 9 or more time zones (western Europe and much of Africa), the position is more complex since adjustment could be by advance or delay; in practice, delaying the phase of the body clock is probably easier, but this issue will have to be referred to again below.

Bearing in mind the disturbance of the body's circadian rhythms following rapid travel across time zones, and accepting that performance and motivation to train will be decreased for some days after arrival, athletes will find that the following advice is the best currently available for reducing these disruptions to a minimum.

**Hypnosis**

Initially, and even during the flight(s), one possibility is to use sleeping pills, since a disturbance of sleep will be one of the most unwanted corollaries of jet lag. Sports teams travelling on long haul flights have used sleeping pills to induce sleep while on board. Minor tranquilizers, such as temazepam and Zolpiden and other members of the diazepine group, have been employed to help get travelers to sleep in order to be refreshed for immediate activities on arrival. Although they achieve this aim, the drugs do not guarantee a prolonged period asleep, nor have they always been satisfactorily tested for subsequent residual effects on sports skills. It is important to realize that they might be counter-productive if given at the incorrect time. A prolonged sleep at the time an individual feels drowsy, presumably when he/she would have been asleep in the time zone from which they had just departed, anchors the rhythms to this time zone, and so operates against any adjustment to the new time zone. The use of melatonin as a hypnotic will be discussed separately below.

**Stimulants**

The effect of loss of sleep is mainly a negative one upon mood and mental performance, with physical tasks appearing to be comparatively immune. Nevertheless, physical performances in training are impaired the longer the session continues (6). An alternative or additional approach towards combating the effects of sleep loss is to use drugs that promote and maintain alertness. Such drugs include amphetamines, caffeine, Modafinil (an ?-adrenoceptor antagonist) and Pemocline (with dopamine-like properties). Although these drugs improve performance in several tasks, they adversely affect the ability to initiate and sustain sleep, and so they could be counter-productive. Also, as with sleeping pills, their effects on physical performance relevant to sport have not been adequately addressed. Also, their use could contravene sport doping regulations.

**Melatonin**

In normal circumstances, melatonin from the pineal gland is secreted into the bloodstream between about 21h00 and 07h00, and can be regarded as a "dark pulse" or "internal zeitgeber" for the body clock. Melatonin capsules taken in the evening by local time in the new time zone reduce the symptoms of "jet lag", the effect having been confirmed in both sexes, after flights in both directions, and at whatever time the flight itself takes place (2). Even so, there are some caveats to the general advisability of taking melatonin:
1. "Jet lag", as defined in these studies, has concentrated on one global subjective scale and on the ability to sleep. It is not known, however, if there are comparable improvements in mental and physical performance, and in the motivation to train hard.

2. In the above experiments, it has not been established if melatonin produced its effect by promoting adjustment of the body clock or by some other means, increasing the ability to sleep, for example. Melatonin has a hypnotic action when it is administered in the daytime as well as in the evening, and this effect might be mediated by its lowering effect on body temperature. Taking melatonin in the evening on the new local time could, by means of its hypnotic action, help to induce sleep and thus reduce the amount of jet lag.

However, recent work (3) indicates that melatonin can also adjust the body clock, ingestion about 3h before to 6h after the temperature minimum causing a phase delay, and about 6-15 h before this minimum, a phase advance. This implies that, on the day of arrival in Sydney, when the body clock is still on "home time", taking melatonin at 20:00 h will promote a phase advance after flights to the west through 1 or 2 time zones and to the east through up to 7 time zones. Conversely, it will promote a phase delay after flights to the east through 10 or more time zones, and flights to the west of 5 or more time zones. Data have not been published to indicate if such phase shifts have taken place after this treatment with melatonin, and the issue awaits resolution.

Melatonin is only just becoming commercially available (largely in the United States), and the results from clinical trials are still awaited.

In summary, more information is required before melatonin can be recommended unreservedly, and the Position Statement of the British Olympic Association was guarded about its use (8). A less conservative approach would be to advise that, in those cases where athletes have taken melatonin on previous occasions, and have found it to be beneficial and have suffered no adverse side-effects, there is, currently, no evidence against using it again.

**Bright Light Exposure**

Bright light can adjust the body clock, but the timing of the exposure to light is critical (7). Bright light in a 6-h "window" before the temperature minimum delays the body clock, and in a 6-h window after this minimum, advances it. In addition, light should be avoided at those times that produce a shift of the body clock in a direction opposite to that desired. Table 1 gives times when light should be sought or avoided on the first day after different time zone transitions. After a couple of days, when partial adjustment of the body clock has occurred, it is then advisable to alter the timings of light exposure and avoidance toward the local light/dark cycle, so that the visitor's habits become synchronized with those of the locals.

**Table 1 The Use of Bright Light to Adjust the Body Clock After Time Zone Transitions**

<table>
<thead>
<tr>
<th>Time variable</th>
<th>Bad local times for exposure to bright light</th>
<th>Good local times for exposure to bright light</th>
</tr>
</thead>
<tbody>
<tr>
<td>Times zones to the west</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 hr</td>
<td>01:00–07:00⁰</td>
<td>17:00–23:00⁰</td>
</tr>
<tr>
<td>8 hr</td>
<td>21:00–03:00⁰</td>
<td>13:00–19:00⁰</td>
</tr>
<tr>
<td>12 hr</td>
<td>17:00–23:00⁰</td>
<td>09:00–15:00⁰</td>
</tr>
<tr>
<td>Times zones to the east</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 hr</td>
<td>01:00–07:00⁰</td>
<td>09:00–15:00⁰</td>
</tr>
<tr>
<td>8 hr</td>
<td>05:00–11:00⁰</td>
<td>13:00–19:00⁰</td>
</tr>
<tr>
<td>10–12 hr</td>
<td></td>
<td>Treat this as 12–14 hr to the west</td>
</tr>
</tbody>
</table>

*This will advance the body clock.

⁰This will delay the body clock.

*This is because the body clock adjusts to large delays more easily than to large advances.

Adjusting as fully as possible to the lifestyle and habits in the new zone would seem intuitively to be the best remedy. Consider, for example, a westward flight through 8 time zones. To delay the clock requires exposure to bright light at 21:00-03:00 h body time and avoidance of it at 05:00-11:00 h body time. By new local time (see Table 1), this becomes equal to 13:00-19:00 h for bright light exposure and 21:00-03:00 h for bright light avoidance (staying indoors in dim light). Natural daylight and night would provide this. In other words, "When in Rome, do as the Romans do". However, such a simple expedient of fully adjusting one's habits immediately to those of the local population is not always the best approach. This time consider the example of a flight to the east through 8 time zones, when a phase advance of the body clock is advised. This (see Table 1) requires bright light exposure at 05:00-11:00 h body time (13:00-19:00 h local time) and dim light (light avoidance) at 21:00-03:00 h body time (05:00-11:00 h local time). That is, morning light for the first day or so would be unhelpful and would tend to make the clock adjust in the wrong direction (though afternoon and evening light are fine).

This result is one explanation of why adjustment to phase advances is more difficult to achieve than adjustment to phase delays. It also suggests that, if a phase advance of the body clock is being attempted, then arrival in Sydney in the afternoon or evening is preferable to arrival in the morning.

**Physical Exercise**

The question, raised above, of whether physical exercise and inactivity can, in some way, add to the effects of light and dark, respectively, has not yet been answered conclusively. Nevertheless, to combine exposure to bright light with training outdoors, and to combine dim light exposure (bright light avoidance) with relaxation indoors would seem a practicable way of combining training sessions, the possible effects of exercise upon phase adjustment and appropriate light exposure.