Amino Acids (2001) 21: 139–150

Amino
Acids
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Printed in Austria

The effects of Red Bull Energy Drink on human performance and mood

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Accepted May 25, 2000

Summary. The effects of Red Bull Energy Drink, which includes taurine, glucuronolactone, and caffeine amongst the ingredients, were examined over 3 studies in a total of 36 volunteers. Assessments included psychomotor performance (reaction time, concentration, memory), subjective alertness and physical endurance. When compared with control drinks, Red Bull Energy Drink significantly ($P < 0.05$) improved aerobic endurance (maintaining 65–75% max. heart rate) and anaerobic performance (maintaining max. speed) on cycle ergometers. Significant improvements in mental performance included choice reaction time, concentration (number cancellation) and memory (immediate recall), which reflected increased subjective alertness. These consistent and wide ranging improvements in performance are interpreted as reflecting the effects of the combination of ingredients.

Keywords: Amino acids – Red Bull Energy Drink – Caffeine – Glucuronolactone – Taurine – Physical endurance – Psychomotor performance

Introduction

University students in Bristol report improved work endurance and subjective state after consuming Red Bull Energy Drink. Key constituents include caffeine, glucuronolactone, and taurine amongst other potentially performance enhancing ingredients. Geiss et al. (1994) reported improved exercise performance in endurance athletes after consuming 500 ml of this taurine-containing drink. The studies presented here assessed physical and mental performance, as well as subjective alertness, in order to investigate the reported effects under controlled conditions.

Some of the individual constituents are known to be potentially performance enhancing, with regards to both physical and mental performance, as well as improving subjective state. Red Bull Energy Drink contains several ingredients that have multiple effects on human metabolism, e.g., taurine (Gaull, 1986; Stapleton et al., 1997), glucuronolactone (Hollmann, 1964;

Masaki, 1972; Poon et al., 1993), caffeine (Arnaud, 1998; Spriet et al., 1992; Daly, 1993; Dodd et al., 1993) and B vitamins (McArdle et al., 1994). The product also contains glucose, an important metabolic substrate. A previous study (Geiss et al., 1994) reported that Red Bull Energy Drink produced a significant increase in endurance in trained athletes. The well-established multiple biochemical actions of taurine (Huxtable, 1992), coupled with the finding that taurine and glucuronolactone have an important effect on endurance in trained athletes (Geiss et al., 1994), make it likely that taurine has important effects on endurance in untrained subjects.

There is also an established literature on the psychomotor effects of caffeine. Adenosine receptor blockade is a principle action of caffeine resulting in a stimulant effect (Biaggoni et al., 1991; Franchetti et al., 1994; Fredholm, 1995; Le Blanc and Soucy, 1994). Caffeine can improve performance, although the latter is affected by dose, time-on-task and memory load (Anderson, 1994; Bättig et al., 1984; Borland et al., 1986; Frewer and Lader, 1991; Loke, 1988). Improvement in memory tasks, including free recall and span, has similarly been observed with caffeine (Barraclough and Foreman, 1994; Davidson and Smith, 1991; Smith et al., 1994).

Some studies have shown that caffeine can increase physical performance capacity, including endurance and peak muscle strength (Anselme et al., 1992; Berglund & Hemmingsson, 1982; Burke, 1992; Costill et al., 1978; Falk et al., 1990; Graham and Spriet, 1991; Lindinger et al., 1993; Meliska and Lawson, 1996; Spriet et al., 1992).

The Red Bull Energy Drink contains glucose and B group vitamins. Glucose is metabolised to release energy during both aerobic and anaerobic metabolism (Sizer and Whitney, 1997), and may improve cognitive performance although the findings are variable (Azari, 1991; Benton and Owens, 1993). Vitamin B12 may facilitate mental performance including concentration (Benton and Cook, 1991; Mayer et al., 1996), and where a state of depletion exists, restoration of B group vitamins may enhance physical performance through their role in energy production (McArdle et al., 1994).

The following studies were designed to investigate the effects of Red Bull Energy Drink, reported by students, under appropriate experimental conditions. Cardiovascular effects were monitored under resting conditions, in addition to mental performance and subjective state. Both aerobic and anaerobic endurance were investigated to determine the range of potential benefits on physical performance. Following a preliminary study to assess potential effects, further investigations replicated assessments under more controlled conditions and incorporated additional cognitive measures. Given the beneficial effects previously reported for individual constituents, the aim of these investigations was to see if the combined constituents of the drink, in its commercially available form, produced consistent effects across a range of human performance measures.

Methods

Subjects

The first study involved 5 male and 5 female subjects, aged 18–30 years with a mean of approximately 23 years; there were 7 male and 7 female subjects in the second study, aged 18–35, mean 24 years; whilst 7 male and 5 female subjects participated in the third study, aged 20–21 years, these unpaid healthy volunteers included moderate caffeine users screened for physical exercise capacity, who were not diabetic and had no known sensitivity to test compounds. They were recruited from amongst the students and their friends at the University of the West of England, Bristol, UK. All participants had the experimental procedures explained or demonstrated to them before giving their informed consent. Study protocols were approved by an Ethics Committee of the University.

Study design

The preliminary study was undertaken in 1997 to establish possible treatment effects, with subsequent studies in the following 2 years including additional controls. A repeated measures, double-blind design was employed with each subject receiving both treatments in a randomised order. Similar designs were employed for subsequent studies although treatment order was based on latin squares.

The preliminary study assessed heart rate, blood pressure, subjective mood and choice reaction time both pre- and post treatment. The second study assessed heart rate, blood pressure, subjective alertness (VAS) and choice reaction time both pre- and post treatment. Aerobic endurance was tested post treatment only. The third study included cognitive tasks with established sensitivity assessing concentration and memory pre- and post treatment, with anaerobic endurance assessed post treatment.

Treatments

The preliminary study included: carbonated mineral water and Red Bull Energy Drink. A no drink control was added for the second study. Still water replaced carbonated water in the third study with a 'dummy' energy drink being added as a comparator for Red Bull Energy Drink. The dummy energy drink comprised low calorie quinine flavoured carbonated water with additional lime, apple and blackcurrent concentrates with no added sugar. Red Bull Energy Drink contains carbonated water, sucrose (21.50 g), glucose (5.25 g), citric acid, taurine (1,000 mg), glucuronolactone (600 mg), caffeine (80 mg), inositol (50 mg), vitamins (niacin, panthenol, B6, B12), flavours, colour (caramel, riboflavin). The volume of all drinks was 250 ml (equivalent to a standard can of Red Bull Energy Drink).

Assessments and equipment

A psychomotor test battery (Comstat) was employed for testing 5-choice reaction time (Hindmarch and Parrott, 1978; Smith, 1999) with 20 stimulus presentations following 5 practice trials for each assessment. The concentration task (Anderson, 1994; Frewer and Lader, 1991) required subjects to cancel a specific digit (e.g. all '7's) from a sheet containing a pseudo-random list of characters such that the distribution of single digits (1–9) was approximately balanced. This was assessed as the number crossed-out within a 1 minute period after a 30 second practice period. A memory task (immediate recall) in which subjects were given 1 minute to learn a list of 22 two-digit numbers (e.g. 12, 45), and then a further minute to recall as many numbers as they could from the list (Baraclough and Foreman, 1994; Smith et al., 1994). Effect on mood/subjective alertness

was based on 100 mm visual analogue scales (VAS) with 50 mm representing a neutral position (Bond and Lader, 1974).

Heart rate and blood pressure were measured with subjects sitting, using on Omega 1400 monitor (Invivo Research Labs. Inc.). A Cat-Eye Ergociser 1600 with built-in ear clip heart rate monitor was used for aerobic endurance assessment and a high torque ergociser (e.g. Tunturi 604) for testing anaerobic endurance.

Procedures

Each study was completed within a 4 week period, whilst for individual participants, test days for separate treatments were within a week. Preliminary test sessions were provided to help control for practice effects on psychomotor or cognitive tasks, and to provide an initial assessment of physical performance on exercise tests. The first study involved the use of opaque cups, lids and straws to enable double-blind, randomised, treatment administration for both experimenters and participants. There were no caffeine consumption restrictions on study days. Subjects were tested as a group, with assessments made both before drinks were consumed (pre-treatment) and 30 minutes after consumption (post-treatment), to allow for absorption. A restful video was watched by participants until post-treatment testing began.

The schedule was designed to allow for absorption and enable testing whilst significant levels of the drinks constituents remained in the plasma. For example, significant absorption of caffeine has occurred within half an hour of consumption, with an elimination half-life between 2.5 to 6 hours (Arnaud, 1998; Griffiths and Woodson, 1988). Elevations of blood glucose are achieved within half an hour, and remain when tested an hour after ingestion (Kennedy and Scholey, 2000). Taurine is rapidly absorbed and excreted in experimental animals and primates following ip or oral administration. Plasma levels peaked within 30 minutes and fell with a half-life of 35 minutes following ip administration of taurine in mice (Hruska et al., 1976). An initial half-life of 24 minutes was seen in plasma levels after iv administration in rhesus monkeys (Matsubara et al., 1985). In humans, 70–80% of radiolabelled taurine given orally as a supplemented diet was excreted in urine within 24 hours; whilst iv administration led to rapid elevation of plasma levels with half appearing in urine 6–12 hours after administration (Sturman et al., 1975; 1976). Oral absorption produced elevated plasma levels which peaked when sampled at 1 hour and remained elevated 2 hours after supplementation (Thompson, 1988). These findings suggest that taurine is rapidly absorbed and that in excess of physiological requirements is rapidly excreted. Limited data are available on the human kinetics of glucuronolactone. It is rapidly metabolised (Hollmann, 1964) with elevation of the urinary metabolite glucaric acid within an hour and peak levels sustained at 5 hours (Poon et al., 1993).

Additional controls were included in subsequent studies. Administration was based on latin squares to provide a balanced treatment order, subjects were tested individually at similar times of day, and a no drink control treatment was added. Caffeine sources were avoided on test days and a hydration procedure of 1 pint water before going to bed and a minimum of 2 pints in the morning before testing, was followed on test days for the final study. Post treatment testing was from 30 minutes after drink consumption. The dummy energy drink was included in the final study because of increased exposure to Red Bull Energy Drink amongst participants, and difficulties in masking the flavour and texture of the drink.

Physical performance assessments followed American College of Sports Medicine guidelines for exercise testing and prescription (1991). Aerobic endurance included an initial trial period to establish aerobic work threshold. A similar 3 minute warm-up period, to enable achievement of maximum oxidative energy production, was used at the start of each test. During the final minute torque and work rate increases brought participants to aerobic threshold measured as maintaining 65–75% maximum heart rate

(Cooper et al., 1975; MacDougall et al., 1991). This work level was maintained until heart rate moved outside these limits, with elapsed time recording maximum aerobic endurance. Anaerobic endurance testing was based on an all-out cycling procedure of less than 20 seconds (Bar-Or, 1987; Katch, 1977; Karlsson et al., 1971). This was preceded by cycling for 5 minutes at around 50 Watts work rate, followed by hamstring, neck and shoulder stretches. Subjects then pedalled at their maximum work rate with elapsed time recorded from achieving maximal speed until it decreased, followed by a wind-down and recovery period. Physical endurance was assessed post treatment only to limit fatigue effects.

Statistical analyses

Differences between treatments were assessed using repeated measures analysis of variance (ANOVA) with pre treatment scores as covariates where both pre and post treatment assessments were made (SPSS release 6). Significant treatment differences ($P < 0.05$) were further investigated using Tukey's HSD to determine specific treatment comparisons between Red Bull Energy Drink and control drinks. Significant performance changes from the preliminary study enabled the use of a priori t-tests assessing pre and post treatment mean differences in the subsequent studies for marginally significant ($P < 0.1$) ANOVA effects, or where relatively conservative HSD comparisons were not significant. Two-tailed significance levels were employed throughout. The results are presented as combined pre treatment means, then with pre-post treatment differences added for individual treatments. Means and standard deviations for raw data were calculated in Excel.

Results

Preliminary study. The results presented in Table 1 show a decrease in heart rate and systolic blood pressure after mineral water when compared with Red Bull Energy Drink, whilst diastolic blood pressure remained more constant across treatments, with differences failing to achieve significance for any measure. Choice reaction time was significantly improved [$F_{(1,8)}$ 18.02; Mse

Table 1. Preliminary study – The effects of Red Bull in comparison to a control drink on resting cardiovascular physiology and choice reaction time: Means (SEM) n = 10 [Combined pre treatment means + pre-post differences for each treament]

Measure	Pre treatment Means	Carbonated water (250 ml)	Red Bull (250 ml)
Heart rate Beats/min.	78.4 (3.0)	74.6 (2.7)	78.8 (2.9)
Systolic blood pressure (mmHg)	117.0 (3.3)	114.1 (3.6)	116.3 (2.7)
Diastolic blood Pressure (mmHg)	70.7 (1.6)	68.0 (2.1)	72.2 (2.2)
Choice reaction time (msec.)	529.5 (19.9)	521.7 (12.8)	433.0* (22.6)

Key: * = HSD: $P < 0.05$ Red Bull Vs carbonated water.

Table 2. Second study – The effects of Red Bull in comparison to no drink and a control drink on resting cardiovascular physiology, performance and mood: Means (SEM) n = 14 [Combined pre treatment means + pre-post differences for each treatment]

Measure	Pre treatment Means	No drink	Carbonated water (250 ml)	Red Bull (250 ml)
Heart rate Beats/min.	75.9 (1.9)	74.8 (1.5)	75.4 (1.9)	83.3* (2.9)
Systolic blood pressure (mmHg)	118.7 (3.2)	117.1 (3.5)	118.3 (3.4)	118.3 (3.2)
Diastolic blood Pressure (mmHg)	73.3 (2.0)	68.7 (3.4)	69.1 (3.0)	74.3 (3.0)
Choice reaction time (msec.)	559.9 (12.9)	558.7 (17.3)	555.5 (13.9)	528.6^{+} (16.3)
Subjective alertness (mm)	39.0 (2.1)	39.6 (2.1)	36.5 (2.2)	61.9* (4.8)
Aerobic endurance (secs.)	Not Recorded	948.5 (87.0)	1,016.1 (76.6)	1,109.0* (85.1)

Key: * = HSD: $P < 0.05$ Red Bull Vs carbonated water; $^{+}$ = t: $P < 0.05$ Red Bull Vs carbonated water.

0.00; $P < 0.005$] by Red Bull Energy Drink when contrasted with carbonated water. Subjective mood was descriptively assessed with greater changes (18 mm) from pre treatment values being seen after Red Bull Energy Drink in comparison to carbonated water (4 mm) on the 100 mm visual analogue ratings.

Second study. The results presented in Table 2. contrast the no drink condition with carbonated water and Red Bull Energy Drink, revealing fairly stable levels for both systolic and diastolic blood pressure. Significant differences were found overall for heart rate [$F_{(2,26)}$ 8.30; Mse 62.38; $P < 0.005$], providing significant contrasts (HSD: $P < 0.05$) between Red Bull Energy Drink and other treatments. Differences in choice reaction time were again significant [$F_{(2,25)}$ 3.93; Mse 956.0; $P < 0.05$] and revealed a significant improvement for Red Bull Energy Drink when compared with carbonated water (t: $P < 0.05$). Significant effects for subjective alertness (VAS) [$F_{(2,25)}$ 28.84; Mse 0.97; $P < 0.001$], and aerobic endurance [$F_{(2,26)}$ 14.67; Mse 6196.5; $P < 0.001$] revealed significant improvements (HSD: $P < 0.05$) for Red Bull Energy Drink when compared with carbonated water. The relative improvement with Red Bull Energy Drink when compared with carbonated water and the poorest performance for the no drink control is plotted in Fig. 1.

Third study. Results presented in Table 3 include those for no drink, water, the dummy energy drink and Red Bull Energy Drink. Differences in memory performance, assessed as immediate recall, were significant [$F_{(3,32)}$ 4.02; Mse 3.14; $P < 0.05$]; whilst concentration task performance provided marginal significance with ANOVA [$F_{(3,32)}$ 2.64; Mse 5.39; $P < 0.07$]. Paired comparisons showed significant improvements for memory (HSD: $P < 0.05$)

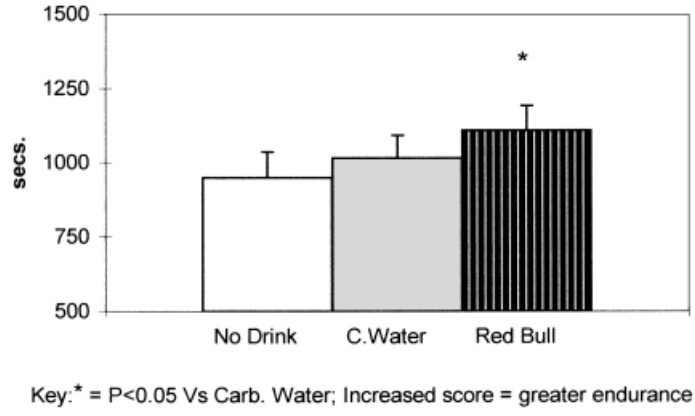

Fig. 1. Aerobic endurance: 65–75% max. HR means (+SEM) n = 14

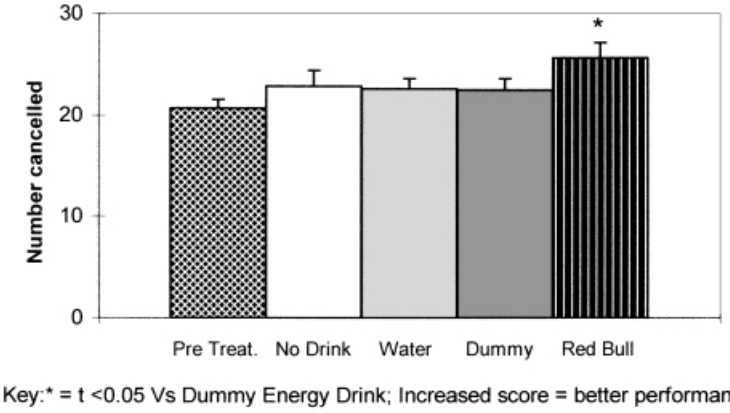

Fig. 2. Concentration task means (+SEM) n = 12

and concentration (t: $P < 0.05$) with Red Bull Energy Drink when contrasted with the dummy energy drink. With anaerobic endurance [$F_{(3,33)}$ 4.13; Mse 1.10; $P < 0.05$] Red Bull Energy Drink significantly improved performance in comparison to the dummy energy drink (HSD: $P < 0.05$). The improvement in concentration after drinking Red Bull Energy Drink when compared to either comparator drinks or the no drink condition is plotted in Fig. 2.

Overall, these studies have demonstrated no significant effects on either systolic or diastolic blood pressure when measured at rest. Changes in heart rate were less consistent, with no effects observed in the preliminary study although an increase was found with Red Bull Energy Drink when contrasted with carbonated water in the second study. Red Bull Energy Drink was associated with enhanced performance on choice reaction time in both the preliminary and second study, and with improved performance for both concentration and memory tasks in the third study. These significant changes in psychomotor and cognitive task performance were compatible with the observed increase in subjective alertness.

Table 3. Third study – The effects of Red Bull in comparison to no drink and a control drink on cognitive task performance and physical endurance: Means (SEM) n = 12 [Combined pre treatment means + pre-post differences for each treatment]

Measure	Pre treatment Means	No drink	Water (250 ml)	Dummy energy Drink (250 ml)	Red Bull (250 ml)
Memory	8.5	9.3	8.6	8.2	10.6*
(Number recalled)	(0.4)	(0.8)	(0.8)	(0.4)	(0.9)
Concentration task	20.7	22.8	22.6	22.5	25.7^{+}
(Number Crossed out)	(0.9)	(1.6)	(1.0)	(1.1)	(1.5)
Anaerobic endurance	Not	5.9	6.1	5.7	7.1*
(secs.)	Recorded	(0.5)	(0.5)	(0.4)	(0.3)

Key: * = HSD: $P < 0.05$ Red Bull Vs Dummy Energy Drink; $^{+}$ = t: $P < 0.05$ Red Bull Vs Dummy Energy Drink.

Improved exercise performance was observed for both aerobic endurance, indicating longer maintenance of 65–75% maximum heart rate with Red Bull Energy Drink, and anaerobic endurance. Comparisons between control conditions (no drink, carbonated water, dummy energy drink) failed to achieve significance, reflecting a similarity in performance for these treatments.

Discussion

The preliminary study recorded cardiovascular effects when at rest and found little change following consumption of Red Bull Energy Drink in comparison to carbonated water. Slight increases in diastolic blood pressure relative to control drinks and pre treatment levels were observed in the first 2 studies, with an increase in heart rate recorded after Red Bull Energy Drink in the second study, following overnight caffeine abstinence. This pattern of response is in keeping with the findings of previous studies. Where caffeine has been given after a temporary withdrawal period such as the night, or 24 hours, before testing a modest increase in blood pressure can occur. This may be accompanied by more variable findings for heart rate with either little effect (France and Ditto, 1992), a decrease (Whitsett et al., 1983), or more rarely an increase (Green and Suls, 1996) being reported. What is clear is that tolerance to these effects soon develops (Robertson et al., 1981) reflecting the lack of a significant cardiovascular response observed in the preliminary study where participants did not undergo temporary caffeine withdrawal. Further, the antihypertensive action of taurine (Huxtable, 1992) may oppose experimentally induced increases in blood pressure, so that observed changes may reflect the combined ingredients of Red Bull Energy Drink.

The significant reduction in choice reaction time, seen in the preliminary and second studies, is supported by some previous caffeine research (Stelt and Snel, 1998). The significant improvements in concentration and immediate recall are supported by the caffeine literature reporting concentration

(Anderson, 1994; Frewer and Lader, 1991; Loke, 1988) and memory changes after caffeine (Arnold et al., 1987; Barraclough and Foreman, 1994; Smith et al., 1994). However, it should also be noted that the energy drink tested contained several biologically active ingredients which may contribute to the improvements (e.g. glucose: Benton and Owens, 1993).

The significant increases in physical endurance seen in the second and third studies clearly demonstrated the ability of Red Bull Energy Drink to improve both aerobic endurance by 9% and anaerobic endurance by up to 24% in comparison to the control drinks. These results support earlier work on both caffeine and taurine (e.g. Anselme et al., 1992; Geiss et al., 1994; Graham and Spriet, 1991; Ono et al., 1987). This may also reflect the action of glucuronolactone in providing additional energy resources (Hollmann, 1964). Similarly, increased subjective alertness is in keeping with the caffeine literature (Loke, 1988; Smith et al., 1994). Other positive effects on mood (VAS), which are apparent in our current research programme, may be related to the taurine content of the drink. Taurine is known to modulate mood (Mandel et al., 1985) as well as stress and behavioural response (Belfer et al., 1998; Milakofsky et al., 1993; Yamamoto et al., 1985). The mechanism of action for taurine within the CNS may involve a variety of neurotransmitter systems (Ramanathan et al., 1997).

In conclusion, the studies presented here have shown consistent positive effects of Red Bull Energy Drink on physical performance with both aerobic and anaerobic endurance enhanced. Mental performance, including psychomotor and more cognitive tasks, was improved, as was subjective alertness. The consistent improvements seen here may well reflect the physical and mental benefits of the combined ingredients in this energy drink.

Acknowledgements

The authors wish to acknowledge the help of Noel Swarbrick and Chris Westwood who contributed to the preliminary study. Professor Ryan J Huxtable provided information on taurine.

References

American College of Sports Medicine (1991) Guidelines for exercise testing and prescription. Lea and Febiger, Philadelphia

Anderson KJ (1994) Impulsivity, caffeine, and task difficulty: a within-subject test of the Yerkes-Dodson law. Pers Ind Diffs 16/6: 813–829

Anselme F, Collomp K, Mercier B, Ahmaidi S, Prefaut C (1992) Caffeine increases maximal anaerobic power and blood lactate concentration. Eur J Appl Physiol 65: 188–191

Arnaud MJ (1998) Pharmacokinetics and metabolism of caffeine. In: Snel J, Lorist MM (eds) Nicotine, caffeine and social drinking: behaviour and brain function. Harwood Academic Publishers, Amsterdam, p 153

Arnold ME, Petros TV, Beckwith BE, Coons G, Gorman N (1987) The effects of caffeine, impulsivity and sex on memory for word lists. Physiol Behav 41: 25–30

Azari NP (1991) Effects of glucose on memory processes in young adults. Psychopharmacology 105/4: 521–524

Bar-Or O (1987) The Wingate anaerobic test: an update on methodology, reliability and validity. Sports Med 4: 381
Barraclough S, Foreman N (1994) Factors influencing recall of supraspan word lists: Caffeine dose and Introversion. Pharmacopsychoecologia 7: 229–236
Bättig K, Buzzi R, Martin JR, Feierabend JM (1984) The effects of caffeine on physiological functions and mental performance. Experientia 40/11: 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. Pers Ind Diffs 12/11: 1151–1158
Benton D, Owens DS (1993) Blood glucose and human memory. Psychopharmacology 113/1: 83–88
Berglund B, Hemmingsson P (1982) Effects of caffeine ingestion on exercise performance at low and high altitudes in cross-country skiers. Int J Sports Med 3: 234
Biaggioni I, Paul S, Puckett A, Arzubiaga C (1991) Caffeine and theophylline as adenosine receptor antagonists in humans. J Pharmacol Exp Ther 258: 588–593
Bond A, Lader M (1974) The use of analogue scales in rating subjective feelings. Br J Med Psychol 47: 211–218
Borland RG, Rogers AS, Nicholson AN, Pascoe PA, Spencer MB (1986) Performance overnight in shiftworkers operating a day-night schedule. Aviation Space Env Med 57: 241–249
Burke ER (1992) Cycling health and physiology. Vitesse Press, Brattleboro, Vt.
Cooper KH, Purdy JG, White SR, Pollock ML, Linnerud A (1975) Age-fitness adjusted maximal heart rates. In: Brunner D, Jokl E (eds) The role of exercise in internal medicine. Medicine and sport, vol 10. Karger, Basel
Costill DL, Dalskt GP, Fink WJ (1978) Effects of caffeine ingestion on metabolism and exercise performance. Med Sci Sports Exer 10: 155–158
Davidson RA, Smith BD (1991) Caffeine and novelty: effects on electrodermal activity and performance. Physiol Perf 49/6: 1169–1175
Daly JW (1993) Mechanism of action of caffeine. In: Garattini S (ed) Caffeine, coffee and health. Raven Press, New York, p 97
Dodd SL, Herb RA, Powers SK (1993) Caffeine and exercise performance: an update. Sports Med 15/1: 14–23
Falk B, Burstein R, Rosenblum J, Shapiro Y, Zylber-katz E, Bashan N (1990) Effects of caffeine ingestion on body fluid balance and thermoregulation during exercise. Can J Physiol Pharmacol 68: 889–892
Franchetti P, Messini L, Capellacci L, Grifantini M, Lucacchini P, Martini C, Senatore G (1994) 8-Azaxanthine derivatives as antagonists of adenosine receptors. J Med Chem 37: 2970–2975
France C, Ditto B (1992) Cardiovascular responses to the combination of caffeine and mental arithmetic, cold pressor, and static exercise stressors. Psychophysiology 29: 272–282
Fredholm BB (1995) Adenosine, adenosine receptors, and the action of caffeine (Astra Award Lecture). Pharmacol Toxicol 76: 93–101
Frewer LJ, Lader M (1991) The effects of caffeine on two computerised tests of attention and vigilance. Human Psychopharm 6: 119–128
Gaull GE (1986) Taurine as a conditionally essential nutrient in man. J Am Coll Nutr 5: 121
Geiss K-R, Jester I, Falke W, Hamm M, Waag KL (1994) The effect of a taurine-containing drink on performance in 10 endurance-athletes. Amino Acids 7: 45–56
Gold PE (1986) Glucose modulation of memory storage processing. Behav Neurol Biol 45: 342–349
Graham TE, Spriet LL (1991) Performance and metabolic responses to a high caffeine dose during prolonged exercise. J Appl Physiol 21: 2292–2298

Green P, Suls J (1996) The effects of caffeine on ambulatory blood pressure, heart rate, and mood in coffee drinkers. J Behav Med 19/2: 111–128
Griffiths RR, Woodson PP (1988) Caffeine physical dependence: A review of human and laboratory animal studies. Psychopharmacology 94: 437–451
Hindmarch I, Parrott AC (1978) The effect of a subchronic administration of 3 dose levels of a 1, 5-benzodiazepine derivative, clobazam, on subjective assessments of sleep and aspects of psychomotor performance the morning following nightime medication. Arzneimittelforschung (Drug Res) 28: 2169–2172
Hollmann S (1964) Nonglycolytic pathways of metabolism of glucose. Academic Press, New York, p 95
Hruska RE, Thut PD, Huxtable RJ, Bressler R (1976) Hypothermia produced by taurine. In: Huxtable RJ, Barbeau A (eds) Taurine. Raven Press, New York, p 347
Huxtable RJ (1992) Physiological actions of taurine. Physiol Rev 72/1: 101–163
Karlsson J (1971) Muscle metabolites during submaximal and maximal exercise in man. Scand J Clin Lab Invest 26: 385
Katch VL (1977) Optimal test characteristics for maximal anaerobic work on the bicycle ergometer. Res Q 48: 319
Kennedy DO, Scholey AB (2000) Glucose administration, heart rate and cognitive performance: effects of increasing mental effort. Psychopharmacology 149: 63–71
LeBlanc J, Soucy J (1994) Hormonal dose-response to an adenosine receptor agonist. Can J Physiol Pharmacol 72: 113–116
Lieberman HR (1992) Caffeine. In: Smith AP, Jones DM (eds) Handbook of human performance, vol 2. Health and performance. Academic Press, London, p 49
Lindinger MI, Graham TE, Spriet LL (1993) Caffeine attenuates the exercise-induced increase in plasma [K+] in humans. J Appl Physiol 74: 1149–1155
Loke WH (1988) Effects of caffeine on mood and memory. Physiol Behav 44: 367–372
Loke WH (1990) Effects of repeated caffeine administration on cognition and mood. Human Psychopharmacol 5: 339–348
MacDougall JD, Wenger HA, Green HJ (1991) Physiological testing of the high performance athlete, 2nd edn, Human Kinetics, Champaign, IL, p 12
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
Masaki H (1972) Metabolic pathway of D-glucaric acid synthesis. II. Identification of the intermediates from D-glucuronolactone to D-glucaric acid. Jpn J Dermat Ser A 82: 233–238
Matsubara Y, Lin YY, Sturman JA, Gaull GE, Marks LM, Irving CS (1985) Stable isotope study of taurine kinetics in rhesus monkey. Life Sci 36/20: 1933–1940
Mayer G, Kroger M, Meier-Ewert K (1996) Effects of vitamin B12 on performance and circadian rhythm in normal subjects. Neuropsychopharmacol 15/5: 456–464
McArdle WD, Katch FI, Katch VL (1994) Essentials of exercise physiology. Lea and Febiger, Philadelphia
Meliska CJ, Lawson CF (1996) Effects of caffeine and sugar-free beverages on psychomotor performance. Perc Mot Skills 82(3, Pt 1): 912–914
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
Ono M, Watanabe M, Minato K (1987) Effects of taurine on the metabolism under physical exercise. Sulfur Amino Acids 10: 183–186
Poon R, Villeneuve DC, Chu I, Kinach R (1993) HPLC determination of D-glucaric acid in human urine. J Anal Toxicol 17: 146–150
Ramanathan VK, Chung SJ, Giacomini KM, Brett CM (1997) Taurine transport in cultured choroid plexus. Pharmacol Res 14: 406–409
Robertson D, Wade D, Carr RK, Workman RJ, Oates JA (1981) Humoral and hemodynamic effects of chronic caffeine in man. J Clin Invest 67: 1111–1117

Sizer FS, Whitney EN (1997) Nutrition: concepts and controversies. Wadsworth Publishing Company, Belmont

Smith AP (1999) Caffeine, caffeine withdrawal, and performance efficiency. In: Gupta BS, Gupta U (eds) Caffeine and behavior: current views and research trends. CRC Press LLC, Florida, p 161

Smith AP, Maben A, Brockman P (1994) Effects of evening meals and caffeine on cognitive performance, mood and cardiovascular functioning. Appetite 22: 57–65

Spriet LL, MacLean DA, Dyck DJ, Hultman E, Cederblad G, Graham TE (1992) Caffeine ingestion and muscle metabolism during prolonged exercise in humans. Am J Physiol 262(6, Pt. 1): E891–E898

Stapleton PP, O'Flaherty L, Redmond HP, Bouchier-Hayes DJ (1998) Host defense – a role for the amino acid taurine? J Parenter Enteral Nutr 22/1: 42–48

Stelt OV-D, Snel J (1998) Caffeine and human performance. In: Snel J, Lorist MM (eds) Nicotine, caffeine and social drinking: behaviour and brain function. Harwood Academic Publishers, Amsterdam, p 167

Sturman JA, Hepner GW, Hofmann AF, Thomas PJ (1975) Metabolism of [^{35}S] taurine in man. J Nutr 105: 1206–1214

Sturman JA, Hepner GW, Hofmann AF, Thomas PJ (1976) Taurine pool sizes in man: studies with 35S-taurine. In: Huxtable R, Barbeau A (eds) Taurine. Raven Press, New York, p 21

Thompson GN (1988) Excessive fecal taurine loss predisposes to taurine deficiency in cystic fibrosis. J Pediatr Gastroenterol Nutr 7: 214–219

Whitsett TL, Manion CV, Christensen HD (1983) Cardiovascular effects of coffee and caffeine. Am J Cardiol 53: 918–922

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

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Received March 20, 2000