Amino Acids (2000) 19: 635–642

Amino
Acids

A taurine and caffeine-containing drink stimulates cognitive performance and well-being

R. Seidl, A. Peyrl, R. Nicham, and **E. Hauser**

Department of Pediatrics, University of Vienna, Austria

Accepted June 5, 2000

Summary. Caffeine- and taurine-containing drinks have been on the European market for about a decade, and research on the individual constituents of these drinks indicates an improvement in cognitive performance resulting from consumption of such drinks.
In this double-blind, placebo-controlled study using 10 graduate students, we obtained the P300 components of event-related potential (ERP) waveforms following an auditory oddball paradigm, measured motor reaction time, and applied the d2 test for the assessment of attention. Status of mood was assessed by the "Basler-Befindlichkeitsbogen" questionnaire, a standard test for evaluation of feelings of well-being. Measurements were made at night, prior to and starting one hour after consumption of energy drink ingredients or placebo.

At the end of the experiment (midnight), P300 latency and motor reaction time were significantly longer compared with baseline measurements in the placebo group, but were unchanged in the energy drink group. In the test system for evaluating feelings of well-being, total scores, vitality scores and social extrovertedness scores were significantly decreased in the placebo group but not in the energy drink group.

The findings clearly indicate that the mixture of three key ingredients of Red Bull^{R} Energy Drink used in the study (caffeine, taurine, glucuronolactone) have positive effects upon human mental performance and mood. These effects may be mediated by the action of caffeine on purinergic (adenosinergic) receptors and taurine modulation of receptors. As half of the study cohort were non-caffeine users, the described effects cannot be explained in terms of the restoration of plasma caffeine levels to normal following caffeine withdrawal.

Keywords: Amino acids – Taurine – Cognitive function – Well-being – Mood

Introduction

For more than a decade so called Energy Drinks are available on the beverage market in Europe. They regularly contain taurine, glucuronolactone and caffeine as active ingredients and claims for improvement of concentration and reaction time, vigilance and endurance are made. These claims are in agreement with published findings on the individual ingredients, especially caffeine (Anderson et al., 1994; Bättig et al., 1984; Borland et al., 1986; Frewer and Lader, 1991) and taurine (Alford et al., 1999; Belfer et al., 1998; Engelmann et al., 1999; Geiss et al., 1994; Kagamimori et al., 1999; Liedsky et al., 1995; Mandel et al., 1985; Milakofsky et al., 1993; Ramanathan et al., 1997; Yamamoto et al., 1985). We tested a mixture of three ingredients – caffeine, taurine and glucuronolactone (CTG) – in capsule form in a blinded fashion and using a similarly capsulated placebo. It was the aim of the study examine the effects of these ingredients (CTG) by an objective, neurophysiological tool, the measurement of event-related potentials ("ERP") in support of psychometric studies. We also addressed the issue of potential caffeine withdrawal effects by testing both non-caffeine users and caffeine users, since it has been suggested by some authors that performance enhancement following caffeine administration was merely due to reversing effects of caffeine withdrawal (James 1997; Rogers and Dernoncourt, 1998).

Another goal of the present study was to test the effects of CTG at night when subjects are expected to be sleepy, and midnight was selected as the end-point for determination of status of cognitive functions and mood.

We tested three ingredients (CTG) and chose to ignore other ingredients with possible positive effects on cognitive performance, expecially glucose (Benton and Owens, 1993; Benton and Sargent, 1992; Manning et al., 1997) or B-vitamins (Benton and Cook, 1991; Mayer et al., 1996).

We show in this study that consumption of a mixture of these three key ingredients at the levels found in a single can of Red Bull Energy Drink has significant effects on cognition and mood in young adult subjects at night.

Methods

Subjects

Ten graduate students (6 female and 4 male) aged between 20 and 28 years (mean age 23.9 $\pm$ 2.5 years) were paid for the participation and screened by interview. They were healthy, non-smoking and of normal weight, in good physical and mental condition, with no previous or current neurologic or psychiatric illness or current drug consumption.

Five subjects (3 males, 2 females) were non-caffeine-consumers and five had been regular caffeine consumers (at least one cup of coffee or/and caffeinated drink per day) for more than one year.

All subjects had refrained from consumption of caffeine and alcohol for at least 24 hours prior to test session. Informed written consent was obtained from the subjects.

Experimental design

ERP recordings and neuropsychological tests were assessed in a single-blind, randomised, placebo-controlled, repeated-measures design. Assignment of subjects to test material (placebo or CTG) was randomised in order to avoid test adaptation.

Procedure

In this double-blind crossover study, the two test sessions were separated by at least one week for each subject. The order of administration of the test material (placebo or CTG) was randomized and balanced among subjects, so that each subject received placebo in one of the sessions and CTG in the other. Subjects reported to the clinic at 9:30 p.m. on the day of each test session. After baseline measurements had been determined, subjects took either 7 capsules containing the quantity of CTG found in a 250 ml can (total of 1.0 g taurine, 80 mg caffeine and 600 mg glucuronolactone) or 7 placebo capsules containing wheat-bran along with 250 ml of water. After 60 min, the tests (ERPs and psychological tests) were performed in a fixed order for all sessions.

Event-related potential (ERP) recording

Subjects were seated in reclining chairs in a quiet, dimly lit room and were instructed to close their eyes in order to avoid eye blink artifacts. Auditory ERPs were recorded (Nihon-Kohdem MEB 4200G recording system) following a simple active oddball procedure using stimuli presented binaurally at a rate of 0.5/sec and at an intensity of 70 dB SPL (Seidl et al., 1997). Stimuli were presented in a randomised sequence of frequent and infrequent stimuli. Frequent stimuli (80% of time) were 1000 Hz tones and infrequent stimuli (20% of time) were 2000 Hz tones. Tone duration was 100 ms (10 ms rise, 80 ms plateau, 10 ms fall). The subjects were instructed to count silently the infrequent (target) tones, while ignoring the frequent (background) tones, and to report the total number of infrequent tones at the end of the session. Stimuli were presented until the ERP recording contained two blocks of 20 artifact-free responses to infrequent stimuli. In addition, subjects had to press a button on each occurrence of the target stimuli as quickly as possible, and the motor reaction time ("RT") was recorded.

For ERP recording, active electrodes were placed around the scalp at Fz (frontal), Cz (central) or Pz (parietal) locations according to the International 10–20 system, referenced to linked mastoids (A1–A2), with a forehead ground. In addition one electrode was placed at the outer canthus of the left eye and the second on the forehead above the eye to monitor horizontal and vertical eye movements. The impedances of the electrodes were maintained below 5 kohm. The filter bandpass was 0.1–50 Hz. The analysis time was 900 ms with 100 ms prestimulus time. Automatic artifact rejection was used for amplitudes exceeding $\pm 100 \mu$V (EEG and EOG). For comparison of the effects of the test materials, the P300 wave peak latencies, the baseline-to-peak amplitude of P300, and RT in response to target-stimuli, were evaluated. Mean P300 latencies/amplitudes and mean RT were calculated.

Psychological procedures

Psychological procedures consisted of the d2 test (Brickenkamp 1994) and the "Basler Befindlichkeit" questionnaire. The d2 test measures attention capacity in a stressful situation. It is a speed-and-power-test that measures quantity (i.e., total number)

(Gesamtzahl – GZ), errors (Fehler – F), quality (i.e., total number minus errors) (GZ-F) and variability (Schwankungsbreite – SB). The "Basler Befindlichkeit" scale (Hobi 1985) measures changes in actual status of mood or subjective feelings of well-being ("Befindlichkeit"), represented by the sum of four components. In addition to this sum value, the test also measures the four components or subscales, namely vitality ("Vitalität" – VT), balance ("Intrapsychisches Gleichgewicht" – IG), social extravertedness ("Soziale Extravertiertheit" – SE) and vigilance ("Vigilität" – VG).

Statistics

Effects of CTG on P300 amplitude/latency and psychological test parameters were evaluated with a repeated-measures ANOVA, as appropriate, with test material (placebo or CTG) as a within-subject factor, age of subjects as independent variable, and sex as a cofactor. In addition, a paired samples t-test was applied, as appropriate. All analyses were run with the SPSS-PC 8.0 statistical software package. The level of significance was set at $p < 0.05$.

Results

The outcome of the study is revealed in Table 1.

RT improved in response to target stimuli after the administration of CTG when compard with placebo. Over the duration of the test, placebo-treated subjects showed a significant decay of P300 latencies and significantly longer reaction times compared with baseline measurements, whereas in CTG-treated subjects attention and reaction time levels were fully preserved. In fact, CTG-treated subjects showed shorter P300 latencies and RTs in comparison with pretreatment, although measured differences did not reach statistical significance.

Psychometry using the d2-test confirmed the electrophysiological findings above. This test system for measuring attention in a stressful situation showed improvement of full-scores (quantifying psychomotor speed) and overall concentration power in the CTG-treated group, leaving error-scores and variability of overall concentration power unaffected. This was also found in the placebo-treated group, albeit with higher p-values.

The "Basler-Befindlichkeit" test revealed that administration of placebo led to a significant decline of the sum of the scores (representing mood or feelings of well-being), as well as in individual scores for vitality and social extrovertedness, compared with baseline values. No significant decline was

Table 1. Event-related-potential – P300, and reaction time (RT) of 2nd block

	baseline	after placebo	baseline	after Red Bull-AI
P300 latency (ms)	307.2 ± 18.4	328.7 ± 26.9**	326.2 ± 28.7	317.6 ± 25.9
RT (ms)	289.7 ± 48.7	316.2 ± 45.8***	291.8 ± 60.4	277.9 ± 49.7

** $P < 0.01$; *** $P < 0.001$ (paired samples t-test).

Table 2. d2-test (raw values)

	baseline	after placebo	baseline	after Red Bull-AI
GZ (total number)	557.3 ± 89.7	585.6 ± 83.7**	583.5 ± 39.1	613.5 ± 39.1***
GZ-F (GZ-failures)	541.9 ± 92.6	571.1 ± 84.6*	564.5 ± 65.7	601.4 ± 45.1***
F (failure)	15.4 ± 18.1	12.2 ± 17.8	19.3 ± 31.9	12.9 ± 23.6
SB (variabilty)	9.0 ± 5.4	7.5 ± 5.3	7.8 ± 5.0	6.0 ± 3.7

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ (paired samples t-test).

Table 3. Basler Befindlichkeits-Skala

	baseline	after placebo	baseline	after Red Bull-AI
Total score	81.6 ± 9.1	71.2 ± 10.9*	75.4 ± 15.0	77.5 ± 8.2
VT	19.6 ± 3.5	16.2 ± 4.3**	17.8 ± 4.3	18.3 ± 4.4
IG	21.6 ± 6.7	23.0 ± 1.7	23.0 ± 3.2	21.1 ± 2.6*
SE	19.9 ± 3.8	15.7 ± 4.5*	17.9 ± 4.3	18.8 ± 3.1
VG	18.5 ± 3.0	15.8 ± 3.0	18.9 ± 3.0	17.0 ± 3.9

* $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ (paired samples t-test).
VT vitality; *IG* balancedness; *SE* social extravertedness; *VG* vigilance.

found for either the sum of the scores or the individual scores following CTG administration, with the exception of the score for balance. When comparing caffeine and non-caffein-consumers, no difference in the response to treatment could be observed (data not shown).

No adverse effects were noticed during or following the study.

Discussion

Methodologically, we consider the applied test systems, neurophysiological and psychometry, as appropriate.

Measuring P300 event-related potentials using an auditory oddball paradigm is a well-established assay in our laboratory and an unequivocally accepted assay system for attention (Seidl et al., 1997). The d2-test is a simple, paper and pencil, non-sophisticated system reflecting attention, visual perceptual speed and capacity for concentration (Schreiber et al., 1991). The evaluation of mood is reliably and reproducibly measured by the "Basler Befindlichkeit" questionnaire, a test system useful for evaluation of mood in terms of "life quality". Thus, it is used for the assessment of side-effects of drugs on emotional well-being (Wichers et al., 1999).

As shown in the Results, auditory event related potentials (ERP-P300) showed shorter latencies and significantly improved motor reaction time after

the administration of CTG when compared with placebo. Practically, at the end of the test at midnight placebo-treated individuals revealed a significant decay of P300 latencies and significantly longer reaction times whereas in CTG-treated individuals attention and reaction time levels were fully preserved; moreover, although levels did not reach statistical significance, probands with CTG-treatment showed shorter P300 latencies and motor reaction times after administration of CTG in comparison to pretreatment.

Psychometry using the d2-test confirmed the electrophysiological findings from above: this test system for measuring attention in a stressful situation revealed improvement of full-scores (quantifying psychomotor speed) and overall-concentration power in the CTG-group, leaving error-scores and variability of overall concentration power unaffected.

The results show that the combination of CTG improves cognitive performance (see above). It is possible to explain our findings on cognitive performance in terms of previously published findings on the effects of caffeine. It is widely accepted that certain doses of caffeine can improve cognitive performance (see above). In our study we demonstrate that caffeine along with taurine and glucuronolactone (CT) has positive effects on cognitive functions.

We also demonstrated that non-caffeine-consuming probands do not differ from caffeine-consuming probands (data not shown).

The status of mood, evaluated by the protocol of the "Basler-Befindlichkeit" test revealed that placebo-administration led to a significant decline of the total scores for well-being, vitality and social outgoingness at the end of the experiments at midnight, whereas no decline was found for these parameters following CTG-administration with the exception of "well-balanced", which was decreased. Vigilance, although not reaching statistical significance, was higher in the CTG-group at the end of the experiments.

While the mechanisms for modulation of cognitive functions by the CTG mixture can be assigned to caffeine via its action on the purinergic (adenosinergic) system, which in turn is closely linked to other neurotransmitter systems (Biaggoni et al., 1991), the positive influence of CTG on mood or feeling of well-being can be assigned to taurine. Taurine is known to modulate mood (Mandel et al., 1985), and to be involved in stress (Engelmann et al., 1999; Milakofsky et al., 1993; Yamamoto et al., 1985) and behavior (Belfer et al., 1998; Lidsky et al., 1995). Mechanisms for these actions of taurine may possibly involve its many interactions with glycinergic, GABAergic, cholinergic and adrenergic neurotransmitter systems (Ramanathan et al., 1997).

In conclusion: The combination of CTG of a can/a single serving of Red Bull Energy Drink has beneficial effects on cognitive performance and mood as evaluated by neurophysiological and neuropsychological methods in non-caffeine consumers as well as in caffeine consumers.

References

Alford C, Cox H, Wescott R (1999) "Red Bull" energy drink significantly improves concentration, reaction time, memory, mood, aerobic and anaerobic endurance. Amino Acids 17: 94

Anderson KJ (1994) Impulsivity, caffeine and task difficulty: a within subject test on the Yerkes-Dodson law. Personality and Individual Differences 16: 813–829

Bättig K, Buzzi R, Martin JR, Feierabend JM (1984) The effects of caffeine on physiological functions and mental performanbce. Experientia 40: 1218–1223

Belfer I, Davidson E, Ratner A, Beery E, Shir Y, Seltzer E (1998) Dietary supplementation with the inhibitory amino acid taurine suppresses autotomy in HA rats. Neuroreport 9: 3103–3107

Benton D, Cook R (1991) Vitamin and mineral supplements improve the intelligence scores and concentration of six-year-old children. Personality and Individual Differences 12: 1151–1158

Benton D, Owen DS (1993) Blood glucose and human memory. Psychopharmacology 113: 83–88

Benton D, Sargent J (1992) Breakfast, blood glucose and memory. Biol Psychol 33: 207–210

Biaggoni I, Paul S, Puckett A, Arzubiaga C (1991) Caffeine and theophylline as aden osine receptor antagonists in humans. J Pharmacol Exp Ther 258: 588–593

Borland RG, Rogers AS, Nicholson AN, Pascoe PA, Spencer MB (1986) Performance overnight in shiftworkers operating a day-night schedule. Aviat Space Environ Med 57: 241–249

Brickenkamp R (1994) Test d2. Aufmerksamkeits-Belastungs-Test, 8. Aufl. Hogrefe, Göttingen

Engelmann M, Singewald N, Ebner K, Lubec G, Landgraf R, Wotjak CT (1999) Taurine modulates the activity of the classical hypothalamo-neurohypophyseal system. Amino Acids 17: 30

Frewer LJ, Lader M (1991) The effects of caffeine on two computerized tests of attention and vigilance. Human Psychopharmacology 6: 119–128

Geiss KR, Jester J, Palke W, Hamm W, Waag KL (1994) The effect of a taurine containing drink on performance in 10 endurance-athletes. Amino Acids 7: 45–56

Hobi V (1985) Basler Befindlichkeits-Skala. Beltz-Test, Weinheim, Switzerland

James JE (1997) Understanding caffeine: a biobehavioral analysis. Sage Publications, California

Kagamimori S, Zhang M, Liu Z, Sekine M, Sokejima S, Qi BLF, Ai Y (1999) Effects of taurine application on visual stress due to VDT works. Amino Acids 17: 31

Lidsky TI, Schneider JS, Yablonski-Alter-E, Zuck LG, Banerjee SP (1995) Taurine prevents haloperidol-induced changes in striatal neurochemistry and behavior. Brain Res 686: 104–106

Mandel P, Gupta RC, Bourgouignon JJ, Wermuth CG, Molina V, Gobaille S, Ciesielski L, Simler S (1985) Effects of taurine and taurine analogues on aggressive behavior. Progr Clin Biol Res 179: 449–458

Manning CA, Parsons MW, Cotter EM, Gold PF (1997) Glucose effects on declarative and nondeclarative memory in healthy elderly and young adults. Psychobiology 25: 103–108

Mayer G, Kroger M, Meier-Ewert K (1996) Effects of vitamin B12 on performance and circadian rhythm in normal subjects. Neuropsychopharmacology 15: 456–464

Milakofsky L, Harris N, Vogel WH (1993) Effects of repeated stress on plasma catecholamines and taurine in young and old rats. Neurobiol Aging 14: 359–366

Ramanathan VK, Chung SJ, Giacomini KM, Brett CM (1997) Taurine transport in cultured choroid plexus. Pharmacol Res 14: 406–409

Rogers PJ, Dernoncourt C (1998) Regular caffeine consumption: a balance of adverse and beneficial effects for mood and psychomotor performance. Pharm Biochem Behav 59: 1039–1045

Schreiber H, Stolz-Born G, Rothmeier J, Kornhuber A, Kornhuber HH, Born J (1991) Endogenous event-related potentials and psychometricperformance in children at risk for schizophrenia. Biol Psychiatry 30: 177–189

Seidl R, Hauser E, Bernert G, Marx M, Freilinger M, Lubec G (1997) Auditory evoked potentials in young patients with Down syndrome. Event-related potentials (P3) and histaminergic system. Brain Res Cogn Brain Res 5: 301–309

Wichers M, Springer W, Bidlingmaier F, Klingmüller D (1999) The influence of hydrocorticone substitution on the quality of life and parameters of bone metabolism in patients with secondary hypercortisolism. Clin Endocrinol 50: 759–765

Yamamoto J, Akabane S, Yoshimi H, Nakai M, Ikeda M (1985) Effects of taurine on stress – evoked hemodynamic and plasma catecholamine changes in spontaneously hypertensive rats. Hypertension 7: 913–922

Authors' address: Dr. R. Seidl, Department of Pediatrics, University of Vienna, Währinger Gürtel 18-20, A-1090 Vienna, Austria, Fax 0043 1 40400 3238

Received January 5, 2000