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EFFECTS OF PROTEIN AND CARBOHYDRATE MEALS ON MOOD AND PERFORMANCE: INTERACTIONS WITH SEX AND AGE

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Summary—Normal adult subjects ($n = 184$) consumed a high-protein or high-carbohydrate meal Two hours later their mood and performance were tested The effects of meal composition on mood were different for men and women, and for older and younger subjects Females, but not males, reported greater sleepiness after a carbohydrate as opposed to a protein meal Male subjects, but not females, reported greater calmness after a carbohydrate as opposed to a protein meal Older subjects responded differently to meals depending upon the time of day when these were consumed When meals were eaten for breakfast (but not for lunch) individuals 40 yr of age or older felt more tense and less calm after a protein than after a carbohydrate meal Although older subjects reported *subjective* discomfort after a morning protein meal, they displayed *objective* performance impairments after a carbohydrate lunch Subjects 40 yr of age or older were impaired on a test of sustained selective attention (dichotic shadowing) after consuming a high-carbohydrate lunch The shadowing impairment after carbohydrate consumption was as pronounced without distraction as with distraction and resulted mostly from increased omission errors Our findings suggest negative effects on concentration when older subjects consume a high-carbohydrate, low-protein lunch These negative effects of carbohydrate consumption appear to arise predominantly from lapses of attention rather than from intrusion of distractors

THIS report describes the mood and performance of a relatively large group of healthy subjects after they consumed a carbohydrate-rich or protein-rich test meal. Previous animal studies had shown that consumption of these two nutrient mixtures causes characteristic and different alterations in brain neurotransmitter synthesis. Differences in behavioral responses related to nutrient ingestion have also been noted in some studies of animals (cf LYTLE *et al.*, 1975; WURTMAN *et al.*, 1981). In addition, some of these findings were affected by the age of the subject and the times of day when meals were eaten. We anticipated that diet might exert measureable effects on behavior via the influence of precursor availability on the synthesis and release of brain neurotransmitters, as described below. We also expected that these effects might show diurnal fluctuations, as well as being influenced by major demographic factors such as age and sex.

When rats fasted over night consume a carbohydrate-rich, protein-poor meal, the resulting insulin secretion profoundly reduces plasma levels of most of the amino acids, but not tryptophan. Levels of such large neutral amino acids (LNAA) as leucine, isoleucine and valine rapidly fall by 40–60%. Those of the aromatic LNAA tyrosine and phenylalanine fall by 15–30%. Since these five LNAA and tryptophan all compete for a common

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transport site to gain access to the central nervous system, the meal-induced changes in plasma composition cause brain tryptophan levels to rise Within neurons that use the tryptophan derivative, serotonin, as their neurotransmitter, the increase in brain tryptophan levels accelerates the synthesis and release of the neurotransmitter A variety of behavioral and physiological phenomena that involve serotoninergic neurotransmission are affected, and, in general, animals exhibit reduced responsiveness to their environment (FERNSTROM and WURTMAN, 1971, 1974; WURTMAN *et al*, 1981) After a test meal of similar composition, humans exhibit the same changes in plasma amino acid levels and in the release of serotonin from brain neurons, insofar as the latter can be assessed by cerebrospinal levels of 5HIAA (serotonin's metabolite).

In contrast, when fasted rats or humans consume a test meal rich in protein, the insulin-mediated fall in most plasma LNAA is more than compensated for by the direct contribution to the bloodstream of the LNAA in dietary protein Such LNAA as leucine, isoleucine and valine are abundant in dietary protein, and not metabolized in the liver They can represent as much as 90% of *all* of the amino acids entering the systemic circulation (i.e from the liver and portal circulation) after a high-protein meal. Tryptophan, however, is scarce in protein (1–1.5%) and is metablized in its passage through the liver Hence the high-protein meal causes opposite changes in the plasma tryptophan/LNAA ratio, and, in rats, reduces serotonin's synthesis and release

When the test animal or human has not been fasting for a sufficient period before the test meal, the effects of the meal on plasma amino acids and brain serotonin are blunted. The attenuation of these effects reflects the contribution of whatever else is still being digested, coupled with the reduced effect of further increases in insulin secretion at a time when insulin levels are already high Hence, the effect of a lunch is likely to be less than that of breakfast. For this reason, as well as the possibility that neurotransmitter synthesis and the behaviors we examined might themselves exhibit circadian rhythms, we studied the effect of our test meals at two times of day Meals were administered either as a breakfast after an overnight fast or as a lunch after a standard breakfast.

Besides serotonin, the synthesis of other neurotransmitters can be affected by the availability to their neurons of their nutrient-precursors Thus, brain tyrosine levels (which can be elevated by a protein-containing meal) and brain choline (elevated after consumption of foods rich in lecithin), can affect the synthesis of the catecholamines (dopamine, norepinephrine and epinephrine) and acetylcholine, respectively However, while a physiologic increase in brain tryptophan reliably accelerates serotonin synthesis, increases in tyrosine or choline only affect the production of their neurotransmitter products when particular catecholaminergic or cholinergic neurons are firing frequently Neuronal firing rates may increase when some neurons have been lost, for example in the normal aging process or in disease One consequence of neuronal loss, well-illustrated in Parkinson's Disease, is that the surviving neurons apparently can, by firing more frequently, take over some of the functions of their deceased counterparts Such neurons are very sensitive to tyrosine. Because of this relationship, we examined the effects of the test meal both in "young" (under 40) and "old" (40 and older) subjects We expected that older subjects might show increased sensitivity to dietary effects

As outlined above, changes in neurotransmitter synthesis and release represent a

mechanism whereby constituents of foods can exert measurable effects on mood and performance. However, relatively little is known about the nutrient as opposed to the energy effects of foods on subjective and objective components of performance in normal human subjects. In comparison with a placebo, L-tryptophan has been found to produce subjective drowsiness and mental sluggishness (GREENWOOD *et al.*, 1975; YUWILER *et al.*, 1981) to increase fatigue, and to reduce vigor and alertness in normal adults (LIEBERMAN *et al.*, 1982). Consumption of a carbohydrate-rich as compared to a protein-rich meal has been reported to increase self-reported sleepiness two hours after the meal (SPINWEBER, 1981). However no effects of tryptophan on psychomotor performance have been demonstrated (LIEBERMAN *et al.*, 1982; BROADHURST, cited in SPINWEBER, 1981). To date there have been no demonstrated effects of tyrosine on mood or performance (LIEBERMAN *et al.*, 1982), and the consequences of protein consumption have not yet been thoroughly studied. One possible subjective effect of a high protein meal was proposed by STROMINGER and BROBECK (1952) in their discussion of the specific dynamic actions of foods. They suggest that all foods contribute a portion of their caloric value to provide the energy needed for digestion. This effect is large in the case of protein foods, where 12–30% of the food's energy is required in the digestion process. We expected that the great amount of food energy required in the digestive process for protein, coupled with protein's slow rate of absorption into the circulatory system (MALAGELADA, 1981) would contribute to sensations of satiety.

The current study compared the acute effects of either a high-carbohydrate or a high-protein meal on mood and performance. The three measures of mood were tests which had all previously proven sensitive to the effects of tryptophan. The measures of performance were a simple psychomotor test (reaction time) and a complex information processing test of sustained selective attention (dichotic shadowing) Our goal was to examine whether the effects of nutrients were influenced by the time of day when foods were consumed, and by major demographic features, such as age and sex.

METHODS

Subjects

Subjects were 184 adults employed at a U.S Army R&D Laboratory. The sample included 55 females and 129 males Of the total group, 81 were between 18 and 39 yr of age, and the remainder were between 40 and 65 yr. Potential subjects were not included in the sample if they were restricting food intake, adhering to a special diet, or taking any medication that might affect food intake (e.g. tranquilizers, birth control pills, appetite suppressants).

Procedure

Subjects were randomly assigned to one of four groups. A high protein meal was given to two groups: one consuming it as a breakfast between 7:15 and 8:30 a.m., the other as a lunch 11:00 a.m. and 1:00 p.m. A third group received a high-carbohydrate breakfast between 7:15 and 8:30 a.m , and a fourth had the same meal as a lunch between 11:00 a.m. and 1:00 p.m. The protein and carbohydrate meals were isocaloric. The high-protein meal was 227 g trimmed turkey breast (containing approximately 57 g protein, 4 g fat, 1 g

carbohydrate and 30–90 mg choline). The high-carbohydrate meal was 304 g non-dairy sherbet (containing no protein, approximately 4 g fat and 57 g carbohydrate, of which 47 g was sucrose and 10 g was corn starch).

Subjects tested in the morning fasted from 8 p.m the previous evening until the experimental meal. Subjects tested in the afternoon were given a standard breakfast of a pastry and black coffee 5 h before testing, and refrained from eating anything else until the experimental meal. The breakfast pastry contained 210 kcal and comprised: 3 g protein, 33 g carbohydrate, 7 g fat, fortified with six vitamins and three minerals Foods were served on a tray with porcelain plates and stainless steel ware and were passed from the food preparation area to the subject Plates were weighed before serving the meal and again upon return of the plates and eating ware. The meals were weighed using a Mettler Top-Loading Balance (P1000) accurate to $+0.1$ g to be sure that all subjects emptied their plates.

Mood and performance testing occurred 2 h after meals were consumed Morning laboratory tests took place between 9:15 and 10:30 a m and afternoon tests took place between 1:00 and 3.00 p m Mood tests were administered first and performance tests second in the following sequence: (1) Stanford Sleepiness Scale; (2) Profile of Mood States, (3) Visual Analogue Mood Scales; (4) Auditory Reaction Time; (5) Dichotic Shadowing. Informed consent was obtained after a full explanation of the procedures. Each subject was tested individually

Measures of mood

Stanford Sleepiness Scale (SSS) The SSS is a 7-point self-rating scale to quantify progressive increments in sleepiness Parallel form reliability of $r = 0$ 88 has been reported (HODDES *et al.*, 1972) The SSS has been successfully validated against subjective state and performance under sleep deprivation (HODDES *et al.*, 1973).

Profile of Mood States (POMS) The POMS is a self-report mood questionnaire consisting of 65 adjectives rated on a 5-point scale The "Right Now" version was used to characterize the subject's mood at the time of testing. The POMS yields scores on factor-analytically derived scales of. tension–anxiety, depression–dejection, anger–hostility, vigor–activity, fatigue–inertia and confusion–bewilderment. All scales possess internal consistency reliabilities in the range of 0.90 and evidence of construct and predictive validity (MCNAIR *et al.*, 1971)

Visual Analogue Mood Scales (VAMS). Analogue ratings of mood (HAYES and PATTERSON, 1921; FREYD, 1923) have been demonstrated to be sensitive to sleep (HERBERT *et al.*, 1976) and drug effects (cf. reviews by AITKEN, 1969; BOND and LADER, 1974) Several studies have used the same 16 bipolar adjective items Because of dispute about whether affective states are appropriately viewed as bipolar (IZARD, 1972, RUSSELL, 1979), we separated the items into 32 monopolar scales

Subjects were presented with 34 lines, 128 mm in length, one per page. Scales using the adjectives full and empty were added to the original list. In addition, wording of four items was changed to suit the American vernacular fuzzy to muddled, mentally slow to sluggish, incompetent to inefficient, and proficient to efficient. At the left of each line was a box that could be checked to indicate "not at all" At the right was the adjective

preceded by the word "very", indicating that the mood was maximally present. Subjects were instructed to work rapidly and make a perpendicular line at the point corresponding to their mood at that moment. Four different orderings of adjectives were prepared and distributed randomly to subjects. Scales were scored by measuring the distance in mm from the left end of the line to the subject's mark, with ratings of "not at all" counted as 0. These values were converted into a 9-point scale of approximately equal intervals.

Although two factor analyses of the VAMS scales have been reported (BOND and LADER, 1974; HERBERT *et al.*, 1976), our treatment of the VAMS data differed in using monopolar rather than bipolar scales and raw rather than log-transformed scores, and in converting mm values to a 9-point scale. To reduce the VAMS data, a new factor analysis was therefore performed using Rao's canonical method from the SPSS computer package (NIE *et al.*, 1975). This analysis yielded seven factors with eigenvalues greater than 1.0, which cumulatively accounted for 97% of the total variation. Orthogonal varimax rotation was performed to simplify the factor structure. Three factors were selected which cumulatively accounted for 76% of the variance. Table 1 shows the loadings of all the individual VAMS scales on the three factors.

Table 2 shows the scales which have the highest loadings on each factor. Despite the differences in procedure, the three derived factors correspond well to the (1) Alertness–Drowsiness, (2) Contentedness–Discontentedness and (3) Calmness–Excitedness factors extracted by BOND and LADER (1974). Scores for each individual subject on the three factor scales were calculated using weights from the factor score coefficient matrix. Computation of factor scores is based on all of the scales, rather than only those with high loadings on the factor. Factor scores were used as the dependent variable in the analyses of the VAMS data.

To examine the external validity of the VAMS factor scales, scores of each subject were correlated with those obtained on the POMS and the SSS. Results of these analyses appear in Table 3 and support the interpretation of the factors. Factor 1 (Alertness) is most highly correlated with scales measuring vigor, sleepiness and fatigue. Factor 2 (Dysphoria) is highly correlated with independent measures of depression and anger. Finally, Factor 3 (Calmness) is highly inversely correlated with self-reported tension.

Measures of performance

Auditory reaction time (RT). After five practice trials, 25 trials of simple auditory reaction time were collected. Subjects depressed a telegraph key when they were ready to begin a trial. This triggered a variable preparatory interval between 1 and 4 s, followed by a supra-threshold auditory stimulus. The auditory stimulus signaled the subject to lift his or her finger from the key as quickly as possible. Reaction time in milliseconds was the length of time from the onset of the signal to the finger lift response. The inter-trial interval was 2 s, after which the subject could depress the key to begin the next trial. To normalize frequency distributions, all reaction times were transformed to base e logarithmic equivalents and averaged to yield a mean RT for each subject. The grand mean for each subject was then transformed to an antilog (yielding a geometric mean) to provide a more readily understandable metric in milliseconds. HAMSHER and BENTON (1977) found that this number of practice and test trials of simple RT is sufficient to yield internal consistency of 0.90 for normal subjects.

TABLE 1 ROTATED FACTOR MATRIX FOR VISUAL ANALOGUE MOOD SCALES

	Scales	Factor loadings			Communalities
1	Alert	0 747	−0 011	0 087	0 859
2	Drowsy	−0 274	−0 000	0 003	0 698
3	Calm	0 347	−0 205	0 766	0 766
4	Excited	0 448	−0 083	−0 319	0 575
5	Strong	0 642	0 114	0 133	0 502
6	Feeble	−0 064	0 156	−0 016	0 316
7	Muddled	−0 105	0 280	−0 172	0 628
8	Clearheaded	0 753	−0 134	0 132	0 742
9	Coordinated	0 764	0 047	0 077	0 642
10	Clumsy	−0 254	0 039	0 100	0 734
11	Lethargic	−0 291	0 310	0 016	0 589
12	Energetic	0 724	−0 085	0 045	0 651
13	Contented	0 493	−0 388	0 427	0 729
14	Discontented	0 009	0 591	−0 134	0 725
15	Troubled	−0 110	0 775	−0 265	0 823
16	Tranquil	0 130	−0 057	0 709	0 578
17	Happy	0 512	−0 462	0 316	0 686
18	Sad	−0 032	0 841	−0 217	0 808
19	Antagonistic	0 170	0 117	−0 155	0 451
20	Amicable	0 500	−0 292	0 246	0 616
21	Sluggish	−0 394	0 058	−0 094	0 715
22	Quickwitted	0 602	−0 227	0 027	0 500
23	Tense	−0 025	0 320	−0 644	0 549
24	Relaxed	0 084	−0 063	0 749	0 589
25	Attentive	0 704	−0 062	0 192	0 667
26	Dreamy	−0 119	0 215	0 036	0 460
27	Interested	0 573	0 021	0 137	0 622
28	Bored	−0 216	0 251	−0 040	0 637
29	Withdrawn	−0 124	0 418	−0 015	0 372
30	Gregarious	0 292	−0 015	0 155	0 450
31	Inefficient	−0 474	0 199	−0 051	0 496
32	Efficient	0 828	−0 060	0 066	0 764
33	Empty	0 030	0 701	−0 117	0 617
34	Full	0 127	−0 238	−0 006	0 201
Eigenvalue		33 6	14 5	8 3	
Percent of variance		45 1	19 5	11 2	
Cumulative percent		45 1	64 5	75 7	

Dichotic shadowing The dichotic shadowing test is a complex information processing measure of the sustained and selective aspects of attention This 45-item procedure presents word strings on the main channel and on the distractor channel either nothing, continuous unassociated distractors, or continuous distractors semantically associated to the main channel. To equalize the difficulty of the three types of items, word strings without distraction (NoD) are of low contextual constraint (MILLER and SELFRIDGE, 1950) and, therefore, the most difficult to anticipate. By contrast, word strings with unassociated distractors (D1) or associated distractors (D2) are of moderate and high constraint, respectively. After four practice items, test items are presented in random order but in the same sequence for all subjects at the rate of 60–75 syllables per min. The main channel is presented to the right ear for the first half of the tape and to the left for the second half

TABLE 2 EXTRACTED VAMS FACTORS WITH LOADINGS AFTER VARIMAX ROTATION

Factor	Scale	Loading
Factor 1 (Alertness)	Efficient	0 828
	Coordinated	0 764
	Clearheaded	0 753
	Alert	0 747
	Energetic	0 724
	Attentive	0 704
	Strong	0 642
	Quickwitted	0 602
	Interested	0 573
Factor 2 (Dysphoria)	Sad	0 841
	Troubled	0 775
	Discontented	0 591
Factor 3 (Calmness)	Calm	0 766
	Relaxed	0 749
	Tranquil	0 709
	Tense	−0 644

TABLE 3 CORRELATION OF VAMS FACTORS WITH OTHER MOOD SCALES ($n = 183$)

Mood Scale	VAMS Factor Alertness	Dysphoria	Calmness
POMS Tension	−0 11	0 30***	−0 63***
POMS Depression	−0 19**	0 65***	−0 26***
POMS Anger	0 07	0 60***	−0 31***
POMS Confusion	−0 34***	0 36***	−0 19*
POMS Vigor	0 79***	−0 21**	0 10
POMS Fatigue	−0 40***	0 27***	−0 11
Sleepiness (SSS)	−0 56***	0 16*	0 01

*$p < 0$ 05, **$p < 0$ 01, ***$p < 0$ 001

Items are presented via stereo headphones, and subjects are asked to shadow, or repeat the main channel syllable by syllable. Subsets of 10 items from the NoD, D1 and D2 conditions of the task have been matched and the matching cross-validated on mean item accuracies, the distribution of item accuracies, coefficient alpha and true score variance. These three scales of 10 items constitute the final matched tests. All possess alphas between 0.90 and 0.94.

Shadowing responses are tape-recorded and transcribed. The data for each item are scored for accuracy (percent of syllables shadowed correctly) and for errors of omission and commission. An omission error is scored when a main channel syllable is not shadowed and no erroneous response is made in its place. The primary commission error is an intrusion, in which the subject erroneously shadows material from the distractor channel as if it were part of the main channel. We consider omission errors to reflect lapses in concentration, whereas intrusion errors reflect inability to exclude distractors. In this study, interrater reliabilities were $r = 0.86$ for omission errors and $r = 0.88$ for intrusion errors.

RESULTS

The data were analyzed by three-factor analyses of variance, using an unweighted means solution because of unequal cell sizes The first analyses examined the effects of meal (protein, carbohydrate), time (breakfast, lunch), and age (younger than 40, 40 or older) on each dependent variable. Forty was taken as the cutpoint, not because of any hypothesis about discrete biological changes at this age, but rather for the pragmatic reason that this value divided the sample approximately in half. The second analyses examined the effects of meal, time and sex. Although, it would have been preferable to examine the interactions among age, sex and diet, the selection of subjects resulted in too few observations in one cell for the interaction to be reliable. In these analyses, only main effects and interactions involving diet were of interest and reported below. In the case of significant effects, *post hoc* comparisons were conducted using the Duncan Multiple Range Test (DUNCAN, 1955). Comparisons of the effects of carbohydrate and protein were undertaken only within and not between demographic subgroups (For example, in the event of a significant interaction between diet, time and age, older subjects who ate a high-carbohydrate breakfast were compared only to older subjects who ate a high-protein breakfast, and neither to younger subjects nor to older subjects who ate the test meal at lunch) Significance was tested using two-tailed confidence intervals

Mood effects

For Stanford Sleepiness scores there were no significant three-way interactions involving meal type, nor was there a significant interaction between meal and age. However, there was a significant interaction between meal and sex [F (1, 177) = 5.30, p = 0.02] indicating that the effect of nutrients on sleepiness depended on the sex of the subject. As Fig. 1 indicates, females reported more sleepiness after eating a carbohydrate meal than they did after eating a protein meal ($p < 0$ 05, Duncan test). In contrast, for males, sleepiness did not vary significantly as a function of diet

For POMS tension–anxiety, there was a significant three-way interaction between Meal, Time of testing and Age [F (1, 176) = 7 43, p = 0 008] As Fig. 2 indicates, individuals 40 yr or older reported greater tension after a protein than a carbohydrate breakfast ($p < 0$ 05, Duncan test) When older subjects ate the same meals for lunch, or when younger subjects at these meals, there was no relationship between diet and POMS tension.

Although there were no significant effects of diet on the remaining POMS scores, an additional effect approached significance The trend (p = 0.052) for an interaction between meal and sex on POMS vigor-activity parallels the findings for sleepiness Inspection of these means suggests that females, but not males, tended to feel less vigorous after a carbohydrate than a protein meal

The VAMS calmness score detected significant interactions between meal, age and time of day [F (1, 174) = 3 53, p = 0 022] as well as between meal and sex [F (1, 174) = 3 80, p = 0 048] The three-way interaction involving age is the mirror image of the previous finding for POMS tension. Also similar to findings for POMS tension, differential effects of diet were greatest among older individuals who consumed the test meals for breakfast Older individuals described themselves as feeling less calm after a protein than a carbohydrate breakfast ($p < 0$ 05, Duncan test). The remaining comparisons failed to reveal

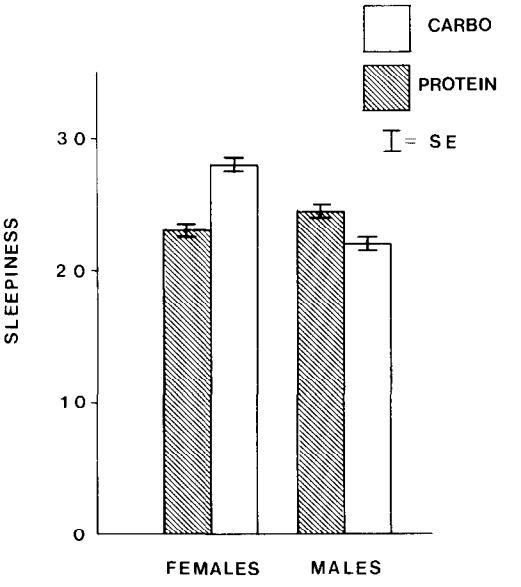

FIG 1 Mean Stanford Sleepiness Score and standard errors for females and males who consumed a protein or a carbohydrate meal The mean of each distribution is indicated by the height of the bar One standard error above and below the mean is represented by the top and bottom of each SE bar, respectively

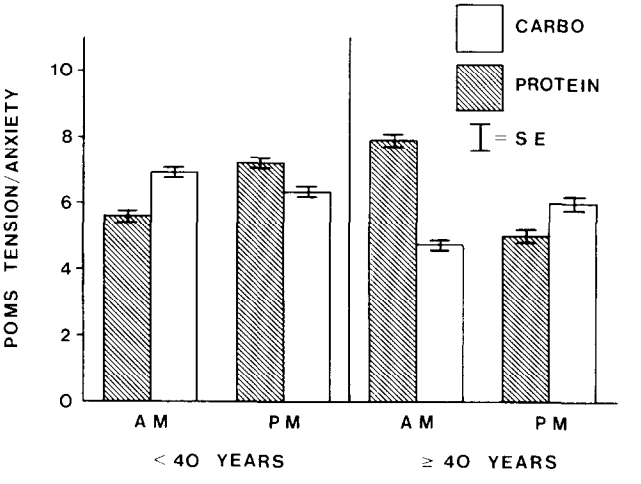

FIG 2 Mean POMS Tension/Anxiety Score and standard errors for individuals younger than 40 and older than 39, who consumed a protein or a carbohydrate meal in the morning or the afternoon

significant differences between nutrients. The significant interaction between sex and meal for calmness is graphed in Fig. 3. This finding can be attributed to the fact that males felt calmer after a carbohydrate than a protein meal ($p < 0.05$, Duncan test). By contrast, females who consumed protein did not differ in calmness from those who consumed carbohydrate. It is instructive to compare the findings for VAMS calmness with those

for sleepiness and vigor. Although all three variables show interactions between meal and sex, female differential responsiveness to foods can be held responsible for the effects for sleepiness and vigor, whereas male differential responsiveness to foods is seen to account for the effects on calmness.

The last finding of note is that, consistent with predictions, subjects report feeling fuller after a protein meal than they do after a carbohydrate meal [$F(1, 176) = 3.96$, $p < 0.05$]

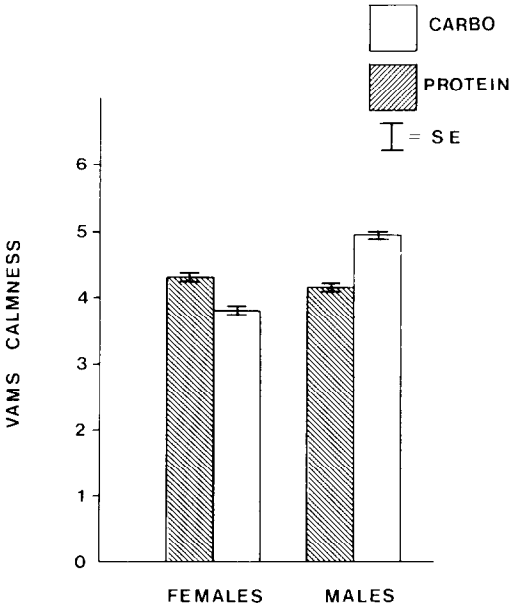

FIG 3 Mean Visual Analogue Scale Calmness Factor Score and standard errors for females and males after consumption of a protein or carbohydrate meal

Performance effects

There were no significant main effects or interactions of diet on reaction time. By contrast, dichotic shadowing performance differed significantly as a function of the subject's meal. There were main effects of meal on overall shadowing accuracy [$F(1, 169) = 7\ 07$, $p = 0.009$], as well as on errors of omission [$F(1, 169) = 7.46$, $p = 0.007$]. Shadowing was more accurate after protein than carbohydrate consumption in all three test conditions ($p < 0.01$ for no distraction; $p < 0.01$ for unassociated distraction, $p < 0.05$ for associated distraction). In addition, there were significant three-way interactions of meal, time and age for shadowing accuracy without distraction [$F(1, 172) = 6.19$, $p = 0.014$] as well as for omission errors summed across the test conditions [$F(1, 169) = 5\ 36$, $p = 0\ 022$]. Figure 4 depicts the interaction for omission errors For both omission errors and shadowing accuracy without distraction, the significant difference between diets is largely due to older subjects who consumed the test meals as a lunch. Only for these individuals was shadowing accuracy significantly lower ($p < 0.01$, Duncan test) and omission errors significantly higher ($p < 0.01$) after a carbohydrate than a protein meal. Although the interaction of meal,

time and age failed to reach significance for shadowing accuracy in the two distraction conditions, inspection of the means indicates a similar pattern. In each case the deficit in shadowing accuracy after a carbohydrate meal was most pronounced for older subjects who consumed the test meals for lunch.

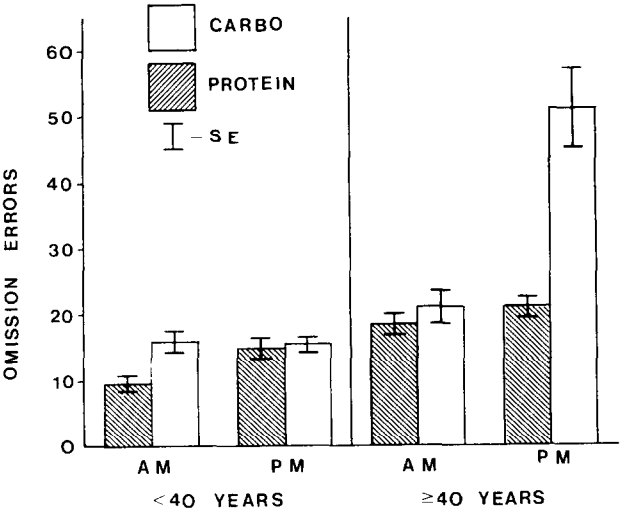

FIG 4 Mean number of dichotic shadowing errors of omission for younger and older individuals who consumed a protein or a carbohydrate meal in the morning or the afternoon

Whereas omission errors varied as a function of diet, especially among older subjects, the commission intrusion error did not. In addition, the reduced accuracy associated with carbohydrate meals was as great without distraction as with distraction. It appears, therefore, that the poorer shadowing performance after a carbohydrate meal reflects lapses of attention rather than intrusion of distractors. Alternatively stated, the difficulty is more likely to reflect influences of nutrients on sustained rather than selective attention.

DISCUSSION

The findings of this study suggest a more complex picture than that expressed in the classic belief that:

> "Food is without any doubt the oldest and most widely used 'tranquilizer' "
>
> (BROBECK, 1960, p 1198)

Our results suggest that "tranquilizing" effects of foods depend upon the specific nutrients, the time of day at which they are consumed and the age and sex of the consumer.

A sleepiness-inducing effect of a carbohydrate-rich as compared to a protein-rich meal has previously been demonstrated in normal adults (SPINWEBER, 1981). However, to our knowledge the present study is the first to demonstrate differential effects of these nutrients on other more qualitative aspects of mood and on performance. The association

between carbohydrate consumption and increased sleepiness, at least among females is consistent with our hypotheses. The likely mechanism for this effect is the increased availability of tryptophan to the serotonnergic raphé neurons involved in sleep induction. For males, consumption of a carbohydrate-rich meal was associated with reports of calmness rather than sleepiness These results raise the possibility that females and males may experience the aftereffects of a carbohydrate vs a protein meal somewhat differently However, from the data it cannot be determined whether men and women were describing qualitatively different internal states, or using different vocabulary to describe the same state. An additional possibility is that the effects of the carbohydrate meal may have been blunted for males because of their generally larger body mass If this hypothesis is correct males might also report sleepiness after consuming a greater amount of carbohydrate

Consistent with the expectation that older subjects might display increased sensitivity to the effects of nutrients, the remaining mood and performance findings were significant only among older individuals. By contrast to the general character of carbohydrate effects, for older subjects the impact of protein consumption was something other than tranquilizing Older subjects described themselves as feeling more tense and less calm after a protein than a carbohydrate breakfast. These effects may be due to the reduction in brain tryptophan and serotonin that follow consumption of a high-protein meal Alternatively, they may result from a direct effect of protein on the synthesis and release of brain catecholamines. In addition to the specific effect of protein-rich breakfasts on older subjects, protein meals had the more general effect of increasing satiety to a greater extent than carbohydrate meals

Although no differential effects of the two meals were evident for a simple psychomotor test of objective performance, effects were consistently in evidence for a more complex measure of information processing Subjects who consumed carbohydrate meals performed worse than those who consumed protein meals in a test requiring sustained attention, with and without filtering out of distraction. However, differences due to diet were small except in the case of older subjects who were tested in the afternoon after a high-carbohydrate lunch. Older subjects failed to sustain attention adequately after a carbohydrate-rich, protein-poor lunch. Findings suggest that their performance deficit was due to lapses in attention rather than to distraction by extraneous stimuli On pharmacologic grounds, we had predicted that the effects of a carbohydrate breakfast would be more pronounced than those of a carbohydrate lunch The findings for older subjects contradict this prediction. This result may indicate that, among older subjects, performance in the afternoon is more vulnerable to disruption as a function of diet

The effects of nutrients on mood in the present study are consistent with previous findings. In contrast to the dichotic shadowing findings, the mood effects were rather modest and might not have emerged as significant in a smaller sample In a cross-sectional design as used in this research it remains possible that selection bias may result in the assignment of atypical subjects to a particular group, even though random sampling renders this unlikely Balancing this risk, the cross-sectional approach is well suited to identifying subgroups of individuals who may show maximal responsivity to the effects of nutrients. Results of the present study indicate that older individuals represent such a group. The objective impairment in concentration observed among older individuals after a carbohydrate-rich, protein-poor lunch was quite large in magnitude Particularly

considering that this effect emerged after a single meal, it is certainly worthy of replication. Ultimately, the pragmatic aim of such research is to understand nutrient-behavior relationships sufficiently well to select diets optimally suited to particular age, sex and task demands.

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