ion between low back pain and occupation.


Effects of Jet Lag on Factors Related to Sport Performance

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Catalogue Data

Key words: circadian rhythm, anaerobic power, anaerobic capacity, mood, travel
Mots-clés: rythme diurne, puissance anaérobie, capacité anaérobie, voyage

Abstract / Résumé

Three studies were performed to evaluate the effects of jet lag on factors associated with sport performance. In Study 1, members of the USA Women's Soccer Team traveled to Taiwan; in Study 2, North American students and faculty traveled to Western Europe; and in Study 3, European students traveled to North America. After travel, there was disruption of mood state and a reduction in dynamic strength; peak 3-s power and 30-s work capacity were reduced for 2 days (5-s power: 9.8 vs. 9.0 W/kg; 30-s work capacity: 213 vs. 199 vs. 201 J/kg). In these studies, mood state, anaerobic power and capacity, and dynamic strength were affected by rapid transmeridian travel, and even highly trained athletes suffered from jet lag. However, effects of travel on the variables tested were essentially eliminated after 3 or 4 days.

Trois études ont été effectuées pour évaluer les effets d'un décalage horaire sur des mesures associées à la performance sportive. Étude 1: des athlètes de l'équipe féminine de soccer des États-Unis sont allés à Taiwan; Étude 2: des étudiants et des professeurs d'Amérique du Nord sont allés à l'Europe; Étude 3: des étudiants de l'Europe sont allés au Nord du Nord. Après les voyages, l'état mental était dérangé, et la force dynamique était réduite. La plus haute puissance de 5 s (la puissance anaérobie) et la capacité de 30 s (la capacité anaérobie) étaient réduites pendant 2 jours (la puissance de 5 s: 9.8 vs. 9.0 W/kg; la capacité de 30 s: 213 vs. 199 vs. 201 J/kg). On a remarqué que l'état mental, la puissance et la capacité anaérobie, et la force musculaire ont été affectés par le décalage horaire, et même les athlètes de haute niveau ont souffert. Cependant, les effets de voyager ont été éliminés après 3 ou 4 jours.

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Introduction

Travel across time zones results in desynchronisation of the body's circadian (24-hr) rhythms (Klein et al., 1972). This is manifested as jet lag, which is characterised by disturbances of sleep, generalised feelings of malaise, and reduced performance capabilities (Klein et al., 1972). Poor sport performance has been attributed to disturbance of circadian rhythms by researchers (Antal, 1975; Sasaki, 1980) and reviewers (Davis, 1988; Shephard, 1984; Winget et al., 1985). Guidelines are available on how to avoid jet lag in athletes (Ledoux, 1988; United States Olympic Committee, 1988) or business travelers (Ehret and Scanlon, 1983); there is little scientific basis for interventions (O'Connor and Morgan, 1990).

There is surprisingly little literature describing the effects of jet lag in elite athletes or on factors related to sport performance (Armstrong, 1988; O'Connor and Morgan, 1990). Antal (1975) reported that sharpshooting performance was reduced after rapid travel; however, the performances were obtained from practice sessions and no data were reported. Based on results of volleyball games between the Soviet Union and Japan after travel by the Soviet team to Japan, Sasaki (1980) cautiously concluded that jet lag may play a role in sport performance. In a nonsport investigation, Wright and colleagues (1983) evaluated the effects of travel from the U.S. to Germany and found a 6 to 13% reduction in dynamic, but not static, strength. In addition, 270-m sprint performances were slower after travel. However, their military subjects appear to have been sleep deprived when tested upon arrival, and it is not possible to determine whether performance decrements resulted from jet lag, sleep deprivation, or both. Although the Wright et al. study (1983) was confounded by sleep deprivation and by a high dropout rate, it remains the only jet lag study that has evaluated physiological responses to exercise.

In a recent review, O'Connor and Morgan (1990) have noted the paucity of studies investigating the effect of rapid air travel on factors related to sport performance. They also noted that few studies (all of nonathletes) have used standardised psychometric instruments. In addition, they suggested that since athletes have different levels of training and motivation, as well as a more positive mood profile, it might be inappropriate to generalise findings from nonathletes to athletes. They noted that there has been no controlled experiment dealing with sport performance after travel across multiple time zones.

In light of the information on the effects of jet lag on psychomotor and cognitive function (Klein et al., 1972), and in light of the lack of information about the effects of rapid transmeridional travel on factors related to sport performance and on psychometric and other variables in athletes (O'Connor and Morgan, 1990), a series of studies was undertaken. The purpose of these studies was to describe the effects of jet lag on several factors related to sport performance. Different test batteries and different types of subjects were used in each of the three studies because, in all cases, subjects were selected based on availability, and the methods and test batteries were constrained by the time, equipment, and facilities available. However, attempts were made to evaluate each variable in at least two of the three studies so that some comparisons could be made. In addition, it was possible in one of the studies to evaluate the effects of travel in elite athletes who were traveling to a series of major competitions.
neurobehavioural effects of the body's circadian rhythms is manifested as jet lag, which is generalised feelings of malaise, and (O'Connor et al., 1972). Poor sport performance has been associated with jet lag by researchers (Antal, 1988; Shephard, 1984; Winget et al., 1988) or business travelers (Ehret, 1988) or business travelers (Ehret, 1988).

Methods

Three experiments were designed to evaluate the effects of rapid transmeridional travel. Because different test batteries and subjects were used in each study, the methods will be presented for each study individually. In two studies travel was westward—from North America to Taiwan in Study 1 and from Western Europe to North America in Study 3. In Study 2 travel was eastward, from North America to Western Europe. The number of time zones crossed was eight in Study 1, seven in Study 3, and six in Study 2. Most variables were examined in two of the three studies. The design and methods of each study follow.

STUDY 1

Overview. Members of the USA Women's National Soccer team were invited to participate in the study. Those who chose to take part provided written informed consent. Data collection was in the form of self-assessments coordinated by the team captain. Baseline data were collected for the 7 days preceding departure from the West Coast of North America. All athletes have been involved in tournament play 8 days prior to departure, and all had at least 2 full days on the West Coast prior to the travel. With the duration of the flight and the time change involved, the athletes essentially lost a day as they traveled to Taiwan.

The following variables were measured: mood state, sleep habits, and grip strength. Each subject kept a daily log of sleep habits throughout the study—frequency prior to departure and during the 12 days in Taiwan. The subjects completed questionnaires designed to evaluate mood state disturbance each morning during this same time period. Strength data were collected only in Taiwan.

Specific Tests. Mood state was evaluated using the Profile of Mood States (POMS) questionnaire (McNair et al., 1971). Subjects were instructed to respond based on how they felt 'right now.' The six POMS subscales provide information about tension/anxiety, depression/dejection, anger/hostility, vigour/activity, fatigue/inertia, and confusion/bewilderment. An overall measure of the total or global mood disturbance was calculated as the sum of the five negative scores minus the vigour score; to avoid negative totals, 100 was added to this value. The average POMS scores obtained during the days prior to departure were used as the baseline scores.

In the daily log, each subject recorded the time she went to bed and woke up, and rated the quality of sleep. The quality of sleep was rated on a 1-to-5 scale with ratings ranging from 1 'terrible—hardly slept at all' to 5 'great—woke up relaxed and refreshed.' This is an unpublished scale we have developed but which has not been validated. The average values for the various sleep variables during the days prior to departure were used as the baseline scores.

Because subjects were traveling to the West Coast departure city from the prior tournament by different routes (e.g., via school or hometown), grip strength data could be collected only in Taiwan. Grip strength was reported to the nearest 0.1 kg as the mean of five trials using a Jamar adjustable handgrip dynamometer (Asimov Engineering, Los Angeles). After the fact, the mean of the last 6 days was calculated and used as a baseline score.

Data Analysis. Data were analysed using repeated-measures analysis of variance (ANOVA) techniques. Because of the limited sample size, repeated-measures ANOVAs were carried out only on the baseline values and the data.
from the first 4 days in Taiwan. Duncan post hoc tests were used to compare daily means for all variables.

STUDY 2

Overview. Ten healthy individuals volunteered to participate and provided written informed consent. Data were collected on two mornings in North America and then on the first four mornings in Western Europe, after overnight travel. Testing in France was scheduled in the mornings to minimise confounding effects of time of day. The following variables were measured: mood state, grip strength, and peak 5-s power and 30-s work capacity.

Specific Tests. Mood state and grip strength were evaluated as described for Study 1. Tests were administered in the same order, under as similar conditions as possible, during baseline testing and after travel. The average of the POMS scores and grip strength scores obtained during the 2 days of baseline testing were used as the baseline scores.

Modified Wingate power tests (Bar-Or, 1987; Vandewalle et al., 1987) were performed on a basket-loaded Monark 864 cycle ergometer (Monark-Crescent AB, Varberg, Sweden). Resistances were 0.086 kp·kg⁻¹ body mass (0.844 N·kg⁻¹) for women and 0.095 kp·kg⁻¹ body mass (0.932 N·kg⁻¹) for the man. The same ergometer was used for all of the testing, and all tests were preceded by a standardised 6-min bout of submaximal cycling. Peak power output was calculated as the highest power output during 5 seconds in the test, and 30-s work capacity was calculated as the total external work performed during the test. The average of the 5-s powers and 30-s work capacities obtained during the 2 days of testing in North America prior to travel were used as the baseline scores.

Data Analysis. As in Study 1 described above, data were analysed using repeated-measures ANOVA techniques and Duncan post hoc tests. Analyses were carried out on the baseline values and the data from the first 4 days at the destination.

STUDY 3

Overview. Nine healthy individuals traveling from Europe to North America as part of an educational exchange program were invited to participate in this study. All nine volunteered and provided written informed consent prior to any data collection. The consent forms were available in both French and English. These subjects were tested only in North America. They arrived in the afternoon, and testing began the next day and was performed in the mornings on the first 5 full days that the students were in North America.

Specific Tests. Peak power output and 30-s work capacity were evaluated as described above in Study 2. For both 5-s power and 30-s work capacity, Day 4 and 5 values demonstrated a plateau, and so the means of Day 4 and 5 scores were used as baseline.

Dynamic strength was measured using a Hydra-Fitness Omni-Tron (Belton, TX), a pseudo-isokinetic multistation dynamometer. Since results of previous research had suggested that speed of contraction was a factor in the magnitude of the effect of jet lag on force production (Wright et al., 1983), exercises were performed at two movement velocities (at settings 8 [slow] and 4 [fast] on the 0-to-12 scale). Four repetitions of the combination shoulder press and pulldown were performed at the slow and fast speeds. Criterion measures for slow and
fast dynamic strength were the means of the two highest press-plus-pull scores at each of the two velocities. For both measures, Day 4 and 5 values demonstrated a plateau, and so the means of Day 4 and Day 5 scores were used as baseline.

Data Analysis. As in Studies 1 and 2 described above, data were analysed using repeated-measures ANOVA techniques and Duncan post hoc tests. Analyses were carried out on baseline data and on data from the first 3 days at the destination.

Results

Characteristics of the subjects in Study 1 are presented in Table 1. Of the 18 national team members eligible, 7 chose to take part. In Study 2, nine women and one man participated: their characteristics are presented in Table 1. Characteristics of the five European women and four European men who participated in Study 3 are also presented in Table 1. Results from the three experiments are summarised in this section. In the Discussion section, relevant findings about each variable will be discussed together.

STUDY 1

The repeated-measures ANOVAs detected effects of travel on mood state. POMS data are summarised in Table 2. Vigour was reduced, p<.05, on Days 1 and 2 in Taiwan. Fatigue was increased on Day 1, p<.05, Day 2 (ns), and Day 3 (ns). Confusion was increased (ns) on Day 1. Total mood disturbance was elevated, p<.05, on Days 1 and 2. Strength data are presented in Table 3. Grip strength measured the first 2 days in Taiwan was lower, p<.05, than the baseline value.

Sleep status was monitored for 1 week prior to and then during the trip to Taiwan. Data are presented in Table 4. During baseline data collection, the athletes went to bed just after midnight (mean ±SE: 00.24 hrs ±25 min). They went to bed at the same time their first day in Taiwan (00.18 hrs ±28 min), but much earlier, p<.05, on Day 2 (21.52 hrs ±33 min). On the 3rd and 4th days, they retired between 11 p.m. and midnight. Number of hours spent sleeping differed, p<.05, from baseline on the 2nd night in Taiwan, with the athletes apparently trying to catch up on lost sleep. There was no significant deterioration in sleep quality, despite an apparent trend toward poorer quality from the 1st through 4th days at the destination.

Table 1 Characteristics of the Subjects

<table>
<thead>
<tr>
<th>Study</th>
<th>Gender (n)</th>
<th>Age M SD</th>
<th>Height M SD</th>
<th>Mass M SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Women (n = 7)</td>
<td>22 2</td>
<td>168 5</td>
<td>64 3</td>
</tr>
<tr>
<td>2</td>
<td>Women (n = 9)</td>
<td>24 2</td>
<td>167 3</td>
<td>64 7</td>
</tr>
<tr>
<td></td>
<td>Men (n = 1)</td>
<td>43</td>
<td>176</td>
<td>79</td>
</tr>
<tr>
<td>3</td>
<td>Women (n = 5)</td>
<td>19 5</td>
<td>165 7</td>
<td>53 1</td>
</tr>
<tr>
<td></td>
<td>Men (n = 4)</td>
<td>19 2</td>
<td>179 6</td>
<td>72 18</td>
</tr>
</tbody>
</table>
Table 2  Mood State (POMS) Data

<table>
<thead>
<tr>
<th>Study/Variable</th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SE</td>
<td>M</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Study 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension</td>
<td>6.3</td>
<td>1.3</td>
<td>5.8</td>
<td>1.1</td>
<td>7.2</td>
</tr>
<tr>
<td>Depression</td>
<td>0.7</td>
<td>0.5</td>
<td>0.0</td>
<td>0.0</td>
<td>1.8</td>
</tr>
<tr>
<td>Anger</td>
<td>2.3</td>
<td>1.0</td>
<td>1.8</td>
<td>1.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Vigour</td>
<td>21.7</td>
<td>2.6</td>
<td>13.5</td>
<td>2.3*</td>
<td>14.8</td>
</tr>
<tr>
<td>Fatigue</td>
<td>2.5</td>
<td>1.3</td>
<td>10.3</td>
<td>2.3*</td>
<td>5.5</td>
</tr>
<tr>
<td>Confusion</td>
<td>2.8</td>
<td>1.0</td>
<td>5.0</td>
<td>1.5</td>
<td>3.3</td>
</tr>
<tr>
<td>Total</td>
<td>92.9</td>
<td>5.3</td>
<td>109.4</td>
<td>4.6*</td>
<td>105.9</td>
</tr>
<tr>
<td>Study 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tension</td>
<td>4.5</td>
<td>2.0</td>
<td>6.4</td>
<td>1.7</td>
<td>5.4</td>
</tr>
<tr>
<td>Depression</td>
<td>1.8</td>
<td>0.7</td>
<td>3.4</td>
<td>1.4</td>
<td>2.9</td>
</tr>
<tr>
<td>Anger</td>
<td>0.8</td>
<td>0.4</td>
<td>3.4</td>
<td>1.5</td>
<td>2.0</td>
</tr>
<tr>
<td>Vigour</td>
<td>21.0</td>
<td>2.6</td>
<td>12.3</td>
<td>2.6*</td>
<td>15.3</td>
</tr>
<tr>
<td>Fatigue</td>
<td>4.1</td>
<td>1.9</td>
<td>13.1</td>
<td>2.6*</td>
<td>9.6</td>
</tr>
<tr>
<td>Confusion</td>
<td>3.5</td>
<td>0.8</td>
<td>6.3</td>
<td>1.2*</td>
<td>5.4</td>
</tr>
<tr>
<td>Total</td>
<td>93.7</td>
<td>6.1</td>
<td>120.3</td>
<td>7.4*</td>
<td>110.0</td>
</tr>
</tbody>
</table>

*Denotes daily mean different from baseline, $p < .05$.

Table 3  Strength Data (expressed in KP)

<table>
<thead>
<tr>
<th>Study/Variable</th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SE</td>
<td>M</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Study 1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>30.9</td>
<td>2.0</td>
<td>26.9</td>
<td>1.5*</td>
<td>27.8</td>
</tr>
<tr>
<td>Study 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grip strength</td>
<td>29.9</td>
<td>3.2</td>
<td>30.3</td>
<td>2.8</td>
<td>29.3</td>
</tr>
<tr>
<td>Study 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dynamic strength</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slow</td>
<td>30.4</td>
<td>3.2</td>
<td>26.3</td>
<td>2.9*</td>
<td>29.6</td>
</tr>
<tr>
<td>Fast</td>
<td>19.5</td>
<td>2.3</td>
<td>17.7</td>
<td>2.3*</td>
<td>19.7</td>
</tr>
</tbody>
</table>

Note. In Studies 1 and 2, static (grip) strength was measured. In Study 3, dynamic shoulder strength was measured at two speeds (see text).

*Denotes daily mean different from baseline, $p < .05$. 
Table 4 Sleep Data During Baseline Testing and During the First 4 Days in Taiwan

<table>
<thead>
<tr>
<th>Study/Variable</th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Study 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bedtime</td>
<td>M 0.24 hrs</td>
<td>18 hrs</td>
<td>21.52 hrs*</td>
<td>23.35 hrs</td>
<td>23.08 hrs</td>
</tr>
<tr>
<td></td>
<td>SE 2.5 min</td>
<td>28 min</td>
<td>33 min</td>
<td>54 min</td>
<td>20 min</td>
</tr>
<tr>
<td>Time asleep</td>
<td>M 6 hrs 54 min</td>
<td>7 hrs 9 min</td>
<td>8 hrs 40 min*</td>
<td>6 hrs 48 min</td>
<td>6 hrs 21 min</td>
</tr>
<tr>
<td></td>
<td>SE 30 min</td>
<td>22 min</td>
<td>24 min</td>
<td>44 min</td>
<td>21 min</td>
</tr>
<tr>
<td>Quality</td>
<td>M 3.5</td>
<td>3.6</td>
<td>3.4</td>
<td>3.0</td>
<td>2.9</td>
</tr>
<tr>
<td></td>
<td>SE 0.2</td>
<td>0.5</td>
<td>0.5</td>
<td>0.4</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Note.</strong></td>
<td>Rated on a scale from 1 to 5, with 5 being highest quality.</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*<strong>Denotes daily mean different from baseline, p &lt; .05.</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

STUDY 2

The repeated-measures ANOVA detected effects of travel on mood state. POMS data are presented in Table 2. Vigour was reduced, p < .05, on Day 1 in Europe. Fatigue was increased, p < .05, on both Days 1 and 2. Confusion was increased, p < .05, on Day 1. Total mood disturbance was elevated, p < .05, the 1st day after travel. Strength data are presented in Table 3. Static strength (grip strength) was unaffected by the travel. Results of the Wingate power tests are presented in Table 5. Peak 5-s power output was 10% lower (ns) on Day 1 in France, and it was 14% lower, p < .05, on Day 2 in France. The 30-s work capacity was 6% lower, p < .05, on Days 1 and 2 in France.

STUDY 3

Strength data are presented in Table 3. The repeated-measures ANOVA detected effects, p < .05, of travel on shoulder strength. Press-plus-pull strength at the slow velocity was reduced, p < .05. 15% the 1st day in North America, and strength at the fast velocity was reduced, p < .05, 9% on Day 1 in North America. Results of the Wingate power tests are presented in Table 5. Peak 5-s power was reduced, p < .05, 7% on Day 1 in the U.S. The 30-s work capacity was reduced, p < .05, 8% on the 1st day after travel. Both 5-s power and 30-s work capacity tended to be reduced on the 2nd day after travel as well.

Discussion

In three separate studies, the effect of jet lag on some variables that are related to sport performance (or are measured by sport scientists) was evaluated. The variables were mood state, sleep status, strength, and peak 5-s power and 30-s work capacity (anaerobic power and capacity). Most variables were evaluated in two of the three experiments.
Table 5 Peak 5-s Power (W) and 30-s Work Capacity (kJ) Data From Study 2 (students traveled east), Study 3 (students traveled west), and Both Studies

<table>
<thead>
<tr>
<th>Study/Variable</th>
<th>Baseline</th>
<th>Day 1</th>
<th>Day 2</th>
<th>Day 3</th>
<th>Day 4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>M</td>
<td>SE</td>
<td>M</td>
<td>SE</td>
<td>M</td>
</tr>
<tr>
<td>Study 2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-s power</td>
<td>568</td>
<td>41</td>
<td>514</td>
<td>29</td>
<td>489</td>
</tr>
<tr>
<td>30-s work</td>
<td>12.0</td>
<td>0.8</td>
<td>11.3</td>
<td>0.6*</td>
<td>11.2</td>
</tr>
<tr>
<td>Study 3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-s power</td>
<td>688</td>
<td>31</td>
<td>638</td>
<td>44*</td>
<td>670</td>
</tr>
<tr>
<td>30-s work</td>
<td>15.4</td>
<td>1.4</td>
<td>14.2</td>
<td>1.2*</td>
<td>14.5</td>
</tr>
<tr>
<td>Studies 2 &amp; 3</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>5-s power</td>
<td>9.8</td>
<td>0.4</td>
<td>9.0</td>
<td>0.5*</td>
<td>9.0</td>
</tr>
<tr>
<td>30-s work</td>
<td>213</td>
<td>13</td>
<td>199</td>
<td>12*</td>
<td>201</td>
</tr>
</tbody>
</table>

Note. Data from both studies are combined and expressed relative to body mass (W kg\(^{-1}\) and J kg\(^{-1}\)).

*Denotes mean different from baseline, p < .05.

MOOD STATE

During baseline testing, the subjects in Study 1, elite USA athletes who traveled westward to Taiwan, and the subjects in Study 2, fit physical education students and faculty who traveled eastward to Europe, demonstrated the iceberg profile which has been described by Morgan, O’Conner, and colleagues (1987) in elite athletes. The subjects’ vigour scores exceeded the population average, and scores for the negative measures of mood state were below the population average.

In both studies, mood state was disrupted after the travel across time zones. Disruption of the profile was most marked on Day 1, with the athletes in Taiwan having significantly altered vigour and fatigue and the students in Europe having significantly altered vigour, fatigue, and confusion: by Day 2 the athletes still had altered vigour and the students still had altered fatigue.

The students in Study 2 who traveled to Europe were essentially tourists, while the soccer players in Study 1 who traveled from the U.S. to Taiwan were highly trained and motivated athletes who were preparing to compete in a major international tournament. Yet both groups seemed to suffer in a similar fashion. This finding suggests that, despite their high level of motivation and preparation, even elite athletes may suffer psychological decrements after rapid transmeridianal travel.

During baseline testing in North America, the two groups had identical iceberg profiles. Although there were no statistical differences in the responses of students who traveled eastward to France and athletes who traveled westward to Taiwan, there was a tendency for the feelings of fatigue to be greater in the students after arrival in Europe. One might speculate that the eastbound travel, with a 10 p.m. departure time, might have involved relatively more sleep loss effects that the westbound travel, and that the sleep loss was specifically reflected.
Capacity (kJ) Data From Study 2
(Travelled west), and Both Studies

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<th>Day 2</th>
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<td>1.89</td>
<td>33*</td>
<td>551</td>
<td>12.2</td>
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<td>0.70</td>
<td>37</td>
<td>700</td>
<td>14.8</td>
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<tr>
<td>0.90</td>
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<td>9.8</td>
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<td>0.01</td>
<td>12*</td>
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to body mass expressed relative to

by the POMS fatigue subscore. Conversely, any differences between the two
groups of subjects might be attributed to the differences in subjects' motivations
for travel or the number of time zones crossed—eight in the westbound group
and six in the eastbound group. There are many other possible confounding
effects, such as previous travel experience, diet, or use of caffeine and/or alcohol.

Other than the POMS and simple grip strength tests, the athletes did not
perform any performance related tests. Moreover, they did not compete during
their first 4 days in Taiwan, when mood state was disrupted by jet lag. Therefore,
we cannot say whether jet lag, or the disruption of mood state by jet lag, would
have affected performance in these athletes.

Since publishing their review (O'Connor and Morgan, 1990), O'Connor,
Morgan, and colleagues (1991) reported on the effect of travel across four time
zones on POMS scores in elite swimmers. In contrast to our findings, they found
decreases in mood disturbances after travel. Before traveling from Madison,
Wisconsin, in wintertime, swimmers were taking exams and training hard, and
mean values for total mood disturbance were 164.4 (women) and 151.6 (men);
after a restful flight and a day off training, values were reduced to 119.3 and
145.5 upon arrival in Honolulu, Hawaii. Subjects then increased their training
volume by about one third during the week in Hawaii, and mood disturbance at
the end of the week reached 162.2 and 149.5. After a day off training for the
return travel to the U.S., levels were 130.6 and 117.5. In light of the work
by Morgan, Brown, and colleagues (1987) describing the relationship between
increases in training volume and disturbance of mood state, it would seem
inappropriate to infer that the mood state improvement after travel reported in
the recent study (O'Connor et al., 1991) could be attributed to the effects of
rapid air travel per se. Indeed, this probably suggests that a major confounding
variable in investigating effects of travel on athletes is the training load preceding
travel and after arrival at the destination.

SLEEP STATUS

Disruption of sleep status of the athletes who traveled westward to Taiwan was
noted: athletes' diaries recorded changing sleep habits and their written comments
reported disturbed sleep patterns. It was interesting that, in response to question-
naires, the athletes reported usually going to bed in the U.S. at about 11:30 p.m.,
and yet actual baseline bedtime during the week prior to the travel was almost
an hour later than usual. Therefore, (a) comparisons with baseline measures might
be misleading and (b) sleep may actually have been disrupted before the travel.
Usual bedtimes (i.e., about the 11:30 p.m. reported in the questionnaires) were
reported by Day 4 in Taiwan.

STRENGTH

Strength was measured in two ways: static grip strength in Study 1 and Study
2, and dynamic shoulder strength in Study 3. Although strength was seen to
increase over the first 4 days in Taiwan, a learning effect must have contributed
to the improvement over time (the first time the athletes performed the test was
in Taiwan). The Day 1 to Day 4 increase of 15% is larger than one would expect
as a learning effect for a simple strength test by trained athletes. Our pilot work
(unpublished) has suggested a learning effect of less than 8%, which would have
been expected from the subjects in this present study as an 8% increase from
Day 1 to Day 2 in Taiwan. However, there was only a 3% change (ns) between Days 1 and 2, suggesting that strength may have been compromised on Day 1 and/or Day 2 after travel. One must be cautious in interpreting results when no true baseline data are collected. We have attempted to estimate the magnitude of the learning effect but recognize the limitations of this approach. Grip strength baseline data were collected in Study 2. In contrast to the findings in Study 1, in Study 2 grip strength was not reduced after travel.

Dynamic shoulder strength was affected by travel in the one experiment in which it was evaluated (Study 3). Our results are in accord with those of Wright and colleagues (1983), who reported that dynamic strength, but not static strength, was reduced by rapid transmeridianal travel. Together these results might suggest that jet lag affects neuromuscular coordination or control; but it is not clear whether there is an effect on the ability of the muscle itself to generate force.

PEAK 5-s POWER AND 30-s WORK CAPACITY

In Study 2, in which students traveled to Western Europe, 5-s power and 30-s work capacity were both affected after the rapid transmeridianal travel. The magnitude of effect appeared to be greater on 5-s power than on 30-s capacity. The 5-s power was reduced 10% (ns) on Day 1 and 14%, $p<.05$, on Day 2. The 30-s capacity was reduced 6% on each of the first 2 days in France, and on both days this was statistically significant, $p<.05$. Individual variation in time course of responses may partly explain the differences in statistical significance. However, for both power and capacity, baseline values were achieved by the 3rd morning in Europe.

In Study 3, in which European students traveled westward to North America, the peak 5-s power and 30-s work capacity were each reduced by about the same magnitude, 7 and 8%, and were significantly reduced on only the 1st day after travel. Based on these two studies, it would be difficult to draw conclusions about differences between the effects of eastbound versus westbound travel, since there were some differences in experimental protocol. For example, in Study 2 subjects traveled overnight, arrived in Europe in the morning, and were tested right away. In Study 3 subjects traveled during the day, arrived in North America in the afternoon, and were tested the next morning. While visual comparison of the progress of 5-s power measured each day after travel suggests that effects of the eastbound travel were of greater magnitude and more persistent, these differences were not statistically significant, $p<.05$. Moreover, decrements in 30-s work capacity after eastbound and westbound travel were virtually identical.

As there was no difference between the effects of eastbound travel across six time zones and westbound travel across seven time zones. Wingate data from the studies were combined for further analysis. ANOVA revealed effects of jet lag on both 5-s power, $p<.01$, and 30-s work capacity, $p<.01$. Post hoc testing of the pooled data detected that both 5-s power and 30-s capacity were reduced on Days 1 and 2 at the destination. Peak power was reduced, $p<.05$, 8% the first 2 days after travel, and 30-s capacity was reduced, $p<.05$, 7% the 1st day and 6% the 2nd day. Combined data are presented in Table 5.

While we report that 5-s power and 30-s capacity were normalised within 3 days after travel, Wright and colleagues (1983), who estimated anaerobic capacity from a 270-m sprint, reported performance decrements on the 2nd
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through the 4th days in Europe. It is difficult to compare results, as their subjects 

(military) appear to have endured a greater degree of sleep deprivation than the 

typical commercial or sport traveler.

It has been suggested (personal communication. T. Reilly. Loughborough, 

UK, 1990) that many of the effects attributed to jet lag may simply reflect a 
persistence of circadian rhythms. For example. Hill and Smith (1991a) demon-

strated that there is a circadian rhythm in peak 5-s power and in 30-s work 
capacity, with values in the morning (3 to 9 a.m.) being 8 and 5% lower, 
respectively, than those in the afternoon (3 p.m.) or evening (9 p.m.). If our 
subjects were tested in the afternoon in North America and then at 3 p.m. in 
Western Europe, then comparisons would be biased because 3 p.m. Paris time 
would be 9 a.m. "body time" for the subjects, and a 5 to 8% decrement would 
be expected. This was not the case in the present study (Study 2) because when 
the data were collected at 9 a.m. clock time in Paris, it was 3 a.m. body time 
for the arriving students, and there are no differences between 3 a.m. and 9 a.m. 
test results which could be attributed to circadian rhythms (Hill and Smith, 1991a).

In addition, subjects who traveled eastbound reported greater feelings of 
fatigue in addition to demonstrating reduced anaerobic performance abilities. 
There is a relationship between feelings of fatigue and subsequent anaerobic 
performance, but this relationship is independent of any circadian rhythms in 
work or performance (Hill and Smith, 1991b). Thus we are confident that the 
results we report do reflect effects of jet lag rather than simple circadian effects.

However, it is obvious that circadian rhythms in performance can compound 
investigation of the effects of rapid transmeridional travel. For example, an 
individual tested in Europe at 9 p.m. would give a peak performance; if he or 
she then traveled to North America and was tested at 9 p.m. clock time, a 5 to 
8% decrement would be expected simply because this would represent 3 a.m. 
body time, the low point for individual performance. The persistence of circadian 
rhythms in performance measures and related variables might contribute to 
differences between effects of eastbound and westbound travel. Of course, it must be 
remembered that it is desynchronisation of circadian rhythms, and the differential 
rates of adjustment to external phase shifts among the major endogenous rhythms, 
that is responsible for jet lag.

Summary

In their recent review, O’Connor and Morgan (1990) reported that only a few 

studies have investigated, in athletes or nonathletes, the effect of rapid air travel 
on factors related to sport performance: one study has evaluated the effect of jet 
lag on physiological responses to exercise; two studies have inferred effects of 
jet lag based on team volleyball performance or shooting scores obtained during 
practice rounds. They also noted that the studies have not always used standardised 
psychometric instruments.

It was the purpose of the three studies reported in this paper to add to the 
body of knowledge regarding the effects of rapid transmeridional travel on factors 
related to sport performance in athletes and nonathletes. In two studies the subjects 
were nonathletes, and in the third study the subjects were elite athletes who were 
traveling to major competitions.

The results of these studies provide information about specific responses 
of the subjects to the specific travel they performed. Although the data were
subjected to statistical analysis, it may be inappropriate to generalise the findings to other groups of athletes; there are many confounding factors, including the selection of subjects (based on availability and willingness to participate), choice of tests (based on constraints of time and availability of equipment), direction and duration of travel, reason for travel, diet and use of alcohol or caffeine, expectations, previous travel experience, level of training/physical activity before and after travel, other individual differences, and so forth.

Rapid eastbound or westbound travel across six to eight time zones affected several variables of interest to sport scientists. Mood state, as evaluated by POMS, was disrupted for the first 2 to 3 days after travel. Sleep patterns were also disturbed. Static strength was affected in one study and unaffected in another; but dynamic strength was reduced significantly during the first full day after travel.

There were decrements in peak 5-s power and 30-s work capacity after transmeridional travel, with reductions of 6 to 8% on the 1st and 2nd days at the destination. These reductions did not reflect persistence of circadian rhythms in performance, although the magnitude of the effect would be similar. In other words, after the rapid transmeridional travel, the subjects’ performance capacity for an anaerobic task was about what it would be at 3 a.m. at home.

Shephard (1984) has suggested that a minimum of 7 days is necessary for resynchronisation of body rhythms and return to maximal performance potential. However, in the subjects in these three studies, performance related variables that were evaluated were seen to return quite quickly to pretravel levels. The ‘iceberg mood state profile of the elite athletes and the fit physical educators was reestablished by the 4th day at the destination. Dynamic strength responded even faster, and peak 5-s power and 30-s work capacity were reduced for only the first 2 days after travel.

These three experiments represent pilot studies: there is a need for controlled studies, using standardised psychometric and physiologic tests, to evaluate responses of athletes traveling to competitions, and for controlled studies to evaluate intervention efforts. Available data would suggest that sport scientists should consider the unique time courses of the effects of jet lag on mood state, strength, and anaerobic performance. Practically speaking, in these studies the effects of travel on the variables tested were essentially eliminated after 3 or 4 days.

References

appropriate to generalize the findings with confounding factors, including the week-end willingness to participate, choice of availability of equipment, direction of diet and use of alcohol or caffeine, level of training/physical activity before and so forth.

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power and 30-s work capacity after 5 to 8% on the 1st and 2nd days at rest. Persistence of circadian rhythms the effect would be similar. In other studies, the subjects' performance capacity would be at 3 a.m. at home.

minimum of 7 days is necessary for return to maximal performance potential. Studies, performance related variables were not quickly to pretravel levels. The fit subjects and the fit physical educators were on, dynamic strength responded even if they were reduced for only the subjects; there is a need for controlled and physiologic tests. To evaluate return and for controlled studies to evaluate suggest that sport scientists should focus jet lag on mood state, strength, taking, in these studies the effects of really eliminated after 3 or 4 days.


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