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Tyrosine Supplementation: A Nutraceutical Approach to Counter Heat Stress Induced Cognitive Decline

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ABSTRACT

Supplementation of tyrosine, non-essential amino acid, and precursor of catecholamine was found to ameliorate the heat-induced alterations in latencies of event-related potential P300 and contingent negative variation. Here we present the effect of tyrosine supplementation on heat stress (exposure to ambient temperature 45 °C and relative humidity 30 %) induced alterations in behavior (attention, mood) and levels of plasma monoamines. Ten healthy male participants received a placebo food bar or tyrosine-containing food bar (6.5 g in 50 g) 90 min before heat stress exposure of 90 min. Plasma and urine samples were assayed for catecholamine levels, their precursor, and metabolites using high-performance liquid chromatography. A computer-based automated test battery was used to assess attention and mood by profile of mood states questionnaire. A significantly higher plasma tyrosine ($p<0.001$) leading to an increased norepinephrine ($p<0.05$) levels in the tyrosine supplemented group was observed. Selective ($p<0.001$) and sustained attention ($p<0.02$) in the tyrosine group were significantly better compared to the placebo group. Reaction time and anger scores decreased ($p<0.001$) with tyrosine supplementation. It may be concluded that tyrosine supplementation improves heat stress-induced decrement in attention by maintaining the synthesis and turnover of norepinephrine.

Keywords: Tyrosine; Norepinephrine; Selective attention; Sustained attention; Reaction time

1. INTRODUCTION

The military occupation presents unprecedented challenges mainly during the war when troops deployed in sensitive areas have to remain alert day and night. The highest degree of mental and physical alertness is imperative among combat soldiers to accomplish complex military missions often under the most adverse and hostile environments. Human performance, both physical and cognitive, is compromised under a harsh environment. Decrements of cognitive functions i.e. performance in objective tasks that require conscious mental effort[1] like alertness, reaction time, logic skills, and short-term memory in environments of cold and hypoxia have also been observed[2]. It has been reported that acute or chronic exposure to extreme environmental conditions such as heat, cold etc. significantly impairs performance tasks[3].

Defensive measures such as minimizing the risk factors by way of translocation of the sufferers to a non-combat environment, psychotherapy, and pharmaceutical interventions are available but these are likely to affect decision making and yet not improve the performance. Therefore, a non-pharmacological substance, such as tyrosine, which is a normal food constituent with the potential to reduce or reverse the stress response, would not only be useful to military combatants but other patients with stress-related disorders too. However, studies on human volunteers have not consistently shown a positive performance effect with tyrosine supplementation[4] which could be attributed to differences in the severity of stress of the experimental paradigm or the individual stress response and hence needs further investigations.

Among the various environmental factors, high heat and humidity particularly, have been reported to impair performance[5]. Ability to accomplish specified tasks is affected by heat stress, leading to a reduction in both physical and mental performance. Rational decision-making and the ability to analyze complex situations may also be affected adversely[5]. Although, the effect of heat exposure on human physiology is well known but its impact on cognitive function is not very well described. In a hot environment, maintenance of vigilance and short-term working memory is probably most vulnerable[6].

The extent of impairment of mental performance depends on the severity and duration of exposure to the environmental stressor and also the intricacy of the cognitive task along with the ability or awareness of the person performing the task[7].

Stressful events cause an increase in the transmission of noradrenergic neurons in the frontal cortex[8]. There is evidence

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relating to catecholamine (CA), stress, and behavior. The central neurochemical circuitry is activated during stress and increase the release of different neurotransmitters which enables an individual to cope with the stress[9]. Different component of cognitive function like learning and memory is highly dependent on catecholamines. Synthesis, utilisation, and depletion of catecholamine is augmented upon stress exposure[10]. Hence, it is plausible that supplementing tyrosine would be effective in counteracting reduction in mental functions in stressful conditions such as the hot environment.

L-Tyrosine is the precursor amino acid for the synthesis of CA neurotransmitters viz. dopamine (DA), norepinephrine (NE) and epinephrine. Literature suggest that administration of tyrosine specifically accelerates brain CA concentration, turnover, and release from physiologically active CA neurons[11]. As tyrosine is a normal constituent of food, it is rapidly metabolised and has no long-term toxicity or side effects, and has been used in various studies in doses from 500 mg to 12 g per day[12].

It is well established that tyrosine increases the synthesis and release of CAs from neurons. Supplementation of tyrosine rich diet in stress exposed rats have not shown any changes in NE level and behavior. In humans, similar results have been obtained earlier. Banderet and Lieberman[13] reported that supplementation of 100 mg/kg tyrosine leads to improvement in psychomotor impairments and curtailment in development of stress symptoms during exposure to cold and hypoxia, compared to a placebo. Dietary administration of tyrosine ameliorates the stress induced behavioral and neurochemical changes[14]. Weiss *et al.*[15] showed 60 per cent - 70 per cent reduction in brain activity with declining NE concentration under stress. A dose of 200 mg/kg body weight (i.p.) of tyrosine, ameliorates the behavioral decline arising from tail shock stress[2]. Improvement in spatial working memory was observed in tyrosine supplemented group compared to saline treated group. Stress-induced increase in CA metabolites, homovanillic acid (HVA), and vanillylmandelic acid (VMA) in the brain was prevented by treatment with tyrosine[16].

Tyrosine may likely have beneficial effects on mental functions during periods of sustained and severe stress[17], but there is a scarcity of conclusive information based on the human model about the beneficial effect of tyrosine in a stressful environment. The beneficial effect of tyrosine (100 mg/kg body weight) on human behavior was examined[13] where soldiers were subjected to hypobaric hypoxia and tested for mood and mental performance. The beneficial effects of tyrosine on the mood state of depressed patients have also been reported. Our previous study[18] reported that tyrosine supplementation can serve as an effective countermeasure in improving cognition in heat stress by reducing the prolongation in latencies of event-related potentials, P300 and contingent negative variation (CNV) and CNV reaction time.

The present study aimed to evaluate the beneficial effect of tyrosine supplementation given in form of an edible nutraceutical bar in amelioration of cognitive deficit in terms of attention and mood in simulated heat stress.

2. MATERIAL & METHODS

2.1 Participants

Human volunteers (n=10), soldiers from the Indian Army in the age group of 20-30 years, weight (mean±SD) 65±2 kg participated in the study. Volunteers with no neurological and cardiac complications were included in the study. It was assured that they were not consuming any psychotropic drugs during the study. Volunteers were explained the purpose and procedure of the study and ink signed consent was taken prior to the study. The study protocol was approved by the Institutional human ethical committee (approval number: IEC/DIPAS/11). All the guidelines of the Helsinki protocol were followed.

2.2 Study Design and Procedure

This study was double-blind, random, cross over and placebo-controlled. The volunteers (n=10) were themselves serving as their own control. All the parameters from these subjects were recorded at baseline, then with placebo or tyrosine bar administration in heat exposure. A gap of one week was kept in between tyrosine and placebo administration. The same volunteers have been used as control, placebo and tyrosine supplemented groups. On the test day, the fasting blood sample and urine of each volunteer were collected which was followed by cognitive function and mood testing. The volunteers were then fed either tyrosine or a placebo containing food bar (made by Defence Food Research Laboratory, Mysore, India) and asked to wait for 90 minutes followed by stress exposure for 90 min duration in a climatic chamber which was maintained at 45 ºC temperature and 30 per cent relative humidity (RH) (Fig. 1). All the parameters were recorded again inside the human climatic chamber after 90 min of heat exposure.

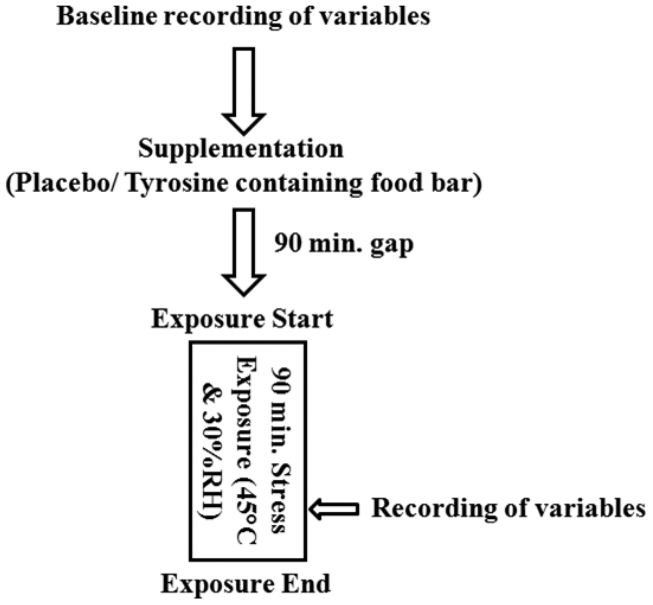

Figure 1. Schematic diagram of the experimental design.

2.3 Stress Exposure

Each volunteer was exposed to simulated heat (45 ºC ± 0.5 ºC and 30 % ± 1 % RH) for 90 min in a human climatic chamber

made by KASCO Industries Ltd., Pune, India. Temperature from different areas of the body (oral, chest, bicep, chest and calf) was recorded in all the groups.

2.4 Preparation of Tyrosine Bar and Placebo Bar

The tyrosine and placebo bars have been prepared by the application of compression technology through standardizing the compressibility characteristics like bulk density, compression ratio and dwell time. The matrix for the bar preparation has been formulated to supplement the required nutrients, subjected for bulk density determination and compression using a hydraulic press. 25 g of the mix was filled in a 3.81 cm square mold and subjected for compression with a dwell time of 8 sec. The bulk density of tyrosine bar/placebo bar before compression was 0.4329 g/cc and the bulk density after compression was 0.7216 g/cc and the compression ratio was 1.67. At the optimised conditions the product exhibited good quality characteristics, both placebo and nutraceutical bar matched in taste and texture.

The tyrosine bar was composed of carbohydrates, fat, moisture, dietary fiber, and L-tyrosine. Whereas, the placebo bar consists of all the components of the tyrosine bar except L-tyrosine. To confirm the percent composition of each constituent of the bar, the constituents were subjected to protein, fat, and carbohydrate analysis and each was determined separately according to the standard methods of the Association of Official Analytical Chemists (AOAC) International so as to arrive at the specific composition of the product.

2.5 Supplementation

Volunteers in the supplemented group were fed with two high-energy nutraceutical bars of 25 g containing a total of 6.5 g l-tyrosine. Similarly, the placebo group received two placebo bars of 25 g which did not contain l-tyrosine. The dosage of tyrosine was 100mg/ kg body weight[13] for a volunteer of 65 kg.

2.6 Sample Collection

Samples (blood and urine) were collected before supplementation and immediately post-stress exposure. Blood samples were collected in heparinised vacutainers. Plasma was separated by centrifuging the blood samples at 3000 g for 10 min at 4 ºC and stored at - 80 ºC till further assay. Urine samples were stored in an acidic medium[19] till further analysis.

2.7 High-performance Liquid Chromatography of Plasma and Urine

High-performance Liquid Chromatography (HPLC) using reverse phase C18 column was used to estimate the concentration of aromatic amino acids viz. tyrosine, phenylalanine, and tryptophan (ClinRep HPLC Kit, Munich, Germany), catecholamines viz. norepinephrine, epinephrine, and dopamine (ClinRep HPLC Kit, Munich, Germany) and serotonin (ClinRep HPLC Kit, Munich, Germany) in plasma samples. Neurotransmitter metabolites, VMA, HVA and 5-Hydroxyindole acetic acid (5-HIAA) in urine using standard kit protocol from RECIEPE, GmBH, Munich, Germany were assayed. Waters HPLC system with an autosampler (Water 717, Milford Massachusetts, USA), HPLC pump (Waters 600, Milford Massachusetts, USA), and electrochemical detector (2465 ECD, Milford Massachusetts, USA), was used to analyze the samples.

2.8 Attention Test Battery and Questionnaires

Attention (selective, divided, and sustained) was measured using a computerised performance assessment battery[20]. Mood questionnaire was administered by paper-pencil test. Subjects performed all these tests before and during the simulated environmental stress except the personality test which was administered once before stress exposure.

2.9 Profile of Mood States Questionnaire

Profile of Mood States Questionnaire (POMS) questionnaire is an inventory of self-reported mood states that describe an emotional picture of people[21]. The volunteer had to read each word and mark his response, indicating to what extent (such as Not at all, A little, Moderately, Quite a bit, extremely) did the written words describe his feelings during the past two or three days, including the day of questionnaire administration.

2.10 Selective Attention

Selective attention measures the ability of an individual to respond to a visual stimulus. In this test, dots of different colors appear on the computer screen. Each dot comes one after another on the computer screen. Volunteers were asked to focus on the red-colored dot(s) and press a space bar of the keyboard whenever they view it.

2.11 Divided Attention

A divided attention test measures the ability of an individual to respond to three different visual stimuli. In this test, dots of different colors appear one after the other on the computer screen. The volunteers were asked to focus on red, blue and green colored dots and press left, down, right arrow keys for red, green, blue dot respectively, whenever they view the same. The reaction time was also calculated from the latency of the response.

2.12 Sustained Attention

Sustained attention was evaluated by using the Mackworth clock test[22] which measures the alertness and concentration of an individual. In this test, a clock is shown on the computer screen and a large black needle (pointer) in a circular background. The needle makes short jumps approximately after every second and sometimes it makes a double jump. The volunteers had to detect and respond to the same (double jump) by pressing the left arrow key on the keyboard.

2.13 Statistical Analysis

Analysis of statistical significance for changes during various conditions of aromatic amino acids, plasma monoamines, and their urinary metabolites was performed

Table 1. Body temperature of volunteers in placebo and tyrosine supplemented groups

	Oral Temp. (°C)	Chest Temp. (°C)	Bicep Temp. (°C)	Thigh Temp. (°C)	Calf Temp. (°C)
Baseline	36.87±0.07	33.99 ±0.26	34.06±0.2 0	34.01±0.23	34.23±0.08
Placebo	38.12±0.06 *	35.79±0.31 *	35.22±0.33 **	35.28±0.18 **	35.14±0.20 **
Tyrosine	38.20±0.09 ##	35.49±0.18 #	35.30±0.16 #	35.12±0.24 #	35.20±0.31 #

Values are Mean ± SEM. n= 10 in each group. Significance level set at $p < 0.05$
* = Placebo compared to baseline (* $p < 0.02$; ** $p< 0.01$) # = Tyrosine compared to baseline (# $p < 0.02$; ## $p< 0.01$)

using one-way ANOVA. Further, Bonferroni posthoc test was performed to know the significance between baseline and placebo, baseline and tyrosine and placebo and tyrosine groups. The non-parametric parameter viz. anger was analysed by Kruskal–Wallis non-parametric ANOVA and then Dunn's post hoc test was performed. Statistical significance was fixed at $p\leq0.05$.

3. RESULTS

3.1 Body Temperature

Temperature from different areas of the body (oral, chest, bicep, chest, and calf) was recorded (Table 1). A significant increase in oral ($p<0.02$), chest ($p<0.02$), bicep ($p<0.01$), thigh ($p<0.01$) and calf ($p<0.01$) temperatures was observed in the placebo group compared to baseline. On comparing the tyrosine group with baseline, it was observed that the temperatures of oral ($p<0.01$), chest ($p<0.02$), bicep ($p<0.02$), thigh ($p<0.02$) and calf ($p<0.02$) regions was significantly higher in tyrosine group compared to baseline.

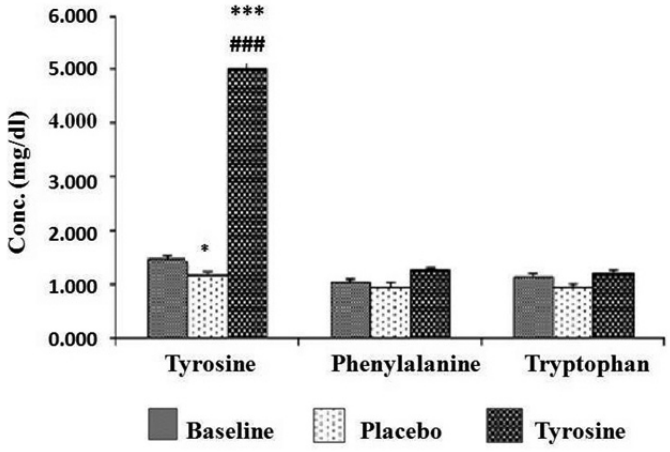

Figure 2. Effect of tyrosine supplementation on aromatic amino acids.

3.2 Aromatic Amino Acid

Analysis of HPLC data by one-way ANOVA showed a significant change ($F_{(2,27)}$= 308.3, $p<0.001$) in plasma tyrosine (Fig. 2) level. Bonferroni posthoc test further indicated that there was a significant decrement ($t_{(27)}$ =2.131; $p<0.05$) in the placebo group as compared to baseline and significant increment ($t_{(27)}$ = 20.59; $p<0.001$) in plasma tyrosine was observed in tyrosine supplemented group compared to baseline. Tyrosine group also showed significantly higher ($t_{(27)}$ = 22.31; $p<0.001$) plasma tyrosine level than placebo. No significant change in plasma levels of other aromatic amino acids i.e. phenylalanine which is the precursor of tyrosine and tryptophan which is the precursor of serotonin was observed in both groups.

Figure 2 show a significant decrease in plasma tyrosine level in the placebo group after stress exposure. With supplementation, the plasma tyrosine levels increased significantly. Values are Mean ± SEM. * $p< 0.05$, ***$p<0.001$ when compared to baseline. ### $p<0.001$ when compared to placebo.

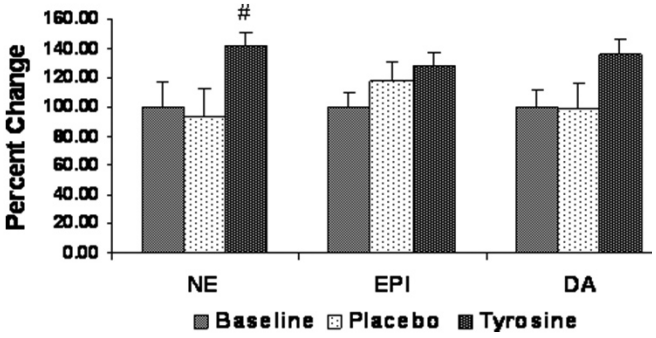

Figure 3. Effect of tyrosine supplementation on plasma monoamines post stress Exposure.

3.3 Plasma Monoamines

Results (Fig. 3) indicated a significant increase ($F_{(2,27)}$= 3.920; $p<0.05$) in NE level in the tyrosine group compared to placebo. A slight increase in levels of catecholamine neurotransmitters epinephrine (EPI) and dopamine in the tyrosine group was observed compared to baseline and placebo, but the difference was statistically not significant.

In Fig. 3, plasma nor-epinephrine (NE) was decreased post exposure in placebo but increased significantly with tyrosine supplementation. Values are Mean ± SEM. # $p < 0.05$ as compared to placebo. EPI: epinephrine, DA: dopamine.

Results of serotonin (5-HT) estimation (Fig. 4) showed a marginal decrease in the placebo group compared to baseline following stress exposure. In tyrosine supplemented group, 5-HT level was significantly higher ($F_{(2,27)}$= 5.115; $p<0.001$;

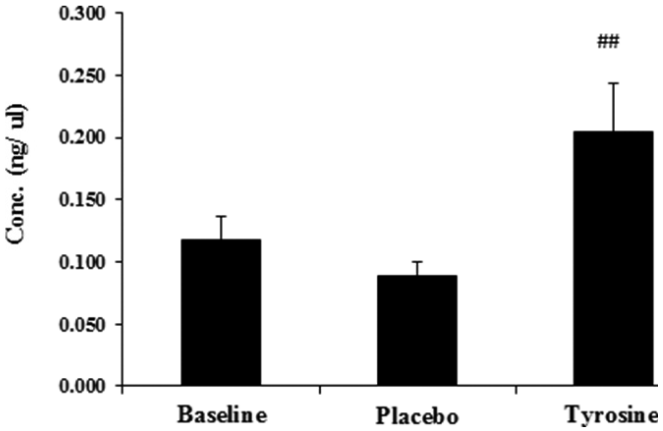

Figure 4. Effect of acute stress on plasma serotonin.

with Bonferroni posthoc test $t_{(27)}$= 3.774; p<0.02) compared to placebo.

Figure 4 shows a significant increase in 5-HT level in the tyrosine group than placebo. Values are Mean ±SEM. ##p<0.02 when compared to placebo.

3.4 Neurotransmitter Metabolites

There was no significant change in VMA level after placebo or tyrosine supplementation (Fig. 5) although VMA level in tyrosine was found lower than placebo. Results of urinary metabolites revealed a significant change in HVA level ($F_{(2,27)}$= 6.219; p<0.01). Significantly higher levels of HVA in the placebo group compared to baseline ($t_{(27)}$=3.219; p<0.01) was observed. With tyrosine supplementation HVA level significantly decreased ($t_{(27)}$= 2.242; p<0.05;) compared to placebo. Levels of 5-HIAA were significantly higher ($F_{(2,27)}$=5.617; p<0.01; with Bonferroni posthoc test $t_{(27)}$= 2.932; p<0.01) in placebo group compared to baseline.

In Fig. 5, a marginal increase in vanillylmandelic acid (VMA) was observed in the tyrosine supplemented group as compared to baseline and placebo. Homovanillic acid (HVA) levels were significantly higher after tyrosine supplementation as compared to baseline and placebo. A significant increase in the 5-Hydroxyindole acetic acid (5-HIAA) level was observed in the tyrosine group as compared to baseline.

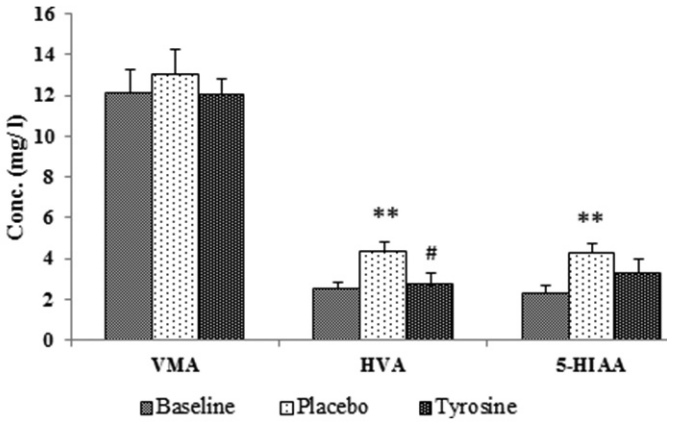

Figure 5. Effect of tyrosine supplementation on urinary metabolites post stress exposure.

Values are Mean ± SEM. ** p< 0.01 as compared to baseline. # p< 0.05 when compared to placebo.

3.5 Attention and Mood Profile

Tests for attention showed a significant change in selective attention ($F_{(2,27)}$= 26.46; p<0.001) and sustained attention ($F_{(2,27)}$= 5.213 ; p<0.02) (Table 2). A significant reduction ($t_{(27)}$= 6.505; p<0.001) in selective attention in the placebo group was observed when compared to baseline. Whereas, tyrosine group showed a significantly increased ($t_{(27)}$= 6.072; p<0.001) selective attention compared to placebo. In the case of sustained attention, tyrosine group showed a significant increase ($t_{(27)}$= 2.691; p<0.02) when compared to the placebo. Divided attention also showed improvement, although it was statistically not significant. Reaction time (RT) was significantly increased ($F_{(2,27)}$= 69.88; p<0.001) in placebo and tyrosine groups than baseline. After Bonferroni posthoc test it was observed that there was a significantly higher ($t_{(27)}$= 11.27; p<0.001) RT in the placebo group compared to the baseline value. In the tyrosine supplemented group, RT significantly decreased ($t_{(27)}$= 8.73; p<0.001) as compared to placebo and remained close to baseline values.

One of the mood profile components i.e. anger, showed a significant (p<0.001) increase in the placebo group as compared to baseline. After tyrosine supplementation anger scores were significantly lower (p<0.001) than the placebo group.

4. DISCUSSION

The present study uses a nutraceutical approach to ameliorate the effect of heat-induced decrement in attention and mood. Tyrosine is a precursor of catecholamines. The compound has received attention due to its testing by the US army as a Performance Enhancing Ration Component (PERC). Tyrosine is a conditionally essential amino acid with hardly any side effects (www.vitamins-supplements.org/aminoacids/tyrosine/php[23]). The amino acid was given in the form of an edible bar in the present study.

Our previous study showed that event related-potential P300 and contingent negative variation, which are widely used neurophysiological tools to measure cognitive function, significantly improved with tyrosine supplementation under stressful condition[18]. Locus coeruleus (LC) is activated due to stress which is a vital step to initiate neuroendocrine and behavioral response[24]. The P300 may reflect phasic activity on nor-epinephrine in the locus coeruleus (LC-NE) system[25] indicating that the effect of tyrosine on P300 may have occurred by facilitating the function of the LC-NE system. This reflects beneficial impact of tyrosine supplementation during stress on alertness[12].

In the present study tyrosine supplementation was given 90 min. before stress exposure keeping in view that the peak plasma tyrosine level in humans is attained two hours post-ingestion. A lower plasma tyrosine level in the placebo group was detected which may be due to the fact that under stressful situations tyrosine enhances neurotransmitter synthesis in catecholaminergic neurons particularly noradrenergic neurons when these neurons are physiologically active and firing rapidly. The effect of tyrosine supplementation was reflected

Table 2. Psychological tasks

	Selective Attention	Divided Attention	Sustained Attention	Anger (Mood Profile)	Reaction Time
	(Scores)				(milli second)
Baseline	45.0 ± 0.42	66.3 ± 16.7	5.8 ± 1.70	2.29 ± 0.27	433.57 ± 5.64
Placebo	40.5 ± 0.40 ***	44.0 ± 11.6	5.5 ± 0.60	8.28 ± 0.35 ***	515.01 ± 5.59 ***
Tyrosine	44.7 ± 0.67 ###	75.8 ± 19.0	7.4 ± 0.40 ##	5.85 ± 0.32 ###	451.88 ± 3.91 ###

Values are Mean ± SEM.
*p<0.05; *** p < 0.001 when compared to baseline ##p<0.02; ###p<0.001 when compared to placebo

by significantly higher plasma tyrosine levels in the tyrosine supplemented group leading to an increased synthesis of norepinephrine, epinephrine and dopamine. A lower level of these neurotransmitters was seen in the placebo group, which was owing to increased neuronal transmission and thus depletion in such stressful setting[26], as well as a lack of adequate precursor for continued synthesis. The level of NE metabolite VMA and DA metabolite HVA in the tyrosine group was found similar to baseline values.

Tyrosine is delivered from the bloodstream to the brain by a specialised carrier system that it shares with other neutral amino acids such as valine, isoleucine, leucine, methionine, phenylalanine, and tryptophan in the production of catecholaminergic neurotransmitters in the brain. The amount of tyrosine that enters the brain depends upon the tyrosine ratio i.e. the amount of tyrosine available relative to the sum of the other neutral amino acids that compete for transport. When the tyrosine ratio is high, an increased amount of tyrosine enters the brain and is available for CA synthesis. Previous studies suggest that in humans[27] and animals[28], tyrosine administration increased plasma tyrosine ratio, elevated brain tyrosine and accelerated DA and NE synthesis.

The endogenous level of amino acid phenylalanine, which is the precursor for tyrosine biosynthesis, was slightly lower in the placebo group compared to its baseline value in this study. This may be due to its utilisation for tyrosine biosynthesis and further conversion to catecholaminergic neurotransmitters in response to stress. Whereas, endogenous phenylalanine level in the tyrosine group was higher than its baseline value. This may be due to its lesser utilisation for tyrosine synthesis as tyrosine was supplemented orally to cope up with the hot environment.

Acute stress exposure in the present study resulted in a decrease in selective attention and 3- choice reaction time (divided attention) tasks, wherein volunteers a committed greater number of errors and responded slowly. The results indicated that tyrosine supplementation before stress exposure leads to an improvement in the attention and RT of volunteers in tyrosine supplemented group. These findings are in tune with earlier studies[9,29]. In animals[30] and humans[31], the role of DA and NE has been described in a variety of attention-related activities such as searching and analysing capability, diversion, response rate, discrimination, and attention swapping. The role of tyrosine in promoting cognitive flexibility, a cognitive-control function that is assumed to be modulated by DA has been investigated[32], suggesting that tyrosine can facilitate cognitive flexibility by repleting cognitive resources. Attention, awareness, concentration, motor activity, and the regulation of emotional processes are all influenced by noradrenergic neuron activity. As mentioned, a significant increase in NE levels in the tyrosine group and an increase in DA was observed in this study. This increase along with significantly increased 5-HT levels in the tyrosine group may be responsible for the improvement in attention, RT and mood with tyrosine supplementation in hot stressful condition.

In animal experiments, tyrosine supplementation, either systemically immediately prior to the onset of stress or as a food supplement, has demonstrated to protect against both neurochemical and behavioural effects of stress[16], where stressors like as immobility, cold, tail shock, and others were utilised. Tyrosine supplementation has also been demonstrated to reduce stress-induced depletion of brain NE and DA in working memory-related CNS areas [14]. Further, the sympathetic adrenal-medullary (SAM) system is activated when an individual is challenged by the environment[33-34]. Psychological stress stimulates the adrenal medulla to secrete epinephrine and norepinephrine into the bloodstream via the hypothalamus and the sympathetic nervous system. This rapid defense reaction prepares the body to battle stress.

In the present study, tyrosine supplementation partially mitigated the enhanced anger behavior of the volunteers. Tyrosine group showed reduced anger compared to the placebo post stress exposure. Increased scores of tension, confusion, and mood disturbance during cold air exposure had been reported[35]. Participants exposed to a stressor consisting of 90 dB noise showed an improvement in cognitive task performances one hour after tyrosine administration[8]. The level of serotonin (5-HT) which influences anxiety, depression[36] and irritability[37] was found to be significantly higher in the tyrosine group compared to placebo group in this study. The level of 5-HT precursor, tryptophan was also found to be marginally higher in the tyrosine supplemented group. Low levels of 5-HT or its precursor tryptophan have been attributed to impulsive aggressive behavior and anger[38].

The positive effects of tyrosine supplementation on cognitive performance shown here are in agreement with the theory that excessive stress induces catecholaminergic neurons

to fire faster. This accelerated firing activates the enzyme tyrosine-hydroxylase, making it dependent on the availability of tyrosine. Hence, the enzyme becomes activated by increased intra-neural tyrosine, available through ingestion or injection of tyrosine[39]. Tyrosine supplementation before stress increases the synthesis of catecholamines required for the optimisation of cognitive functions. Studies show that exposure to a range of stresses depletes brain CAs, particularly NE and DA, in specific areas of the brain, and that this depletion is linked to a decline in cognitive ability.

5. CONCLUSION

It is concluded that pre-treatment with aromatic amino acid tyrosine has a potential beneficial effect in the amelioration of heat-induced decrements in attention and can serve as an effective neutraceutical countermeasure to optimise cognitive function in a hot environment.

6. ACKNOWLEDGMENTS

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