FURTHER ASSESSMENTS OF THE RELATIONSHIP BETWEEN JET LAG AND SOME OF ITS SYMPTOMS

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The disruption of circadian rhythms following time-zone transitions gives rise to the syndrome of jet lag. The power of some of the symptoms of jet lag to predict the amount of jet lag measured at the same and at different times of the day has been investigated. Eleven healthy subjects were studied in an Isolation Unit for two days after a simulated flight from the UK to Beijing (8 time zones to the east). At six time-points (08:30, 11:00, 14:00, 17:00, 20:00, and 23:00 h), the subjects recorded their jet lag, and the differences from “normal” (that is, from days in which there is no jet lag) of alertness, hunger, indigestion, concentration, motivation, and irritability. They recorded at 08:30 h the type of food they had eaten since rising at 08:00 h and, at the other times, the type of food eaten in the last three hours. Assessments were made by visual analogue scales or, in the case of type of food, by a nominal scale. Following the time-zone transition, the adjustment of meals appeared to be complete almost immediately. Jet lag and its symptoms were present during both experimental days. Jet lag tended to rise during the course of the daytime, accompanied by falls in alertness, motivation, and concentration. Correlation matrices between jet lag and each of the other variables were produced, using lags between the variable (from up to 5 time-points before the assessment of jet lag to 5 time-points afterwards) and pooling the results from both days. These matrices indicated that significant correlations existed only between jet lag and alertness, concentration, and motivation, and then only when these other variables were assessed at the same time as jet lag or 1 or 2 time-points earlier. Jet lag was then treated as the dependent variable and the symptoms as covariates in analysis of covariances (ANCOVAs), with the days treated as a random effect. This analysis enabled the significance of potential predictors of jet lag, together with their \( \beta \)-coefficients (the relationship between a unit change of each significant predictor and the change in jet lag), to be calculated. Falls in alertness and motivation were
significant predictors of increased jet lag, provided that they were measured at the same time, when they accounted for about 50% of the jet lag; when measured at other time-points, they did not act as significant predictors. It is concluded that the amount of jet lag varies during the course of the day and that it can be predicted from contemporaneous assessments of alertness and motivation—but not from assessments made at other times of the day, nor from other variables that are symptoms of jet lag, even though these other variables are significantly increased. In considering the results of this and our previous study, we reiterate the view that the exact meaning of “jet lag” is complex and that the particular combination of factors that contribute to it might vary with the time of day that the assessment is made. Inferences about any decrements due to time-zone transitions cannot be made reliably at times of the day that differ from the time when jet lag is assessed.

**Keywords** Time-Zone Transitions, Alertness, Mood, Mealtimes, Circadian Rhythms, Jet Lag

**INTRODUCTION**

“Jet lag” is the term applied to a group of symptoms that exist transiently after undergoing a rapid time-zone transition. The daytime symptoms include increased fatigue, a loss of concentration and motivation, increased irritability, altered bowel activity, and decreased enjoyment of food (Graeber, 1982; Winget et al., 1984; Arendt et al., 1987; Waterhouse et al., 1997; Haimov and Arendt, 1999; Herxheimer and Petrie, 2002). The symptoms are believed to result from the slow rate of adjustment of the endogenous circadian oscillator (the “body clock”) to the new time zone, as a result of which there is a dissociation between the timing of the individual’s lifestyle and his/her habits (Graeber, 1982; Waterhouse et al., 1997).

In a previous study, Waterhouse et al. (2003b) investigated a group of elite athletes, their coaches, and administrative staff during the first six days after having travelled from the UK to Sydney (an eastward transition across 10 time zones) in preparation for the Olympic Games in 2000. Six times per day, distributed fairly evenly throughout the waking part of it, subjects assessed their jet lag and their sensation of fatigue. On some occasions, the subjects also subjectively assessed their motivation, their ability to concentrate and their irritability, as well as their interest in meals and their bowel habits. Results showed that the assessment of fatigue made at a particular time strongly predicted the amount of jet lag perceived at the same time, but that the assessment of fatigue made at a particular time did not predict assessments of jet lag made at other times. We referred to this link between the assessments of fatigue and jet lag made simultaneously as “temporal specificity.” By contrast, the predictive powers of motivation, the ability to concentrate, and the amount of irritability were weaker and showed less temporal specificity. That is, the
amounts of jet lag measured on the previous, the same, or the following occasion were predicted equally well by these variables. Stool consistency and the enjoyment of meals were not only weak predictors of the amount of jet lag but showed hardly any temporal specificity. That is, the amount of jet lag measured on any occasion was predicted almost equally well by these symptoms, at whatever time of the day they had been measured.

While such results support the concept that “jet lag” and its symptoms are not all linked equally strongly, they were obtained from a group of subjects possessing an exceptionally high desire to perform as well as possible in the new time zone, in spite of any sensations of jet lag and its debilitating effects. The results might not apply to other groups of subjects in whom the motivation to throw off any effects of jet lag might not be as strong. Moreover, the study was performed in field conditions, where the participants’ demanding schedules meant that some restrictions existed with regard to the number of assessments that could be made at any time. (For example, apart from fatigue, all the other predictors could be measured only at 12:00 and 16:00 h, see Table 1 in Waterhouse et al., 2003b).

The aim of the present study was to investigate more systematically than previously the links that might exist between jet lag and its symptoms. For this reason, there were no control days before the simulated time-zone transition since, during them, there would be no jet lag. Subjects were chosen who were not elite athletes and not approaching important competitive events, so they would have no particular need to shrug off any effects of jet lag or its symptoms. Finally, in order to reduce the amount of “noise” in the data, and to obtain complete data sets, the experiments have been performed in an Isolation Unit at the University.

**METHODS**

**Isolation Unit, Subjects, Protocol, and Questionnaire**

The Isolation Unit (Waterhouse et al., 2003) is sound-attenuated and maintained at a constant temperature and humidity (20 ± 2°C and 60 ± 5% relative humidity, respectively). It has facilities for relaxation (video and music systems) and for the storage, preparation, and eating of food. It also has a separate sleeping area (for four subjects), toilet facilities, facilities for exercise (cycle ergometer), and a computer for the performance of various psychometric tests. Subjects can live comfortably in this unit, independently of the outside world.

Eleven healthy subjects, nonsmokers and with conventional eating and sleeping habits, and taking no form of medication, were studied in groups of 2–4. There were 4 males and 7 females, these latter being studied at all phases of their menstrual cycles. The subjects’ ages ranged from 20–39
The subjects entered the Isolation Unit at about 14:00 h on a Friday. After settling into this new environment, local time was advanced at 15:00 h by 8 h (to 23:00 h, Friday evening) for example, simulating a time-zone transition from the UK to Beijing, China. Subjects were instructed to live by Beijing time for the rest of the experiment. They were then allowed 1 h to eat a meal, if they so chose, before retiring to bed.

Sleep was permitted from midnight to 08:00 h only, no naps in the “daytime” being permitted. For the next 2 1/2 days (until 17:00 h on the Monday, equivalent to 09:00 h on UK time), subjects performed a series of tests at six time-points (referred to as t1–t6, respectively), at 08:30, 11:00, 14:00, 17:00, 20:00, and 23:00 h. These tests consisted of answering a questionnaire on jet lag and its symptoms; answering a questionnaire on food intake; measuring left and right hand grip strengths; and measuring simple reaction time. Only the results from the jet lag questionnaire and the type of meal eaten will be considered in this report.

Apart from these requirements, subjects were free to spend the time as they chose. This included whether or not to eat and, if so, the nature of the food eaten. Food for the subjects was provided, the food having been chosen by the subjects before the experiment began. The subjects were required to prepare and cook any meals for themselves.

The jet lag questionnaire was a modification of the Liverpool Jet Lag Questionnaire (Waterhouse et al., 2000). It requested an assessment of “jet lag” on a visual analogue scale (VAS), the extremes of which were designated “0” (no jet lag) and “10” (very severe jet lag). In addition, the questionnaire requested information about: alertness, ability to concentrate (concentration), motivation, irritability, hunger, and indigestion. The responses required for these questions were ticks placed somewhere on lines that were marked from −5 through 0 to +5, where “−5” was described as “much less than normal,” “0” as “normal,” and “+5” as “much more than normal” for that time of day. The questionnaire is shown in Figure 1. Note that on days before a time-zone transition the score for jet lag would be zero, as would the scores for the symptoms, since, in the absence of jet lag, the subjects’ assessments of alertness, etc. would all be “normal.”

The food intake questionnaire has been described before (Waterhouse et al., 2003a,b); in the current report, the meals eaten in the half hour since waking (t1) and in the previous 3 h (t2–t6) have been analyzed. The type of meal was assessed on a nominal scale, where “0” signified no meal, “1” a snack, “2” a previously cooked cold meal, “3” a small hot meal, and “4” signified a large hot meal. Meals before the time-zone transitions were not formally investigated, though each subject had, prior to the experiment, indicated that the pattern of food intake was conventional for example, hot meals being eaten at lunch and dinner time.
1. Jet lag:
   How much jet lag do you have?
   
   0 ----------------------------------------------- 10
   (no jet lag)  (very severe jet lag)

2. Alertness. Compared with normal:
   How alert do you feel at the moment?
   
   -5 ------------ 0 ------------+5
   (much less alert)  (normal)  (much more alert)

3. Meals. Compared with normal:
   a. How hungry do you feel?
   
   -5 ------------ 0 ------------+5
   (much less hungry)  (normal)  (much more hungry)

   b. How much indigestion do you have?
   
   -5 ------------ 0 ------------+5
   (much less)  (normal)  (much more)

4. Mental performance and mood. Compared with normal:
   a. How well have you been able to concentrate?
   
   -5 ------------ 0 ------------+5
   (much worse)  (normal)  (much better)

   b. How motivated do you feel?
   
   -5 ------------ 0 ------------+5
   (much less)  (normal)  (much more)

   c. How irritable do you feel?
   
   -5 ------------ 0 ------------+5
   (much less)  (normal)  (much more)

FIGURE 1 The jet-lag questionnaire (based on Waterhouse et al., 2000).

While any questions about filling in the questionnaires were freely answered, it is stressed that no information or advice with regard to the meaning of the questions asked, particularly the meaning of “jet lag,” was given. Moreover, subjects were not advised as to the exact meaning to be placed on “snack” etc. (for example, see Lennernas et al., 1993).
Subjects were not informed as to the exact purposes of the study and questionnaires, and were encouraged neither to check their previous answers nor to discuss them with their colleagues performing the experiment with them.

The protocol was approved by the Human Ethics Committee of Liverpool John Moores University and was conducted in accord with the ethical criteria of the journal (Touitou et al., 2004).

**ANALYSES**

All food intake data from the 2 1/2 days of the study were used. The fraction of possible occasions that no meal or each of the four types of meal (for definitions of the types see above) had been eaten was calculated for each individual and time of day.

Amounts of jet lag and the other measured variables over the course of the 2 full days of the experiment were assessed by 2-way analysis of variance (ANOVA) with repeated measures (SPSS, version 11). Factor 1 was Day Number (2 levels) and factor 2 the Time of Day (6 levels). Greenhouse-Geiser corrections for violations of sphericity were applied, and Bonferroni corrections were used to assess the significance of pairwise differences within a factor.

The main aim of the current study, the relationship between jet lag and the other variables, was investigated in two stages. In the first, the Pearson product-moment correlations between jet lag and separately for each of alertness, concentration, motivation, lack of irritability, hunger, type of meal eaten, and indigestion were investigated. For each of these pairs of variables, the correlations were separately calculated between jet lag measured at time \( t \), where \( t \) could vary from \( t_1 \) to \( t_6 \) (see above), and the other variable measured at each of the six times on the same day. This gave a matrix of 36 correlation coefficients for each of the seven pairs of variables (jet lag vs. alertness, jet lag vs. concentration, etc), each with 20 degrees of freedom (2 days, 11 subjects). Each matrix of 36 entries was comprised of the following:

- Six occasions when jet lag was compared with the other variable measured at the same time of day: \( t_x \) of jet lag and \( t_x \) of the other variable, \( x \) varying from 1–6;
- Five occasions when jet lag was compared with the other variable measured one time-point before: \( t_x \) of jet lag and \( t(x-1) \) of the other variable, \( x \) varying from 2–6;
- Four occasions when jet lag was compared with the other variable measured two time-points before: \( t_x \) of jet lag and \( t(x-2) \) of the other variable, \( x \) varying from 3–6;
- Three occasions when jet lag was compared with the other variable measured three time-points before: \( t(x - 3) \) of the other variable, \( x \) varying from 4–6;
- Two occasions when jet lag was compared with the other variable measured four time-points before: \( t(x - 4) \) of the other variable, \( x \) varying from 5–6;
- One occasion when jet lag was compared with the other variable measured five time-points before: \( t(x - 5) \) of the other variable, \( x \) equal to 6;
- One occasion when jet lag was compared with the other variable measured five time-points after: \( t(x + 5) \) of the other variable, \( x \) equal to 1;
- Two occasions when jet lag was compared with the other variable measured four time-points after: \( t(x + 4) \) of the other variable, \( x \) varying from 1–2;
- Three occasions when jet lag was compared with the other variable measured three time-points after: \( t(x + 3) \) of the other variable, \( x \) varying from 1–3;
- Four occasions when jet lag was compared with the other variable measured two time-points after: \( t(x + 2) \) of the other variable, \( x \) varying from 1–4;
- Five occasions when jet lag was compared with the other variable measured one time-point after: \( t(x + 1) \) of the other variable, \( x \) varying from 1–5.

When, as indicated above, more than one correlation coefficient could be calculated for a particular time interval between the assessments of jet lag and the other variables (for example, there were six coefficients when jet lag and the other variables were measured at the same times; five coefficients when jet lag was measured either one time-point after the other variables or one time-point before them, etc.), then the median value was used when the results were presented graphically. Inspection of these seven correlation matrices enabled the significant correlations between each variable and jet lag to be established for all time intervals between the two measurements.

In the second stage of the analysis relating jet lag to the other variables, those variables and time lags that had shown significant correlations were used in analysis of covariance (ANCOVA), with jet lag as the dependent variable, day number and subjects as random effects, and the “significant” variables as the covariates. The \( \beta \)-coefficients associated with significant covariates—that is, the change in the rating of jet lag predicted by a unit change in the score of the independent variable, having also adjusted for differences between day number and subjects—were extracted from the analyses.
RESULTS

First, by way of an introduction to the main analyses, some results relating to the time-courses of changes to the measured variables during the course of the two days after the time-zone transition are considered. Figure 2 shows the mean daily amounts of jet lag (which would be zero before the time-zone transition) and of the differences from “normal” (defined in Figure 1) of its symptoms during the two days after the time-zone transition. Apart from the fall of hunger on the first day and amount of indigestion on the second, all values were significantly different from zero ($p < 0.05$), indicating the general malaise that follows a time-zone transition.

Table 1 summarizes the results from the 2-way ANOVA. There was a highly significant effect of time of day on the distribution of meal type. The statistically significant interaction was due partly to the difference between the two days in the distributions of meal type in the first two waking periods (data not shown). Figure 3 illustrates the mean fraction of possible occasions when hot food (a small or large hot meal) was eaten by the group of 11 subjects. It shows two peaks, a main one in the period 17:00–20:00 h and a smaller one at 11:00–14:00 h. By contrast, cold food (snacks and previously cooked cold meals) dominated meals eaten in the period 14:00–17:00 h and just before retiring (20:00–23:00 h).

When the other results from the 2-way ANOVA are considered, the main findings are as follows. The factor day number was highly significant for indigestion, indicating that this was felt more commonly on the first
day. For the other variables, even though disturbances were worse on the first day (Figure 2), these were not significantly reduced by the second. There were significant time-of-day effects for the amount of jet lag and the fall in alertness, and effects of marginal statistical significance (0.10 > p > 0.05) for the decreases in concentration and motivation. The significant increase in jet lag with time of day is shown in Figure 4. Alertness, concentration, and motivation all showed falls as the days progressed, their plots being the inverse of that for jet lag. There were significant interactions between time of day × day number for jet lag and decreased alertness, concentration, and motivation, because changes during the course of day 1 were more marked than during day 2, as is illustrated for jet lag in Figure 4.

**FIGURE 3** The mean (+SE) fraction of possible occasions when a hot meal was eaten. Results shown on local (Beijing) and UK clock time. Capital letters A–D indicate the times when the fractions were significantly different (p < 0.05); lowercase letter e indicates when the fractions were marginally significantly different (0.10 > p > 0.05).

**TABLE 1** The Results of the Two-Way ANOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>Day number</th>
<th>Time of day</th>
<th>Interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>F ratio</td>
<td>d.f.</td>
<td>p value</td>
</tr>
<tr>
<td>Jet Lag</td>
<td>2.86</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
<tr>
<td>Alertness</td>
<td>0.54</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
<tr>
<td>Concentration</td>
<td>2.63</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
<tr>
<td>Motivation</td>
<td>4.39</td>
<td>1.0, 10.0</td>
<td>0.06</td>
</tr>
<tr>
<td>Irritability</td>
<td>0.65</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
<tr>
<td>Hunger</td>
<td>0.53</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
<tr>
<td>Indigestion</td>
<td>8.09</td>
<td>1.0, 10.0</td>
<td>0.02</td>
</tr>
<tr>
<td>Meal Type</td>
<td>0.24</td>
<td>1.0, 10.0</td>
<td>n.s.</td>
</tr>
</tbody>
</table>

Significant (p < 0.05) differences shown in bold, differences approaching significance (0.10 > p > 0.05) shown in italics; n.s., p > 0.10.
These results indicate that there was some association between changes in jet lag, alertness, concentration, and motivation, and these were investigated further in the major part of this report. The results of the correlation analyses are summarized in Figure 5. This figure shows the median values of the correlation coefficients calculated between jet lag and some of its symptoms, using different intervals between the times of measurement.

**Figure 4** Mean (+ or − SE) jet lag scores during days 1 and 2. The capital letter B indicates the times when the means of the scores for the two days were significantly different ($p < 0.05$). The lowercase letter a indicates times when the means of the scores for the two days were marginally significantly different ($0.10 > p > 0.05$).

**Figure 5** Median correlations between jet lag and some of its symptoms, the times of measurement of the symptoms being before ($t - 5$ to $t - 1$), at the same time as ($t$), or after ($t + 1$ to $t + 5$) the times when jet lag was measured. For more details of the times and the calculation of these median values, see text. Vertical line, correlations when symptoms compared with jet lag measured at the same time ($t$). Horizontal dotted lines, correlation coefficient significant at the $p = 0.05$ level. Rectangular box, those correlations that were further analysed (see text).
Meal type, hunger, and irritability are not shown, since these variables showed results that were the same as that for indigestion. It is evident that the only symptoms that correlated significantly with jet lag were falls of alertness, concentration, and motivation, and that these variables correlated significantly with jet lag only when they were measured at the same time as jet lag (t, see Figure 5) or one (t − 1) or two (t − 2) time-points earlier than jet lag. No significant correlations were observed when the symptoms were assessed earlier than this, at times (t − 3) to (t − 5), nor when jet lag was correlated with these variables measured later in the day, times (t + 1) to (t + 5).

These results suggest that an individual subjectively assesses the amount of jet lag from the perceived deteriorations in alertness, concentration, and motivation assessed at the same time or up to 6 h earlier (since the time-points were separated by 3 h intervals). In other words, since perceived alertness, motivation, and concentration correlated significantly with jet lag only when they were measured at the same time as, or before, jet lag, then the direction of causality is from them to jet lag rather than the other way around.

These findings form the rationale for treating jet lag as the dependent variable in ANCOVAs (and the other variables as predictors) in the last part of the analysis. They also enable the further analysis to be limited to only three potential predictors (falls in alertness, concentration, and motivation) and to only three time-points: measurements of the predictors at the same time as jet lag, at one time-point before, or at two time-points before—(t), (t − 1), and (t − 2), respectively, in Figure 5.

The results of the ANCOVA analyses are summarized in Table 2. When there was no delay between the times of estimating jet lag and the predictors (and so there were 6 data sets for each day) and when both subjects and day number were entered as random effects, then falls in alertness and motivation were significant predictors, and there was a significant interaction between time of day × day number. Given the β-coefficients for alertness and motivation (Table 2) and that the mean scores for alertness and motivation over the two experimental days were 2.13 and 2.20, respectively, this indicates that these two predictors accounted for 14 and 35% of the mean jet lag score of 4.20 (see Figure 2), that is, almost half.

However, when the same analysis was performed but the measurements of the potential predictors at the previous time-points were compared with jet lag (that is, there were 5 data sets for each day), there were no significant predictors (p > 0.05), even though the interaction between time of day × day number remained significant. When potential predictors measured two time-points earlier than jet lag were used (that is, there were four data sets for each day), then there were no significant
predictors nor any significant interactions between time of day × day number (see Table 2).

These results suggest the significant correlations found between jet lag and the predictors measured one or two tie-points before—at times \( t_2 \) and \( t_2 \), respectively, see Figure 5—were artifacts caused by an effect of day number. In support of this, when day number was eliminated from the ANCOVA and only subjects was entered as a random effect, then the fall in motivation acted as a significant predictor for jet lag when measured one or two time-points before jet lag (Table 2).

**DISCUSSION**

We consider, first, the time-courses of jet lag and its symptoms. This was a subsidiary aim of the present study, the results of larger studies having previously been published (Waterhouse et al., 2000; 2003a). However, the current results show many similarities to these studies.

Before the experiment began, it had been established that subjects normally ate a small hot meal at lunchtime and a larger meal for evening dinner; the results of Figure 2 clearly indicate that this behavior pattern was practiced also in the two days immediately after the simulated time-zone transition. Subjects ate a cooked “lunch” and “dinner” and with snacks and cold food in the afternoon (“tea-time”) and before retiring (“supper”). Relating food intake after the time-zone transition to UK time, by contrast, would mean that meals were eaten as frequently in the

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**TABLE 2** The Significant Predictors for Jet Lag, as Assessed by ANCOVA

<table>
<thead>
<tr>
<th>Variable</th>
<th>( F_{d.l} )</th>
<th>( P ) value</th>
<th>( \beta )-coefficient ± SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Day and subjects treated as random effects</td>
<td>( \beta )-coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A. Predictors measured at same time (( t )) as jet lag (( t ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Alertness</td>
<td>5.13,1,48</td>
<td>0.028</td>
<td>-0.27 ± 0.12</td>
</tr>
<tr>
<td>Motivation</td>
<td>13.37,1,48</td>
<td>0.001</td>
<td>-0.66 ± 0.18</td>
</tr>
<tr>
<td>Time × days interaction</td>
<td>3.97,5,48</td>
<td>0.004</td>
<td></td>
</tr>
<tr>
<td>B. Predictors measured in the time interval before (( t - 1 )) jet lag (( t ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Time × days interaction</td>
<td>3.88,4,40</td>
<td>0.009</td>
<td></td>
</tr>
<tr>
<td>C. Predictors measured in the time interval two before (( t - 2 )) jet lag (( t ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>None</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Time × days interaction</td>
<td>1.20,3,27</td>
<td>n.s.</td>
<td>—</td>
</tr>
<tr>
<td>2. Subjects treated as random effect</td>
<td>( \beta )-coefficient</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B. Predictors measured in the time interval before (( t - 1 )) jet lag (( t ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>17.48,1,94</td>
<td>0.0005</td>
<td>-0.56 ± 0.13</td>
</tr>
<tr>
<td>C. Predictors measured in the time interval two before (( t - 2 )) jet lag (( t ))</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td>10.99,1,73</td>
<td>0.001</td>
<td>-0.52 ± 0.16</td>
</tr>
</tbody>
</table>

n.s., \( p > 0.05 \).
night as during the daytime (compare this with findings with food intake in night workers, Waterhouse et al., 2003a), and that the main hot meal was taken during the morning (09:00–12:00 h) with only cold food at “lunch-time.” This rapid adjustment of food intake accords with the view that it possesses a very weak endogenous component, as has been found in previous studies by ourselves (Waterhouse et al., 2004) and others (Aschoff et al., 1986; Aschoff, 1998; Bogdan et al., 2001).

A significant effect of the time of day was also present in jet lag and alertness, with a trend for this being present in concentration and motivation. For all these variables, the negative effects worsened as the day progressed (Figure 4). This effect has been found previously for “fatigue,” the opposite of alertness (Waterhouse et al., 2003b). The current study also showed that jet lag, alertness, concentration, and motivation all showed a significant interaction between day number and time of day, there being a greater deterioration during the course of the day on the first day (Table 1 and Figure 3). A simple and intuitive explanation would be that deleterious effects of time spent awake would be worse on a day when the overall negative effects were more marked; whatever the detailed reason, there are clear implications for the traveller who wishes to avoid attempting important tasks when the conditions are inopportune.

The effect of the factor day number was generally small and nonsignificant (with the exception of indigestion, see Table 1), even though all variables were closer to normal values on the second day. This result reflects the fact that only two days have been studied, with negative effects still quite marked by the end of the second day. In the previous study (Waterhouse et al., 2000), when results were extended to six days, there was a loss of jet lag and its symptoms by the end of the study; however, to measure the recovery from jet lag was not the aim of the present study.

The general similarities between the between-day and within-day changes to jet lag, alertness, concentration, and motivation implied some link between these variables, and a lack of links with other variables such as irritability, hunger, and indigestion (Table 1 and Figure 4). This supposition was confirmed by the correlation matrices (Figure 5). It is accepted that there is the possibility of Type II errors when this number of correlation coefficients is calculated; however, the “significant” results were used only to limit the number of ANCOVAs that were performed in the final part of the analysis (see below).

A consideration of the effect upon the correlation coefficients of different time intervals between the assessments of jet lag and the other variables provided a rationale for treating jet lag as the dependent variable and the other measurements as predictors. This result could not be obtained in our previous study (Waterhouse et al., 2003b) since practical constraints had meant that we could not measure all variables at all times of the day.
The ANCOVAs enabled the significant predictors of jet lag to be determined after the effects of subject and day number had been taken into account (Table 2). This more sophisticated analysis confirmed the value of alertness and motivation as significant predictors for jet lag, but only if the variables were measured contemporaneously; under these circumstances, the falls in alertness and motivation accounted for half of the mean score for jet lag found on the two days of study. Removing day number as a random factor from the analysis resulted in jet lag being predicted significantly by alertness and motivation over a wider spread of time intervals (Table 2), a result more in accord with the correlation analyses performed in both the present and a previous (Waterhouse et al., 2003b) study.

Both this study and that by Waterhouse et al. (2003b) point to alertness (or fatigue) and motivation as being important determinants of jet lag, with concentration, irritability, food intake, and bowel activity playing less important roles. This would also agree with the earlier observations (Waterhouse et al., 2000) that the time-courses of recovery of some variables (fatigue and motivation, for example) were closer to that of jet lag than were the recoveries of other variables (hunger and bowel activity, for example).

The closer link found in the present study between jet lag, alertness, and motivation might derive from the fact that all have been associated with the circadian rhythm of core temperature (see, for example, Arendt et al., 1987; Folkard, 1990; Dijk et al., 1992; Boivin et al., 1997). Accordingly, it would be predicted that all would be affected more by the desynchronization that presents immediately after a time-zone transition (Graeber, 1982; Waterhouse et al., 1997). By contrast, the weaker link between jet lag and other variables (for example, irritability, hunger, and indigestion) might reflect the fact that these other variables have weaker endogenous components. However, the finding that these variables are negatively affected by a simulated time-zone transition (see Figure 2), where there is no change in the type of food eaten or the general lifestyle, renders untenable the view that, after a real time-zone transition, the responses are solely due to changes in lifestyle and culture in the new environment. As has been suggested previously (Waterhouse et al., 2000; Waterhouse et al., 2003b), these negative feelings appear to contribute to a more general malaise that is associated with jet lag—a feeling of being “below par”; they might, in some way, reflect some of the effects of sleep loss and the disruption to the individual’s routine that arise from the “lost” or “extra” hours following time-zone transitions to the east or west, respectively. Whatever the exact explanation might be, the results indicate that “jet lag” is multifactorial and that a detailed interpretation of it is complex.

While the more sophisticated analysis performed here might account for some of the differences from the results of the previous study...
(Waterhouse et al., 2003b), other possibilities cannot be discounted. Thus, the present study had less subjects, the subjects were less motivated to perform as well as possible, whatever the circumstances, and their schedules were far less demanding.

We conclude that, from a practical viewpoint, “jet lag” not only reflects a general negative effect of time-zone transitions but also can be linked more specifically to contemporaneous falls in alertness and motivation. When these findings are coupled with the previous observations (Waterhouse et al., 2003b)—that jet lag can also be related to some aspects of sleep, whether to the sleep just taken or to that about to be attempted—we reiterate our view that it is important to consider when jet lag is assessed, since the factors determining its severity might depend on the time of assessment. Although some of the negative effects associated with jet lag (for example, alertness) can be inferred with confidence from an assessment of the amount of jet lag made at the same time, even this decrement (in alertness) need not apply reliably at other times of the day.

We consider also that there are arguments for a considering a more focused definition of what constitutes “jet lag,” and for specifying the time of day when jet lag is to be measured—or for making, instead, direct measurements of some of the symptoms of jet lag (Spitzer et al., 1999). We believe that these issues are important when the effectiveness of interventions designed to ameliorate the effects of jet lag (see for example, Haimov and Arendt, 1999; Herxheimer and Petrie, 2002) are considered.

REFERENCES


