Appetite, 1996, *27*, 151–164

Acute Effects on Mood and Cognitive Performance of Breakfasts Differing in Fat and Carbohydrate Content

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Sixteen subjects consumed low-fat/high-carbohydrate (LFHC), medium-fat/medium-carbohydrate (MFMC), high-fat/low-carbohydrate (HFLC) iso-energetic breakfasts and no breakfast in a counterbalanced order on four separate days. The LFHC breakfast was similar in macronutrient composition, though not in meal size (more kcal) and types of foods offered, to the habitual breakfast of the subjects. A battery of cognitive performance tasks together with mood and appetite ratings were completed before and during the 3 h following breakfast. Results showed no clear differences in performance between the four dietary conditions, but significant effects on mood were observed. Mood improved (a decline in fatigue/dysphoria) following the LFHC breakfast compared to the other meals. The findings show that the macronutrient content of breakfast, independent of energy value and oro-sensory qualities, can exert small but reliable effects on subsequent mood, and suggest that deviation from habitual meal composition can produce a relative decline in mood state. These conclusions are supported by results from a previous study of the effects of lunch which found very similar relationships between meal composition, habitual choices and postprandial mood changes.

Introduction

Many studies have shown post-lunch changes in mood and impairment of cognitive efficiency (Craig, Baer & Diekman, 1981; Smith & Miles, 1986a, 1986b), although the same phenomena have not been found to occur following consumption of breakfast. Despite the fact that this is commonly believed to be "the most important meal of the day", relatively few studies have investigated the effects of breakfast on subsequent performance. Some early studies relating to the effects of breakfast on performance were carried out in the 1940's and 50's and were collectively known as the Iowa Breakfast Studies. Tuttle *et al.* (1949, 1950, 1952, 1954) compared the effect of breakfast vs. no-breakfast on mental and physical performance, and it was these studies that were influential in promoting the common belief that skipping breakfast is detrimental to performance. The actual findings, however, were in-

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0195–6663/96/050151 + 14 $25.00/0

consistent, and in addition have been criticized (Dickie & Bender, 1982) for their small subject numbers, the use of only simple reaction time as a measure performance, and the subjective nature of some of the other assessments.

Since then, most studies have focused on the effect of missing breakfast in school-children, in whom it has been shown that skipping breakfast is quite common. Pollitt *et al.* (1981, 1983) looked at the effects of missing breakfast on the performance of 9–11 year old well-nourished children, and found lower scores for accuracy of matching figures in the no-breakfast group compared to those children who had been fed. On the other hand, a marginal *improvement* in memory and higher scores on tasks of incidental learning after omitting breakfast were observed. In a similar study, Connors & Blouin (1983) found improvement on a test of attention span and vigilance in a group of adolescents when fed breakfast compared to no breakfast.

Richards (1972) studied the effects of a 450 kcal breakfast vs. no-breakfast on a range of tasks, including a visual search test, a short-term memory test, an error vigilance test and a coding test. The study used habitual breakfast and non-breakfast eaters, and the results showed no change in performance associated with the consumption or omission of breakfast. Dickie and Bender (1982) also reported no effect of missing breakfast on performance on arithmetic, short-term memory and vigilance tasks in a sample of school-children. Benton and Sargent (1992), however, found that fed subjects (university students) were significantly faster on two memory tasks than starved subjects. In agreement with Benton and Sargent (1992), Smith, Kendrick, Maben and Salmon (1994) found that memory was improved following consumption of breakfast compared to missing breakfast, but that it had no effect on simple reaction time, choice reaction time or sustained attention. There were also some significant effects on mood, with the group receiving a cooked breakfast (bacon, egg and toast) reporting feeling more sociable and outward-going and less discontented than those having either an iso-caloric light breakfast (toast and cereal) or no breakfast.

As with lunch, the size and composition of breakfast appears to be a factor involved in the post-meal response. Michaud, Musse, Nicolas & Mejean (1991) found in adolescents consuming higher than normal energy intakes at breakfast that there was an improvement in immediate recall, but a decline in concentration. In addition, Richards (1972) found that deviation from normal breakfast produced the worst performance on a range of tasks. In one of the few studies to look at the effect of breakfast composition on cognitive performance, Conners, Caldwell and Caldwell (1985) reported slower reaction times in children fed a high carbohydrate breakfast compared to those fed a high protein breakfast or no breakfast.

A previous study by this research group (Lloyd, Green & Rogers, 1994) has shown that differences in the fat and carbohydrate content of lunch can have significant effects on subsequent mood and simple reaction time performance. This has not been investigated at breakfast, and the main objective of the present study was to investigate the effects of breakfast composition on morning mood and cognitive performance. An important aspect of the study was the fact that the fat and carbohydrate content of the breakfasts were manipulated covertly. In addition, a no breakfast condition was included, although it is realized that changes in mood and performance associated with this manipulation may be due to altered expectations of the subjects, as well as to nutritional effects.

TABLE 1
Components of the three test breakfasts

	LFHC breakfast	MFMC breakfast	HFLC breakfast
White bread rolls (g)	50	50	50
Margarine (g)	13	10	15
Jam (g)	20	15	15
Sweetened milk drink (ml)[a]	250	200	200
Extra-thick double cream (ml)[a]	—	30	40
Maltodextrin (g)[a,b]	37	20	—
Water (mls)	—	40	40

Nutritional information obtained from standard food composition tables (Paul & Southgate, 1978), except for [a] which were obtained from manufacturers' data.
[b] C*PUR from Cerestar U.K. Ltd.

METHODS

Subjects

Sixteen healthy habitual breakfast eaters (14 female, 2 male, mean and *SEM* age 26·1 ± 0·4 years) were recruited from the staff of the Institute of Food Research, Reading. All were of normal weight for height (mean ± *SEM* body mass index [weight(kg) height(m)$^{-2}$] = 23·4 ± 0·5). Subjects gave their informed written consent prior to participation in the study, which was approved by the Institute of Food Research Human Research Ethics Committee.

Design and Treatments

The study was carried out according to a within subjects design. Subjects were required to attend for testing at the Institute of Food Research on the same morning of four consecutive weeks, where they received, in a counterbalanced order, low-fat/high-carbohydrate (LFHC), medium-fat/medium-carbohydrate (MFMC), high-fat/low-carbohydrate (HFLC) iso-energetic breakfasts and no breakfast (NB). Each of the breakfasts consisted of bread rolls with margarine and jam and a milkshake (Table 1). Fat content was manipulated by varying the amount of margarine used on the rolls and by the addition of extra thick double cream to the MFMC and HFLC milkshakes. The carbohydrate content of the MFMC and LFHC shakes was increased by adding a maltodextrin (C*PUR, Cerestar U.K. Ltd). The macronutrient composition of the breakfasts is shown in Table 2. Each of the three breakfasts were similar in energy and protein content (and the milkshakes of equal volume), while the fat and carbohydrate content of the meals varied from 27%–56% energy from fat and 62%–34% energy from carbohydrate.

Procedure

The subjects were blind to the true purpose of the study. They were told that they were taking part in a study to examine the effects of time of day on mood and cognitive performance, and that they needed to consume a standard breakfast in

TABLE 2

Energy content and macronutrient composition of the three test breakfasts

	LFHC breakfast	MFMC breakfast	HFLC breakfast
Energy (kcal)	600	601	608
Fat g (% of energy)	18·4 (27)	29·3 (44)	38·5 (56)
Carbohydrate g (% of energy)	98·7 (62)	74·8 (47)	56·2 (34)
Protein g (% of energy)	15·2 (10)	13·8 (9)	14·5 (9)

Values calculated from standard food composition tables (Paul & Southgate, 1978) and manufacturers' information.

order to minimize any external confounding effects, and on one occasion to have no breakfast as a control condition.

Subjects were asked to eat a similar meal on the evening before each test session and to refrain from eating or drinking after 10 pm that night until the test session. Breakfast was given at 8.30 am and subjects were required to consume all of the meal within 15 min. The time taken to finish the meal was recorded for each subject at each session. Immediately after each meal, subjects were asked to rate the "pleasantness" of the bread rolls and the milkshake using two separate 100 mm line scales with the end points labelled "not at all" and "extremely". Assessment of mood and cognitive performance was carried out beginning 30 min before and 30, 90 and 150 min after breakfast, with mood also being assessed immediately on finishing breakfast. In addition, ratings of "hunger", "fullness" and "desire to eat" were completed before breakfast, on finishing breakfast and 30, 90 and 150 min after breakfast using 100 mm line scales labelled from "not at all" to "extremely". Subjects were asked to refrain from eating or drinking anything (except water) after they had eaten breakfast until the end of the last testing session. In order to assess habitual breakfast intake subjects were interviewed by a State Registered Dietician prior to commencement of the study.

Measures

Mood ratings

Subjects rated their mood using 16 line scales covering the major dimensions of alertness, anxiety and depression (see Table 3 for list of mood adjectives). Each mood descriptor was followed by a 100 mm line labelled at the extremes "not at all" and "extremely". Subjects were instructed to rate how they felt at the time by placing a short vertical stroke at the appropriate place on each line. These ratings were converted to a score for each mood by measuring the distance in cm of the stroke from the left hand side ("not at all") of the line.

This questionnaire was developed from the Profile of Mood States Bipolar form (POMS-BI) (Lorr & McNair, 1988) and the short form of the Activation–Deactivation Adjective Checklist (AD ACL) (Thayer, 1989). For each of five of the mood states characterized by POMS-BI two adjectives were included in the questionnaire as follows: "friendly", "angry" (Agreeable–Hostile scale); "cheerful", "dejected" (Elated–Depressed); "confident", "uncertain" (Confident–Unsure); "clearheaded", "muddled" (Clearheaded–Confused); and "calm", "tense" (Composed–Anxious). Four adjectives

TABLE 3
Factor loadings and % of variance explained for the 16 mood scales

	Factor 1 (fatigue/dysphoria)	Factor 2 (relaxation)	Factor 3 (alertness)	Factor 4 (elation)
Angry	<u>0·48</u>	0·09	<u>−0·55</u>	−0·09
Calm	−0·19	<u>0·80</u>	0·05	0·13
Cheerful	−0·03	<u>0·40</u>	0·17	<u>0·76</u>
Clearheaded	−0·07	<u>0·73</u>	0·31	−0·00
Confident	0·01	<u>0·83</u>	0·06	0·07
Dejected	<u>0·49</u>	0·21	−0·25	<u>−0·52</u>
Drowsy	<u>0·62</u>	−0·03	<u>−0·53</u>	0·34
Energetic	0·05	0·18	<u>0·89</u>	0·08
Friendly	−0·03	<u>0·43</u>	−0·01	<u>0·59</u>
Jittery	<u>0·75</u>	−0·24	0·18	−0·15
Lively	0·03	0·23	<u>0·85</u>	0·22
Muddled	<u>0·87</u>	−0·16	−0·04	0·01
Placid	−0·03	<u>0·74</u>	0·07	0·20
Tense	<u>0·74</u>	0·03	−0·23	0·03
Tired	<u>0·44</u>	−0·19	<u>−0·56</u>	<u>0·41</u>
Uncertain	<u>0·82</u>	0·04	0·01	−0·09
% variance	30·0%	18·5%	12·3%	8·0%

Values underlined indicate the greatest contributors to the factor.

were included for the remaining mood state characterized by POMS-BI, namely "energetic", "lively", "drowsy" and "tired" (Energetic–Tired), together with "jittery" and "placid". Six of these last eight adjectives are also included in the four subscales of the AD ACL: "energetic", "lively" (Energy); "tense" (Tense); "drowsy", "tired" (Tiredness); "calm" (Calmness). These subscales can be combined to form the bipolar dimensions of energetic arousal (Energy and Tiredness) and tense arousal (Tension and Calmness) (Thayer, 1989), which in turn correspond closely to the Energetic–Tired and Composed–Anxious scales from POMS-BI.

Performance tests

Subjects were asked to carry out a series of computer based cognitive tasks which have been shown to be sensitive to dietary manipulations (Lloyd *et al*., 1994; Green, Rogers, Elliman & Gatenby, 1994). The total time taken to complete this task battery was approximately 20 min. External testing conditions were uniform for all subjects. One week before commencement of the study, subjects were given a practice session in order for them to become familiar with the instructions and the working of the tests. All tasks were programmed, and initial data collected and analysed using MEL 1.0 (Psychology Software Tools, Inc., Pittsburg, PA, U.S.A.) installed on a Viglen 386 PC with a 13″ VGA colour monitor. The tasks were carried out in the order shown below.

Bakan task. This was a 6 min version of a rapid visual information processing task with a high working memory load in which subjects were presented with a continuous sequence of single digits on the computer screen. The subjects' task was to press the space bar as fast as possible when they thought they had detected a sequence of either three odd or three even numbers. The presentation rate was 100 digits per minute with no inter-stimulus interval. Eight target sequences were presented each minute. The number of targets correctly detected and the number of false positives were recorded.

Two-finger tapping task. This was a test of motor speed in which subjects were required to alternately tap the 1 and 2 numeric keys on the computer keyboard as quickly as possible using their index and middle fingers. The dependent variable was the number of taps made per second.

Free recall task. Subjects were shown two lists of 20 words each. All the words were concrete nouns between four and eight letters long and were matched on frequency of use and abstractness. Subjects received a different list each time they completed the task—one list was presented at a rate of 1 second per word and the other at 2 seconds per word. Immediately following each list, subjects were given 4 min to write down as many of these words as they could remember.

Simple reaction time task. This was a self paced task in which subjects were required to press the space bar on the computer as quickly as possible after seeing the target stimulus (*) appear on the screen. There was a variable stimulus onset of 1–3 seconds, in order to control for possible stimulus anticipation effects. There were 80 stimulus presentations and the dependent variable was the mean reaction time for all stimulus presentations.

Analysis

Principal Components Analysis (with varimax rotation) was performed on the baseline mood ratings to produce a smaller number of independent moods. The loadings for these (rotated) principal components were used to calculate principal component scores for all the time points, which were used in subsequent analyses. Baseline scores for the principal components and baseline performance scores for each task were subtracted from the post-meal scores in order to compare changes in mood and performance between conditions. Baseline measurements of all performance and mood scores were also analysed to check for differences using analysis of variance. Within subject analyses of variance (Schlich, 1993) were carried out on the mood and performance data to examine the effects of meal macronutrient composition (MEAL) in relation to the time elapsed after consumption of the meal (TIME) and the order in which the meals were given (ORDER). Nutritional analysis of the subjects' habitual breakfast intake was performed by CompEat nutritional analysis programme (Lifeline Nutritional Services Ltd, London, U.K.).

RESULTS

Mood Ratings

Mood ratings at baseline produced four principal components which accounted for 62% of the variance (Table 3). The four varimax rotated principal components were described as fatigue/dysphoria, relaxation, alertness and elation. There were no

TABLE 4

F *ratios and significance levels for analysis of variance of MEAL, TIME, ORDER and interaction effects for the four mood factors, hunger, fullness and desire to eat (results for analyses which included the no breakfast condition are given in square brackets)*

	Meal $df=2,26$ [$df=3,40$]	Time $df=3,78$ [$df=3,120$]	Order $df=3,26$ [$df=3,40$]	Time × order $df=9,78$ [$df=9,120$]	Meal × time $df=6,78$ [$df=9,120$]
Mood factor					
Fatigue/dysphoria	2·29	0·42	1·74	0·42	2·37*
	[1·95]	[0·33]	[2·45]	[0·56]	[2·14*]
Relaxation	0·33	3·52*	0·81	0·69	1·18
	[0·30]	[4·88*]	[0·35]	[1·21]	[1·28]
Alertness	1·25	0·83	0·11	0·63	0·94
	[1·17]	[1·94]	[0·29]	[0·63]	[0·89]
Elation	0·50	0·27	4·64*	0·94	1·06
	[0·37]	[0·47]	[1·94]	[1·56]	[1·62]
Appetite rating					
Hunger	0·47	20·28**	1·51	1·31	0·86
	[11·34**]	[19·44**]	[1·21]	[0·61]	[1·21]
Fullness	0·54	50·99**	1·31	0·50	0·80
	[26·31**]	[62·24**]	[0·67]	[0·47]	[3·74**]
Desire to eat	1·28	23·19**	0·89	0·94	0·43
	[13·44**]	[20·98**]	[0·26]	[0·44]	[0·96]

*$p<0·05$; **$p<0·001$.

significant MEAL effects for baseline principal component scores for any of these four factors, $F(3,42)<0·64$, $p>0·1$.

Initial inspection of the data revealed large variations in the way subjects responded to missing breakfast. For this reason, and because this was the one condition which was obviously different (to the subjects) from the other three treatments, the description of the results presented here excludes the NB data. For the sake of completeness, however, the summaries of the analyses given in Tables 4 and 5 show results both with and without the NB condition included.

Table 4 shows that there was a significant MEAL × TIME effect for factor 1 ($p=0·038$). This result was due primarily to a rapid and sustained reduction in fatigue/dysphoria following the LFHC breakfast, in contrast to the negligible changes in fatigue/dysphoria after the MFMC and HFLC meals (Fig. 1). The figure also shows that on average the response to missing breakfast was most similar to the effects of the MFMC and HFLC breakfasts. There were no significant effects involving MEAL for the other three factors (Table 4).

There was a significant effect of ORDER for the fourth factor, elation, but there were no other effects of ORDER for mood or for any of the appetite or performance measures (see below).

TABLE 5

F *ratios and significance levels for analysis of variance of MEAL, TIME, ORDER and interaction effects for the performance tasks (results for analyses which included the no breakfast condition are given in square brackets)*

Performance task	Meal $df=2,27$ [$df=3,42$]	Time $df=2,54$ [$df=2,84$]	Order $df=3,27$ [$df=3,42$]	Time × order $df=6,54$ [$df=6,84$]	Meal × time $df=4,54$ [$df=6,84$]
Simple reaction time	1·69 [1·32]	0·37 [1·15]	0·88 [0·43]	1·35 [1·67]	1·66 [1·39]
Tapping task	2·54 [2·24]	3·18* [2·80]	1·11 [1·83]	0·17 [0·96]	1·77 [1·07]
Bakan (total no. of hits)	1·12 [0·92]	4·10* [3·57*]	1·90 [1·03]	1·71 [1·37]	1·20 [0·79]
Memory task	1·21 [0·79]	8·12** [13·47**]	0·81 [1·73]	1·39 [1·68]	0·60 [0·58]

*p<0·05; **p<0·001.

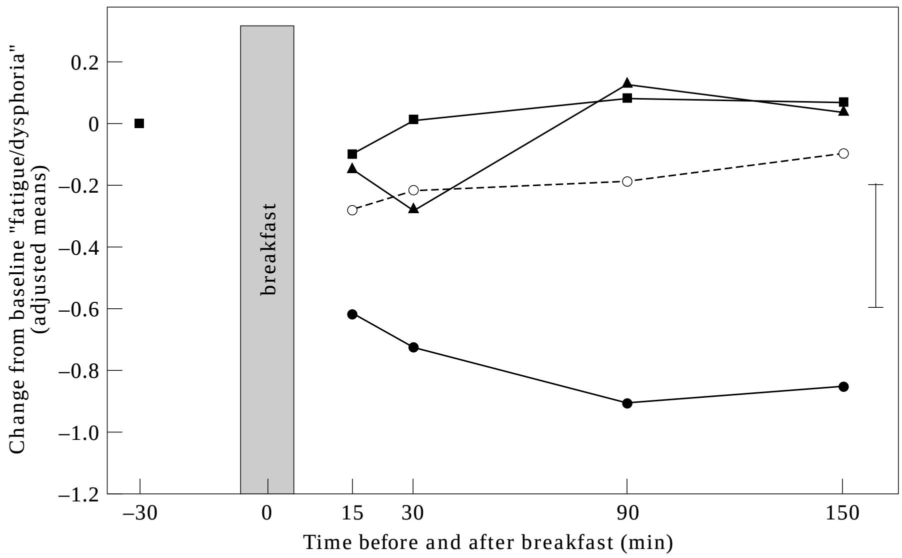

FIGURE 1. Change in fatigue/dysphoria after equi-caloric breakfasts of differing fat and carbohydrate content and when no breakfast was consumed. LF = low fat, HF = high fat, LC = low carbohydrate, HC = high carbohydrate, NB = no breakfast. Within the same time point, means further apart than the least significant difference (indicated by the vertical bar) are significantly different, p<0·05. The statistics are for an analysis which excluded the NB data. The standard deviations for these individual means ranged from ±0·43 to ±1·32 for the three breakfasts and from ±1·03 to ±1·45 for NB. HFLC, ■; MFMC, ▲; NB, ○; LFHC, ●.

Hunger, Fullness and Desire to Eat

When the NB data were excluded (Table 4), there were no significant effects involving MEAL, although as expected hunger and desire to eat increased and fullness decreased during the interval between breakfast and lunchtime.

Performance Tasks

There were no significant ($p>0{\cdot}1$) MEAL effects for baseline performance for any of the tasks.

There were no significant effects involving MEAL for any of the tasks when the NB data were again excluded from these analyses (Table 5), although performance means were slightly better following the LFHC meal (free-recall task), or slightly worse after the HFLC meal (simple reaction time task). There was no indication that performance was impaired by missing breakfast.

There were significant effects of TIME for the tapping, Bakan and free-recall tasks. For the tapping and Bakan tasks this was due to a steady improvement in performance across the three test periods following breakfast, whereas for the free-recall task there was decline in performance at 90 min compared with 30 min and then an improvement at 150 min after breakfast. Performance was generally poorer than at baseline during the first test after breakfast.

As expected there was a significant decrement in performance over the 6 min of the Bakan task ($p<0{\cdot}01$), but neither this nor performance summed over the whole 6 min (Table 5) was affected by the MEAL consumed.

Hedonic Ratings

There were no significant differences in "pleasantness" scores between the three meals for either the rolls or the milkshake. Mean pleasantness of the LFHC, MFMC and HFLC rolls was $6{\cdot}53 \pm 0{\cdot}5$, $6{\cdot}56 \pm 0{\cdot}6$ and $6{\cdot}83 \pm 0{\cdot}6$ cm respectively, $F(2,30) = 0{\cdot}19$, $p = 0{\cdot}82$. Mean pleasantness of the LFHC, MFMC and HFLC milkshakes was $6{\cdot}49 \pm 0{\cdot}6$, $5{\cdot}61 \pm 0{\cdot}7$ and $6{\cdot}07 \pm 0{\cdot}7$ cm respectively, $F(2,30) = 0{\cdot}64$, $p = 0{\cdot}54$. The mean times taken to eat the LFHC, MFMC and HFLC breakfasts were $7{\cdot}5 \pm 0{\cdot}4$, $7{\cdot}2 \pm 0{\cdot}3$ and $7{\cdot}6 \pm 0{\cdot}2$ minutes respectively, $F(2,34) = 0{\cdot}20$, $p>0{\cdot}1$.

It was also apparent from post-study interviews with the subjects that they had not become aware of any differences in the composition of the three breakfasts. It was clear that they had accepted the "explanation" that this was a standard breakfast given to control nutrient intakes.

Dietary Intake

Dietary analysis showed the subjects' habitual breakfast to be of similar macronutrient composition to that provided by the LFHC meal consumed during the study, but of a lower energy content. They consumed $25 \pm 8\%$ energy from fat (compared to 27% in the LFHC breakfast), $65 \pm 10\%$ energy from carbohydrate (compared to 61% in the LFHC breakfast) and $14 \pm 3\%$ energy from protein (compared to 10% in the LFHC breakfast).

The average energy content of the habitual breakfast was 252 ± 80 kcal compared to 600 kcal in the LFHC breakfast.

Discussion

This study demonstrated significant acute effects of the manipulation of the fat-to-carbohydrate ratio of breakfast on morning mood in habitual breakfast eaters. These effects were independent of meal size and any obvious differences in the sensory quality of the breakfasts. Moreover, in agreement with a previous study on the effects of lunch (Lloyd *et al*., 1994), it appeared that consumption of a breakfast similar in macronutrient composition to that eaten habitually (in this case the LFHC meal) resulted in a more positive mood state than that after equi-caloric meals higher in fat and lower in carbohydrate. The nature of the effects on mood was also similar in these two studies: the relative improvement in mood after a MFMC lunch largely arose from differences in ratings of "muddled", "uncertain", "drowsy" and "tense" (Lloyd *et al*., 1994), which loaded strongly on the mood factor (fatigue/dysphoria) influenced by the LFHC breakfast in the present study. Analyses (not shown) conducted on the individual mood descriptors confirmed that these were indeed among the "moods" predominantly affected. A difference between these studies, however, was that the experimental breakfasts were higher in energy content than the habitual breakfast, whereas the experimental and habitual meals in the lunch study were equal in size.

Although the fatigue/dysphoria factor is rather broad, it does correspond well to the particular context of this study, in which the subjects were challenged with a battery of cognitive tasks. Under these circumstances feelings such as muddled, uncertain, drowsy, jittery and tense (Table 3) are likely to be highly salient. This interpretation is supported by the replication of a very similar constellation of effects on mood in the two studies, and the finding from a further study which investigated the effects of low doses of alcohol on mood and performance. Alcohol (8 g) was found to improve performance on the Bakan task, the most cognitively demanding task in the battery, and this was associated with an improvement in mood, with subjects feeling significantly less tense, muddled and uncertain after this dose of alcohol (Lloyd, 1995; Lloyd & Rogers, 1995).

One interpretation of the relationship between habitual dietary choices and effects on mood revealed by these studies is that a particular meal composition comes to be preferred because it helps to optimize mood in the immediate post-meal interval. It is well established that food preferences can be modified by the aftereffects of ingestion (e.g., Garcia, Hankins & Rusiniak, 1974; Booth, 1978; Sclafani, 1990), and these consequences of eating and drinking may include the psychoactive effects of dietary constituents (see Rogers, 1995 for detailed review). In this respect, caffeine and alcohol are likely to be particularly potent reinforcers (Rogers, Richardson & Elliman, 1995), but the present studies together with a variety of other results (reviewed by Spring, Chiodo & Bowen, 1987; Rogers & Lloyd, 1994) show that the macronutrient composition of single meals can also have significant behavioural effects. The mechanisms underlying such effects are, however, rather less clear. Modulation of serotoninergic function by high-carbohydrate low-protein meals has been suggested as one route by which the post-absorptive effects of food could alter mood. This has received only modest empirical support (e.g., Rogers, 1995) and is in any case unlikely to be relevant to the results described here because the rapid onset of the changes in mood following eating suggests that pre-absorptive mechanisms are involved (Lloyd *et al*., 1994).

It is possible that meals could influence brain functioning through effects on gut hormones released in response to eating (Young, 1993). For example, one study has demonstrated substantial, dose-related effects of intravenously administered cholecystokinin (CCK) on mood and performance (Stacher, Bauer & Steinringer, 1979), with subjects feeling more relaxed, drowsy, sluggish and inert with increasing doses of the hormone. This is of particular interest, as fat and protein are more potent releasers of CCK than carbohydrate (Liddle, Goldfine & Williams, 1983). Therefore CCK may provide part of a mechanism mediating effects of meal composition. These mechanisms will be investigated in future studies.

In another study on the effects of breakfast on subsequent mood, Smith *et al.* (1994) found that subjects who consumed a cooked breakfast (bacon, egg and toast) rated themselves as more sociable and outward-going, and less bored and discontented, than subjects who consumed an iso-energetic "light" breakfast (toast and cereal) or no breakfast. No information was given, however, on these subjects' habitual intakes in the morning. Of course these differences may have been mediated, at least in part, by subjects' expectations of the effects of the different meals or of the effects of missing breakfast. The present results indicated rather variable responses to missing breakfast; for some subjects there was a deterioration in mood, perhaps due to the disappointment of receiving no meal, whereas for others mood improved. On average, though, there was no substantial decline in mood due to missing breakfast.

A further finding was that there were no strong effects of breakfast composition or of skipping breakfast on performance efficiency. Previous studies have used a variety of tasks to test performance and different study populations, and have provided mixed results on the effects of breakfast on performance. However, in a study with a similar design, and in agreement with the present one, Smith *et al.* (1994) found no differences in reaction time performance or sustained attention between subjects given breakfast or fasted. Other studies support these results (Dickie & Bender, 1982; Richards, 1972), although in a group of either habitual or non-habitual breakfast eaters it was noted that performance was worst when subjects deviated from their normal practice (Richards, 1972). Nonetheless, some performance differences have been reported for immediate memory. Several studies have reported beneficial effects of breakfast (Benton & Sargent, 1992; Smith *et al.*, 1994), although fasting has also been shown to improve memory (Pollitt *et al.*, 1981). It has been proposed by Benton and Sargent (1992) that improvement in memory associated with consumption of breakfast is linked to the availability of glucose to the brain. They reported a significant correlation between the level of blood glucose and performance in a test of spatial memory in a group of university students (the higher the blood glucose level the better the performance). However, positive correlations were also found in the absence of a beneficial effect of the glucose drink irrespective of which drink was given (placebo or glucose), suggesting an indirect link between these variables (reviewed by Rogers & Lloyd, 1994). Measurements of blood glucose or other physiological parameters were not taken in the present study as it was felt that these might well have interfered with subtle behavioural effects of these dietary manipulations.

There is some evidence suggesting that higher than usual energy intakes at lunch lead to reduced performance efficiency (Craig, 1986; Craig & Richardson, 1989; Smith, Ralph & McNeill, 1991). Michaud *et al.* (1991) also reported that concentration was impaired by increasing the energy content of adolescents' breakfast by 63%, although memory was improved. In the present study the breakfasts provided on average 350 kcal more than the subjects' usual intake. Performance was not impaired, at least compared to the NB condition. It is possible, however, that a smaller (LFHC) meal would have produced optimal performance, better than both NB and the larger breakfasts.

From these various results it is becoming increasingly clear that meal size and macronutrient composition can influence mood and cognitive functioning. These effects, however, appear not to be very large, especially when it is considered that typical everyday variations in meal composition are likely to be smaller than those imposed in experimental studies. Accordingly, it may be that relatively small differences in methodology and subject population can account for differences between studies. For example, significant effects of meal macronutrient composition on cognitive performance have been found in some studies for meals fed at lunchtime (Smith, Leekham, Ralph & McNeill, 1988; Lloyd *et al.*, 1994), but not in others (e.g., Kelly, Foltin, Rolls & Fischman, 1994). Kelly *et al.* reported that neither the energy content nor the fat to carbohydrate ratio of the meal altered post-lunch performance; however, both the timing (in relation to lunch) and the nature of the tasks differed substantially between these studies. The moods affected by the macronutrient manipulation in present study were very similar to those affected by varying the fat and carbohydrate composition of lunch (Lloyd *et al.*, 1994), but the effects on performance were smaller and unreliable. This again points to the rather subtle impact of these dietary variables on cognitive functioning.

In conclusion, the present study found effects of breakfast composition (fat-to-carbohydrate ratio) on certain aspects of mood in a group of habitual breakfast eaters. In particular, improved mood was associated with consumption of breakfast similar in macronutrient composition to that habitually eaten, although no clear performance differences emerged. Also of interest was the fact that omission of breakfast did not have any marked detrimental effects on morning performance or mood.

References

Benton, D. & Sargent, J. (1992). Breakfast, blood glucose and memory. *Biological Psychology*, *33*, 207–10.

Booth, D. A. (1978). Acquired behaviour controlling energy intake and output. *Psychiatric Clinics of North America*, *1*, 545–79.

Connors, C. K. & Blouin, A. G. (1983). Nutritional effects on behaviour of children. *Journal of Psychiatric Research*, *17*, 198–201.

Connors, C. K., Caldwell, J. A. & Caldwell, J. L. (1985). Effects of breakfast and sweetener on the cognitive performance of children. *Psychophysiology*, *22*, 573.

Craig, A., Baer, K. & Diekman, A. (1981). The effects of lunch on sensory-perceptual functioning in man. *Internal Archives of Occupational and Environmental Health*, *49*, 105–14.

Craig, A. & Richardson, E. (1989). Effects of experimental and habitual lunch-size on performance, arousal, hunger and mood. *Internal Archives of Occupational and Environmental Health*, *61*, 313–9.

Dickie, N. H. & Bender, A. E. (1982). Breakfast and performance in schoolchildren. *British Journal of Nutrition*, *48*, 483–96.

Garcia, J., Hankins, W. G. & Rusiniak, K. W. (1974). Behavioural regulation of the milieu interne in man and rat. *Science*, *185*, 824–31.

Green, M. W., Rogers, P. J., Elliman, N. A. & Gatenby, S. J. (1994). Impairment of cognitive processing associated with dieting and high levels of dietary restraint. *Physiology and Behavior*, *55*, 447–52.

Kelly, T. H., Foltin, R. W., Rolls, B. J. & Fischman, M. W. (1994). Effect of meal macronutrient and energy content on human performance. *Appetite*, *23*, 97–111.

Liddle, R. A., Goldfine, I. D. & Williams, J. A. (1983). Bioassay of circulating CCK in rat and human plasma. *Gastroenterology*, *84*, 1231–6.

Lloyd, H. M. (1995). Acute and chronic effects of dietary manipulations on mood and cognitive performance. PhD thesis, University of Reading, U.K.

Lloyd, H. M., Green, M. W. & Rogers, P. J. (1994). Mood and cognitive performance effects of iso-caloric lunches differing in fat and carbohydrate content. *Physiology and Behavior*, *56*, 51–7.

Lloyd, H. M. & Rogers, P. J. (1995). Mood and cognitive performance improved by a low dose of alcohol administered double blind. *Appetite*, *24*, 280.

Lorr, M. & McNair, D. M. (1988). *Profile of mood states Bi-polar Form*. San Diego: Educational and Industrial Testing Service.

Michaud, C., Musse, N., Nicolas, J. P. & Mejean, L. (1991). Effects of breakfast-size on short-term memory, concentration, mood and blood glucose. *Journal of Adolescent Health*, *12*, 53–7.

Paul, A. A. & Southgate, D. A. T. (1978). *McCance and Widdowson's The composition of foods*. 4th Edn. London: HMSO.

Pollitt, E., Leibel, R. L. & Greenfield, D. (1981). Brief fasting, stress and cognition in children. *American Journal of Clinical Nutrition*, *34*, 1526–33.

Pollitt, E., Lewis, N. L., Garza, C. & Shulman, R. J. (1983). Fasting and cognitive function. *Journal of Psychiatric Research*, *17*, 169–74.

Richards, M. M. K. (1972). Studies on breakfast and mental performance. *Nutrition*, *26*, 219–23.

Rogers, P. J. (1995). Food, mood and appetite. *Nutrition Research Reviews*, *8*, 243–69.

Rogers, P. J. & Lloyd, H. M. (1994). Nutrition and mental performance. *Proceedings of the Nutrition Society*, *53*, 443–56.

Rogers, P. J., Richardson, N. J. & Elliman, N. A. (1995). Overnight caffeine abstinence and negative reinforcement of preference for caffeine-containing beverages. *Psychopharmacology*, *120*, 457–62.

Schlich, P. (1993). Uses of change-over designs and repeated measurements in sensory and consumer studies. *Food Quality and Preference*, *4*, 223–35.

Sclafani, A. (1990). Nutritionally based learned flavour preferences in rats. In E. D. Capaldi & T. L. Powley (Eds), *Taste, feeding and experience*. Pp. 139–56. American Psychological Association: Washington D.C.

Smith, A.P., Leekham, S., Ralph, A. & McNeill, G. (1988). The influence of meal composition on post-lunch performance efficiency and mood. *Appetite*, *10*, 195–203.

Smith, A. P. & Miles, C. (1986a). Effects of lunch on selective and sustained attention. *Neuropsychobiology*, *16*, 117–20.

Smith, A. P. & Miles, C. (1986b). The effects of lunch on cognitive vigilance tasks. *Ergonomics*, *29*, 1251–61.

Smith, A., Ralph, A. & McNeill, G. (1991). Influences of meal size on post-lunch changes in performance efficiency, mood and cardiovascular function. *Appetite*, *16*, 85–91.

Smith, A., Kendrick, A., Maben, A. & Salmon, J. (1994). Effects of breakfast and caffeine on cognitive performance, mood and cardiovascular functioning. *Appetite*, *22*, 39–55.

Spring, B., Chiodo, J. & Bowen, D. J. (1987). Carbohydrates, tryptophan, and behaviour: a methodological review. *Psychological Bulletin*, *102*, 234–56.

Stacher, G., Bauer, H. & Steinringer, H. (1979). Cholecystokinin decreases appetite and activation evoked by stimuli arising from the preparation of a meal in man. *Physiology and Behavior*, *23*, 325–31.

Thayer, R. E. (1989). *The biopsychology of mood and arousal*. New York: Oxford University Press.

Tuttle, W. W., Wilson, M. & Daum, K. (1949). Effect of altered breakfast habits on physiologic response. *Journal of Applied Physiology*, *1*, 545.

Tuttle, W. W., Daum, K., Myers, L. & Martin, C. (1950). Effect of omitting breakfast on the physiologic response of men. *Journal of the American Dietetic Association*, *26*, 332–5.

Tuttle, W. W., Daum, K., Imig, C. J., Randall, S. & Schumacher, M. T. (1952). Effect of omitting breakfast on the physiologic response of the aged. *Journal of the American Dietetic Association*, *28*, 117–20.

Tuttle, W. W., Daum, K., Larsen, R., Salzano, J. & Roloff, L. (1954). Effect on schoolboys of omitting breakfast: physiologic responses, attitudes and scholastic attainments. *Journal of the American Dietetic Association*, *30*, 674–7.

Young, S. N. (1993). The use of diet and dietary components in the study of factors controlling affect in humans: A review. *Journal of Psychiatry and Neuroscience*, *18*, 235–44.

Received 6 June 1994, revision 20 March 1996