Effects of meals on objective and subjective measures of daytime sleepiness

ANITA S. WELLS,1 NICHOLAS W. READ,1 CHRIS IDZIKOWSKI,2 AND JANE JONES3
1Centre for Human Nutrition, University of Sheffield, Northern General Hospital, Sheffield S5 7AU; 2Department of Therapeutics and Pharmacology, Queen's University, Belfast BT9 7BL; and 3New Clinical Entities for Brain Waves, Belfast BT28 2SF, United Kingdom

Wells, Anita S., Nicholas W. Read, Chris Idzikowski, and Jane Jones. Effects of meals on objective and subjective measures of daytime sleepiness. J. Appl. Physiol. 84(2): 507–515, 1998.—Effects of recent food ingestion on daytime sleepiness were assessed in 16 subjects (8 men and 8 women) who were each studied on two occasions, 28 days apart. On each occasion, subjects ate a high-fat low-carbohydrate (CHO) (fat/CHO energy ratio 54:41) meal and an isoenergetic low-fat high-CHO meal (fat/CHO energy ratio 7:88) 4 h apart in a counterbalanced order. Sleepiness was measured at 2-h intervals by using the Multiple Sleep Latency Test and the Akerstedt electroencephalograph sleepiness test. To control for circadian factors, one group (4 men, 4 women) ate the meals 2 h later than did the other group of subjects. There were no differences in sleepiness according to the composition of the meal. Sleepiness in the Multiple Sleep Latency Test was significantly greater 1.5 h after the meals than before (F 11.37; df 1,15; P = 0.004). Sleepiness was also enhanced in the Akerstedt sleepiness test 3 h 20 min after the meals. The results suggest that the meals induced an enhancement in sleepiness that was not solely due to circadian rhythms.

Previous studies have indicated that subjective feelings of sleepiness increase after meals (27, 32, 34, 35) and that the extent of these feelings varies according to the fat and carbohydrate (CHO) content of the food ingested (20, 34, 35). However, neither of these observations has been confirmed by objective measures of sleepiness such as the Multiple Sleep Latency Test (MSLT) (22, 33). One group (33) investigated the effects of a midmorning meal consisting of a hamburger, french fries, and ginger ale (4,067 kJ, 43% energy fat, 44% energy CHO) on sleep latency 20 min and 1–1.5 h later. No premeal sleepiness measures were collected, and no significant differences in sleep latency were observed after the meal compared with when subjects fasted. These negative results may have been due to the timing of the tests; the peak sleepiness may have occurred later than 1–1.5 h after the meal, and sleep latency may have been lengthened in the second test due to the short intervals between naps. Also, some of the effects of the meal may have been masked by subjects drinking coffee as part of their breakfast at 0800. In another study, sleep latency was reduced after both small and large lunches (1,516 and 5,061 kJ), but, because there is a daytime peak in sleepiness in the early afternoon due to circadian variation (5), it is not possible to determine whether this change was fully circadian or whether it was a combination of the time of the day and the recent food ingestion.

Several studies have demonstrated that feelings of sleepiness differ after fat-rich and CHO-rich meals. Subjects fell less alert 2.5 h after high-fat low-CHO lunches than after isoenergetic low-fat high-CHO lunches (20, 35) and less vigorous and more dreamy, feeble, and fatigued after a high-fat brunch than after a low-fat high-CHO brunch (34). However, to our knowledge, no studies have investigated the effects of the fat and CHO content of meals on objective measures of sleepiness.

The present study was designed to explore the relationship between food ingestion and objective measures of sleepiness [the MSLT and the Akerstedt electroencephalograph (EEG) sleepiness test]. The primary aim of the study was to investigate whether objective measures of sleepiness indicate that sleepiness increases after meals and, if so, to demonstrate that this increase is not simply due to circadian variation in sleepiness. The study also aimed to investigate whether isoenergetic high-fat and low-fat meals have differing effects on objective measures of sleepiness. This was done by taking measurements before both high-fat and low-fat meals and 1.5 and 3.5 h afterward and by studying two groups of subjects so that the effects of the time of day with and without recent food ingestion could be compared. Where the opportunity arose, subjective measures of sleepiness and performance in a sustained-attention task were also monitored.

Methods

Subjects

Eight male and eight female subjects [mean age 27 ± 0.9 (SE) yr, mean body mass index 23.4 ± 0.32] were recruited from the Centre for Human Nutrition volunteer register by means of a short telephone interview. Volunteers with high levels of habitual caffeine ingestion, shift workers, smokers, and anyone taking any type of medication or suffering from excessive daytime sleepiness or disturbed nocturnal sleepiness were not accepted into the study. Subjects were randomly divided into two groups (group 1 and group 2), each consisting of four men and four women.

All volunteers gave their written consent for the study to be conducted. The protocol was approved by the ethics committee of the Northern General Hospital Trust.

Protocol

Paired studies to test the effects of meals were conducted on 2 days, 28 days apart, to control for variations due to the menstrual cycle in the female subjects. On each day, subjects...
ate an isoenergetic high-fat low-CHO (HFLC) meal and a
low-fat high-CHO (LFHC) meal in a balanced crossover
design. A no-meal condition was rejected as an adequate
experimental control for a number of reasons. Fasting all
day is unusual; most people eat at least one meal before 1800.
Subjects used to eating breakfast and lunch may experience
adverse physiological symptoms such as headaches, faint-
ness, and dizziness if they fast all day. Furthermore, hunger
is an alerting stimulus that is likely to affect sleep latency,
mood, and concentration.

The subjects were randomly divided into two groups (each
containing 4 male and 4 female volunteers), and the test
meals were eaten by groups 1 and 2 at different times of the
day (Fig. 1). This design enables the effects of the meals on
sleepiness to be assessed in two different ways. First, a simple
comparison may be made between sleepiness before and 1.5 h
after ingestion of food. Second, it provides an opportunity
to examine whether any change is solely due to circadian
variation because comparisons may be made between sub-
jects who have recently eaten a meal (1.5 h previously) and
subjects who have eaten less recently (not for 3.5 h) at a range
of times throughout a typical working day (Fig. 1).

The isoenergetic HFLC (fat/CHO ratio 54:41) and the
LFHC (fat/CHO ratio 7:88) test meals looked and tasted very
similar, were identical in protein content, and consisted of
pancakes with orange slices and a drink of lemon squash
(Table 1). The test meals were designed to supply each
volunteer with one-third of his or her daily estimated energy
requirements (10). Subjects were asked to rate the palatabil-
ity of each test meal by using a five-point scale. Group 1 fasted before their first test meal, and group 2 ate
a similar low-fat caffeine-free breakfast on both test days
day (mean energy 1,049 kJ, mean fat 3 g) consisting of toast,
low-fat spread, jam, breakfast cereal, skim milk, and decaffein-
ated coffee or tea.

The study days were matched for nonnutrient variables in
a number of ways. During the week before each study day,
volunteers kept a diary of their sleep and were instructed to
go to bed and get up at the same times the week before the
second test day as they did before their first test day. On
the evenings before the study, subjects visited the laboratory, ate
a standardized evening meal (lasagne, salad, Danish pastry,
and diet soda; 3,795 kJ, 40% energy fat), and were fitted with
EEG electrodes for the following day's sleep studies. Immedi-
ately before the study, facial electrodes were attached and
volunteers completed a questionnaire about the amount and
quality of sleep the night before.

Testing Procedure

Four subjects were studied on each test day. Two subjects
completed the protocol at the times listed in Fig. 1, and two

<table>
<thead>
<tr>
<th>★M1</th>
<th>?</th>
<th>★</th>
<th>★</th>
<th>M2</th>
<th>?</th>
<th>★</th>
<th>★</th>
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<tr>
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<td>M1</td>
<td>?</td>
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<table>
<thead>
<tr>
<th>Group 1</th>
<th>Group 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time (hours)</td>
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</tbody>
</table>

Fig. 1. Timetable for each test day for groups 1 and 2. ★, Times at which EEG-based measures of sleepiness were recorded; ? , times at which performance and subjective measures of daytime sleepiness and mood were recorded; B, breakfast; M1, first test meal; M2, second test meal.

Table 1. Nutrient composition of test meals

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<th>Fat</th>
<th>CHO</th>
<th>Protein</th>
</tr>
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<tr>
<td>High-fat low-CHO</td>
<td>54</td>
<td>41</td>
<td>5</td>
</tr>
<tr>
<td>Low-fat high-CHO</td>
<td>7</td>
<td>88</td>
<td>5</td>
</tr>
</tbody>
</table>

Values are given as %energy and were calculated by using Com-
Eat nutritional analysis program (Lifeline Nutritional Services Ltd.,
London W2 3EN, UK). CHO, carbohydrate.

subjects completed the protocol 1 h later. The earlier times
are shown throughout the paper.

On each test day, the EEG measures of sleepiness (Aker-
stedt EEG sleepiness test and MSLT; described in EEG
Measures of Sleepiness) were recorded five times, at 2-h
intervals, starting at 0820. This provided measures of sleep-
ness from the Akerstedt EEG sleepiness test before the meals
and 1 h 20 min and 3 h 20 min after the test meals and
measures of sleepiness from the MSLT before the meals and
1.5 and 3.5 h after the test meals (Fig. 1). Subjective
measures of subjective sleepiness (described in Subjective
and Performance Measures of Sleepiness) and a performance
test were also completed at 2-h intervals (Fig. 1). A prescribed
protocol was strictly maintained during the study days;
between tests and questionnaires, subjects were fully super-
vised that they completed a range of filler tasks (e.g., cancel-
certain letters in lines of text, indicating whether sentences
were true or false).

EEG Measures of Sleepiness

Akerstedt EEG sleepiness test. In this test described by
Akerstedt and Gillberg (2) for monitoring sleepiness, the EEG
was recorded while the subjects sat and looked straight ahead
(focusing on a mark on a wall 1 m in front of them) for 5 min.
The recordings were analyzed by using spectral analysis. It
has previously been reported that there is a high correlation
between increased sleepiness and increases in the power
density in the alpha and theta bands of the EEG but only
when subjective sleepiness is quite high (1, 2).

MSLT. This is a validated objective measure of sleepiness
(6). Subjects lay on a bed in a darkened room and were
instructed to keep still with their eyes shut and not resist
falling asleep. EEG electrodes fixed to the subject's head
enabled a polysomnographic technologist in an adjoining
room to monitor arousal objectively. The criterion used for
sleep onset was three consecutive 30-s epochs of stage 1 sleep
or one epoch of stage 2 sleep, determined by using the
standard sleep-stage criteria (25). Sleep latency, the time
between eyes closed and sleep onset, was measured five times
throughout the day at 2-h intervals. If subjects did not fall
asleep within 20 min, the test ended and a score of 20 min was
recorded.

Subjective and Performance Measures of Sleepiness

Stanford Sleepiness Scale (SSS). The SSS is a widely used
method of quantifying changes in sleepiness (15). The scale
consists of seven statements ranging from “feeling active and
vital; alert; wide awake” (one) to “almost in reverie; sleep
onset soon; lost struggle to remain awake” (seven).

Profile of Mood States Questionnaire (POMS). This ques-
tionnaire was used to measure vigor-activity and fatigue-inertia.
Subjects were asked to rate a list of adjectives on a five-point
scale, and from these responses scores were derived by a
factor-analytic technique. The POMS has been shown to be a
sensitive measure of the effects of experimental manipula-
tions on normal subjects and has been shown to have good
internal consistency and validity (23).
Visual Analog Scales (VAS). These were used to assess subjective feelings of sleepiness. Subjects indicated how they felt by marking the appropriate place on each of nine 10-cm lines separating pairs of adjectives: alert-drowsy, dearheaded-muddled, dreamy-attentive, efficient-inefficient, energetic-tired, feedable-strong, quick-witted-mentally slow, vigorous-lethargic, and wide awake-sleepy. The measure taken was the distance in millimeters from the end of the line indicative of arousal. Then the mean of the nine VAS ratings was calculated to give a summary score of subjective sleepiness. The validity and reliability of such VAS have previously been demonstrated in research related to daytime alertness.

University of Wales Institute of Science and Technology Mood Adjective Checklist (UMACL). The UMACL was used to measure energetic arousal. The questionnaire consists of a list of words, and, for each word, volunteers indicated whether it described how they were feeling. This scale has been validated and shown to be sensitive to a range of external stressors such as drugs with sedative effects and sleep deprivation.

Sustained-attention task. This is a high-paced task that places heavy demands on the capacity to pay continuous attention. It reliably indicates failures to maintain the speed and accuracy of performance for longer than a few minutes and has proved sensitive to variations in arousal associated with time on task, time of day (8), and alcohol (26). In this task, a sequence of single digits were displayed in the center of a personal computer visual display unit. To make the task sufficiently demanding, the appearance of the digits was degraded by reversing the polarity of a random 30% of the pixels that defined the digits and their background, thereby producing images that were fuzzy and grainy. Each digit was displayed for $<1$ s, and subjects were required to press the space bar each time a zero appeared. The task lasted continuously for 10 min, during which a total of 600 randomly selected digits were presented, containing an average of 150 zeros. Data analysis of this task was confined to the final 9 min, with the first minute providing an initial warm-up period.

Data Analysis

EEG measures of sleepiness. The data were analyzed to provide answers to three different questions: question 1, Did sleepiness increase after eating a meal? question 2, If so, was this simply due to the time of the day or did recent food ingestion have an influence? question 3, Did the composition of the meal influence sleepiness? Question 1 was answered by using the first analysis, and question 2 was answered by using the second analysis. The third question was addressed in both analyses.

**Analysis 1: Comparison of Sleepiness Before and 1.5 h After Ingestion of Food.** To test whether sleepiness increased after eating a meal, a $2 \times 2 \times 2$ repeated-measures analysis of variance (ANOVA) was performed. The within-subjects factors were composition of meals (HFLC vs. LFHC meal), earlier/later (before and 1.5 h after meal 1 vs. before and 1.5 h after meal 2), and before/after (before eating vs. 1.5 h after eating). Any baseline differences were taken into account by including the data from before test meal 1 as covariates.

Because the effects of the first meal may not have completely worn off just before the second meal, a comparison was made between sleepiness before and 1.5 and 3.5 h after the first meal by using a $2 \times 3$ repeated-measures ANOVA. The within-subjects factors were meal type (HFLC vs. LFHC) and time (3 levels).

**Analysis 2: Examination of Whether Any Changes in Sleepiness Are Solely Due to Circadian Variation.** To answer the second question, measures of sleepiness taken at the same time of the day were compared in subjects who had eaten a meal 1.5 h previously and those who had eaten less recently (not for 3.5 h). This was done by using a repeated-measures ANOVA with composition of meals (2 levels) and time (4 levels) as within-subject factors and group (1 or 2) as a between-group factor. Data from the first tests of the day were used as covariates to adjust for any underlying differences in sleepiness between the groups.

Because the effects of the first meal may not have completely worn off just before the second meal, the effects of just the first meal were analyzed separately in the same way. That is, measures of sleepiness taken at the same time of the day were compared in subjects who had eaten a meal 1.5 h previously and those who had eaten less recently by using a $2 \times 3 \times 2$ repeated-measures ANOVA, with the within-subjects factor being meal type (HFLC vs. LFHC) and time (3 levels) and the between-subject factor being group (1 or 2).

Subjective and performance measures of sleepiness. To test whether subjective measures of sleepiness reported by group 2 increased after they ate a meal, a $2 \times 2 \times 2$ repeated-measures ANOVA was performed. The within-subjects factors were composition of meals (HFLC then LFHC vs. LFHC then HFLC), earlier/later (before and 45 min after meal 1 vs. before and 45 min after meal 2), and before/after (before eating vs. 45 min after eating). Any baseline differences were taken into account by including the data from before test meal 1 as covariates.

Because the effects of the first meal may not have completely worn off just before the second meal, a comparison was made between sleepiness before and 45 min and 2 h 45 min after the first meal by using a $2 \times 3$ ANOVA. The within-subjects factors were meal type (HFLC vs. LFHC) and time (3 levels).

The data from the sustained-attention task completed by group 2 were analyzed in a similar way as was the subjective sleepiness data, except that in the sustained-attention task an additional factor, block, was also included. This was because before analysis the data collected during minutes 2-10 were separated in three 3-min blocks. However, covariates were unable to be included in this analysis as there were too few degrees of freedom available. It is important to note that the data from the sustained-attention task and questionnaires from group 1 were excluded because there were no premeal baseline data available.

Palatability ratings of the test meals were analyzed by using a repeated-measures ANOVA, with the within-subject factors being composition of meals (HFLC vs. LFHC) and time (first meal of the day vs. second meal of the day). Sleep before the test days was compared by using a paired Student’s $t$-test.

The F values, degrees of freedom, and significance levels listed are for averaged tests; however, in Tables 3 and 5 when the word Wilks follows the F score, the values are based on the Wilks test, which is a multivariate test, because the data failed to meet univariate assumptions of homogeneity of both variance and covariance tested by the Mauchly sphericity test.

**Results**

Comparison of Pre- and Postmeal Sleepiness

MSLT. Mean sleep latency was significantly shorter 1.5 h after the test meals than it was just before the meals ($F_{1,15} = 11.37; df = 1,15; P = 0.004$): 12.6 ± 3.8 (SD) compared with 14.3 ± 4.1 min. Sleep latency did not
Table 2. Analysis of data from before and after both test meals to compare pre- and postmeal measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Composition of Meals by Before/After (df 1,15)</th>
<th>Composition of Meals by Early/Late (df 1,15)</th>
<th>Composition of Meals by Before/After (df 1,15)</th>
<th>Composition of Meals by Early/Late (df 1,15)</th>
<th>Composition of Meals by Before/After (df 1,15)</th>
<th>Composition of Meals by Early/Late (df 1,15)</th>
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<tr>
<td>MSLT</td>
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<td>11.37†</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
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<td>&lt;1</td>
<td>11.37†</td>
<td>&lt;1</td>
<td>&lt;1</td>
<td>&lt;1</td>
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<tr>
<td>Theta</td>
<td>&lt;1</td>
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<td>&lt;1</td>
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<tr>
<td>Alpha</td>
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<tr>
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Table 3. Analysis of data from before and after first meal only to compare pre- and postmeal measures

<table>
<thead>
<tr>
<th>Measure</th>
<th>Meal Type by Before/After (df 1,15)</th>
<th>Time (df 2,30)</th>
<th>Meal Type by Time (df 2,30)</th>
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<td>POMS fatigue</td>
<td>&lt;1</td>
<td>4.58*</td>
<td>2.87</td>
</tr>
<tr>
<td>POMS vigor</td>
<td>&lt;1</td>
<td>13.17†</td>
<td>3.61</td>
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<tr>
<td>VAS sleepiness</td>
<td>&lt;1</td>
<td>72.85‡</td>
<td>1.88</td>
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<td>Energetic arousal</td>
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<td>5.90‡</td>
<td>3.18</td>
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Values are F ratios. MSLT, Multiple Sleep Latency Test; SSS, Stanford Sleepiness Scale; POMS, Profile of Mood States Questionnaire; VAS, Visual Analog Scale. *P < 0.05, †P ≤ 0.01, ‡P ≤ 0.001.

significantly differ according to the composition of the test meal or between tests earlier or later in the test day (Table 2). The analysis of the effects of the first test meal indicated that sleep latency significantly differed over time (F 5.07; df 1,15; P = 0.013) (Table 3). Sleep latency declined 1.5 h after the first test meal and only partially returned to the premeal level 2 h later (Fig. 2).

Akerstedt EEG sleepiness test. Power in the alpha and theta bands of the Akerstedt EEG was greater in the later part of the day compared with earlier (F 12.52; df 1,15; P = 0.003 and F 11.00; df 1,15; P = 0.005, respectively), but there were no significant differences between the pre- and postmeal scores or according to the type of food ingested (Table 2). Analysis of the effects of the first test meal indicated that power in the alpha and theta bands significantly varied at the different test times (F 5.39; df 2.30; P = 0.010; F 6.84; df 2.30; P = 0.004) (Table 3). Power was at a similar level in the premeal and 1 h 20 min postmeal tests, whereas in the test 3 h 20 min after the meal, power was considerably heightened in both bands (Fig. 3).

Power in the beta band increased steadily throughout each test day, (earlier/later F 11.91; df 1,15; P = 0.004 and before/after F 15.44; df 1,15; P = 0.001). There were no significant changes in power in the delta band according to any of the within-subject factors (Tables 2 and 3). The composition of the test meals did not significantly affect power in the beta or delta bands.

Fig. 2. Sleep latency in Multiple Sleep Latency Test at 2-h intervals throughout the working day, before and after meals. □, High-fat low-carbohydrate (CHO) meal eaten as meal 1 and low-fat high-CHO meal eaten as meal 2; ■, low-fat high-CHO meal eaten as meal 1 and high-fat low-CHO meal eaten as meal 2. Values are means for 16 subjects; SEs are indicated by vertical bars.
Changes in Sleepiness in Relation to the Time of Day and Recent Food Ingestion

MSLT. Analysis of the data to establish whether the pre- and postmeal changes in sleepiness were solely due to the time of day or whether they were also due to recent food ingestion revealed that for sleep latency there was a significant interaction between the group subjects were in and the time of the day ($F_{2.99}; df = 3,42; P = 0.042$; Table 4). From Fig. 4, it is apparent that sleep latency tended to decline to a greater extent (or increase to a lesser extent) in subjects who had eaten a meal 1.5 h previously than in those who had not eaten for 3.5 h. The largest postmeal changes occurred between tests 2 and 3 and between tests 3 and 4, i.e., when meals were eaten between 1100 and 1400. A similar group by time interaction was significant when the analysis was restricted to effects of the first test meal of the day only ($F_{6.66}; df = 1,14; P = 0.022$).

Akerstedt EEG sleepiness test. There were no significant interactions between group and time when the Akerstedt EEG data from both test meals were analyzed; however, analysis of the data from the first three tests of the day revealed a significant group by time interaction for power in the theta ($F_{5.00}; df = 1,14; P = 0.042$) and alpha ($F_{5.28}; df = 1,14; P = 0.037$) bands in the Akerstedt EEG sleepiness test (Table 4). There was a substantial increase in power in the theta and alpha bands between 1 h 20 min and 3 h 20 min after group 1 ate meal 1 (mean change: theta $3.88 \pm 1.86$, alpha $6.81 \pm 2.58$), but parallel changes were not observed in group 2 at that time of day (mean change: theta $-0.75 \pm 0.91$, alpha $0.19 \pm 1.3$). There were no significant changes in the beta and delta bands (Table 4).

Subjective Ratings of Sleepiness

Analysis of the effects of both test meals indicated that subjective ratings of sleepiness on the SSS and VAS and of fatigue, vigor, and energetic arousal varied significantly ($P < 0.05$) between the earlier and later meals.

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Table 4. Analysis to compare changes in sleepiness in relation to time of day and recent food ingestion

<table>
<thead>
<tr>
<th>Measure</th>
<th>Both Meals</th>
<th>First Meal Only</th>
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<tr>
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<td>Time (df 3,42)</td>
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<td>1.19</td>
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<tr>
<td>Akerstedt EEG</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Theta</td>
<td>$&lt;1$</td>
<td>4.08*</td>
</tr>
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<td>10.73*</td>
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<tr>
<td>Delta</td>
<td>$&lt;1$</td>
<td>1.34</td>
</tr>
</tbody>
</table>

Values are $F$ ratios. *$P < 0.05$, †$P < 0.01$, ‡$P < 0.001$.  

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Fig. 3. Power in Akerstedt EEG sleepiness test in alpha (○, ●) and theta (□, ■) bands at 2-h intervals throughout the working day, before and after meals. □, ○: high-fat low-CHO meal eaten as meal 1 and low-fat high-CHO meal eaten as meal 2; ●, ■: low-fat high-CHO meal eaten as meal 1 and high-fat low-CHO meal eaten as meal 2. Values are means for 16 subjects; SEs are indicated by vertical bars.

Fig. 4. Changes in sleep latency in Multiple Sleep Latency Test at different times during working day. Group 1 (○) and group 2 (●) ate meals at different times (as indicated). A: when a high-fat low-CHO meal was eaten as meal 1 and a low-fat high-CHO meal was eaten as meal 2. B: when a low-fat high-CHO meal was eaten as meal 1 and a high-fat low-CHO meal was eaten as meal 2. Values are means for 8 subjects; SEs are indicated by vertical bars.
parts of the test days (Table 2). Feelings of sleepiness and fatigue increased and feelings of vigour and energetic arousal declined throughout the day (Fig. 5). Overall, subjects tended to feel less vigorous 45 min after the meals than they did before eating (mean vigor: premeal 15.72 ± 2.46, postmeal 13.88 ± 2.41).

There were also significant three-way interactions among the composition of meals, early/late, and before/after for fatigue, VAS sleepiness, and energetic arousal. These interactions were due to differences in ratings at the start of the test days, before the first meal.

Analysis of the effects of the first test meal only (Table 3) revealed that overall feelings of sleepiness tended to increase over time.

**Sustained-Attention Task**

Performance declined throughout each test day; correct responses were fewer and false alarms more frequent in the latter half of the test day (early/later hits F 5.90; df 1,7; P = 0.046 and false alarms F 11.12; df 1,7; P = 0.013) (Table 5). The type of meal affected the frequency of false alarms. Compared with before eating, there were more false alarms made 45 min after the first test meal when it was low in fat and less when it was high fat (composition of meals by earlier/later by before/after F 5.83; df 1,7; P = 0.046). Analysis of the effects of the first test meal indicated that the speed of correct hits varied according to the meal ingested and block of the test (F 12.82; df 2,14; P = 0.007). After the LFHC meal there was a linear decline in speed across the three blocks, whereas, after the HFLC meal, responses slowed between the first and second blocks but thereafter remained more steady.

**Previous Night’s Sleep**

Analysis of the post-sleep questionnaires revealed that there were no significant differences in the length of sleep or ratings of the quality of sleep experienced on the night before the first and second test days or between members of groups 1 and 2.

**Palatability of the Test Meals**

Whether the test meal was liked varied according to the composition and the time of the day at which it was eaten (F 9.67; df 1,15; P = 0.007). The LFHC meal was rated as being more palatable in the morning than in the afternoon, whereas the ratings of the HFLC meal were similar in the morning and the afternoon.

Fig. 5. Ratings of subjective sleepiness at 2-h intervals throughout working day, before and after meals. Shown are ratings of sleepiness on Stanford Sleepiness Scales (SSS; ○), subjective feelings relating to enhanced sleepiness on Visual Analog Scales (VAS; ●), ratings of vigor (▲) and ratings of fatigue (●) on Profile of Mood States Questionnaire (POMS), and ratings of energetic arousal on UWIST Mood Adjective Checklist (■). A: when a high-fat low-CHO meal was eaten as meal 1 and a low-fat high-CHO meal was eaten as meal 2. B: when a low-fat high-CHO meal was eaten as meal 1 and a high-fat low-CHO meal was eaten as meal 2. Values are means for 8 subjects; SEs are indicated by vertical bars.
Effects of Food Ingestion Per Se on Sleepiness

The results of both the MSLT and the Akerstedt EEG sleepiness test indicate that sleepiness increased after eating. Sleep latency was significantly shorter 1.5 h after the subjects ate a meal than it was before they ate, and there were increases in power in both the alpha and theta bands during the Akerstedt EEG sleepiness test 3 h 20 min after eating. By varying the times at which the meals were ingested by the two groups of subjects, we have shown that these increases in sleepiness after food were not solely due to circadian effects, thereby demonstrating for the first time in humans that the ingestion of meals can increase objective signs of sleepiness.

It is not unusual for sleepiness measured by the MSLT to show changes before other measures of sleepiness. For example, Johnson and colleagues (18) reported that peak sleepiness measured by the MSLT occurred 2 h before the peak sleepiness measured by the SSS and VAS. The Akerstedt EEG sleepiness test and the MSLT are very different tests. Subjects sat in a chair staring ahead during the Akerstedt EEG sleepiness test, whereas in the MSLT they lay on a bed and were asked not to resist falling asleep. Thus the underlying state of their sleep and wakefulness systems is not likely to be the same in both tests, and it is not surprising that the increased sleepiness was indicated by the MSLT and the Akerstedt EEG sleepiness test at different times after the meals. Furthermore, the changes in subjective ratings of sleepiness measured by the SSS and VAS in the present study followed a similar pattern to changes in sleepiness indicated by the Akerstedt EEG sleepiness test.

Our findings also indicate that meal-related sleepiness is not confined to the middle of the day. Postprandial increases in sleepiness in the MSLT were apparent at a wide range of times during a typical 9-to-5 working day, although the magnitude of the postprandial sleepiness was greatest after meals eaten between 1100 and 1400. This is consistent with the observation that performance in tasks requiring sustained attention is affected to a larger extent by meals eaten at lunchtime than at breakfast or in the evening (28, 31). One might expect sleepiness to be greater at the end of the day than at the beginning, but it is possible that the sharp increase in circadian alertness and performance that occurs after 1500 (3) masked the effects of the food.

The MSLT has been shown to be predictive of the vulnerability to fall asleep in low-stimulus environments (5). Real-life situations when there is little stimulation might include driving on a quiet highway, performing repetitive tasks on an assembly line, and performing tasks requiring prolonged vigilance such as air-traffic control and work in the control room of power stations (5). Several studies have shown that in the early afternoon there is a daytime peak in the number of errors and lapses of attention in tasks such as meter reading and driving (trains and cars) (see Ref. 6 for a review) as well as in sleep-related vehicle accidents (16). Thus the results of the present study indicate a possible need for food ingestion to be controlled in any studies investigating daytime sleepiness/alertness and vigilance, both in the workplace and in the laboratory. Further studies are needed to develop ways of minimizing food-induced sleepiness, e.g., by exploring the effects of meal size, timing, and consumption of stimulants such as caffeine.

Comparison of the Effects of High-Fat and Low-Fat Meals

The objective EEG-based tests did not show any significant differences in sleepiness after isoenergetic high-fat compared with low-fat meals. This contrasts

### Table 5. Analysis of performance in the sustained attention task

<table>
<thead>
<tr>
<th></th>
<th>df</th>
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<th>Number of False Alarms</th>
<th>Response Time for Hits</th>
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Analysis of effects of meal 1 only

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<td>&lt;1</td>
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</table>

Values are F ratios. (Wilks) indicates that values are based on Wilks test. *P < 0.05. †P < 0.01.
with previous studies using subjective and performance measures of sleepiness that demonstrated that HFLC and LFHC meals have differing effects on sleepiness (21, 33). Discrepancies between different measures of sleepiness are not at all unusual (17) and may simply be due to differences in the sensitivity of the tests to small changes in sleepiness (11). Some investigators believe that performance tasks are more sensitive measures of sleepiness than are pure observations like the MSLT because they focus the subject’s mental activity on a specific task (36).

There was some evidence that performance in the sustained-attention task differed according to meal composition. Forty-five minutes after the first meal, subjects made more false alarms in the sustained-attention task when they had eaten the LFHC meal than after the HFLC meal. This observation is consistent with previously reported differences in the number of false alarms after a low-fat brunch than after a high-fat brunch (34). Differences in subjective ratings of sleepiness after the HFLC and LFHC meals were not apparent in the present study. Collection of these data was not a primary aim of the investigation, and the measurements had to be taken where there were available opportunities. The difference between the results of the present study and those of previous investigations may be because this type of data is usually collected more frequently (every 1 or 0.5 h) and investigations may be because this type of data is available opportunities. The difference between the results of the present study and those of previous investigations may be because this type of data is usually collected more frequently (every 1 or 0.5 h) and investigations may be because this type of data is usually collected just before the meal rather than 1 h 15 min before the meal as in the present study (20, 34, 35). Also, aspects of the present protocol such as the subjects lying in a darkened room, falling asleep, and then being immediately woken up may have impacted on subjective ratings of sleepiness.

In conclusion, the results of the present study suggest that the ingestion of food can cause an enhancement in sleepiness, which can be measured by using electrophysiological techniques and which is not solely due to circadian effects.

Address for reprint requests: A. S. Wells, Centre for Human Nutrition, Univ. of Sheffield, Northern General Hospital, Harries Rd., Sheffield S5 7AU, UK (E-mail: A.S.Wells@sheffield.ac.uk).

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