SUMMARY AND INTEGRATED DISCUSSION
Nutrients obtained from ingested food provide the building blocks for the athletes' growth, development and maturation, plus the fuel elements, for routine energy expenditure and for initiation and maintenance of high level performance. The contracting muscle requires a continuing supply and replenishment of the substrates of fuels used to support contraction. It has been said that an athlete is no better than the adequacy of his nutrition. Neither can a balanced diet alone compensate for poor skill development and training. Diet, conditioning and training should be regarded as mutually complementary. Manipulating the diet and taking extra quantities of various vitamins and minerals seem to be a relatively harmless method to make the body work at its best. Vitamins are essential for normal body function.

There is a great deal of interest among sports physiologists, coaches and sportsmen about whether or not supplementation of additional vitamins, especially of B complex (B₁, B₂ and B₆), enhances athletic performance. It is an established fact that the vitamin needs increase a great deal in active athletes. However, few controlled studies have been conducted to assess the role of B vitamins supplementation in athletes, and fewer studies still on girl athletes at the nutritional level under Indian conditions.

Muscular work and exercise being basically a matter of transforming bound energy into mechanical energy, the specific roles of B vitamins as micronutrients pertain in facilitating this energy transfer. The roles of the B vitamins in exercise performance are thus related to the specific metabolic roles of these vitamins.
Girl athletes of West Bengal, eastern India, volunteered to participate in this study. From a screening of their background those were selected to be the subjects who were born and brought up under more or less similar socio-economic and environmental conditions. Nearly all had some acquaintance with cycling. They were motivated strongly to put in their maximal efforts, as can be judged by their maximal heart rates, the mean value of which varied from 184 to 191 beats per minute.

A total of sixty girl swimmers from a number of swimming clubs in and around Calcutta, West Bengal, constituted the subjects in this investigation for instantaneous and prolonged effects of supplementation of three B vitamins - thiamine, riboflavin and pyridoxine - on physical performance in terms of parameters dealing with the respiratory and cardiovascular systems and changes in the metabolic processes. Over the period of study the mean age of these subjects ranged from 14.20 (±0.33) to 17.40 (±1.16) years, the height from 150.20 (±5.38) to 153.80 (±2.07) cm, and the body weight from 42.85 (±2.87) to 46.50 (±2.66) kg.

A survey of literature was undertaken in the first place to review the findings of different investigators on the relationship between thiamine, riboflavin and pyridoxine, separately or in combination, and the physical performance of men and women. An experimental design was prepared and a number of parameters dealing with the respiratory and cardiovascular systems was selected in the following design:
Experimental Design

Before supplementation of vitamin (control) and placebo

Instantaneous Supplementation
Effects of vitamin B complex or placebo investigated an hour after supplementation of vitamins (B₁, B₂ and B₆)

Prolonged Supplementation
Effects of vitamin B complex or placebo investigated after continuous daily supplementation of vitamins (B₁, B₂ and B₆) for 15 days

The subjects were divided into 3 vitamin groups (thiamine, riboflavin and pyridoxine) and 3 corresponding placebo groups, each group comprising 10 subjects. The study proforma had 3 parts - the first included, besides the physical characteristics of age, height, weight and body surface area, haemoglobin concentration and Physical Fitness Index; the second included measurement of maximal oxygen uptake, maximal pulmonary ventilation and O₂ pulse; the third included measurement of endurance time, blood lactic acid and blood pyruvic acid concentrations.

In selecting doses of the vitamin supplements (B₁, B₂ and B₆) the host of factors which influence the human needs of these vitamins, the recommendations by different investigators and the imperative need to keep an adequate margin (where ingestion in quantities far above the daily recommended allowances does not cause any toxic effect) were taken into account. Thiamine requirement of
athletes is known to be enhanced owing to their increased energy metabolism, the relatively high carbohydrate content of their daily food, the demand of their strenuous physical exercise, the losses through substantial sweating and the ambient heat of the tropical countries as in the present case. Considering these factors a dose of 50 mg per day of thiamine was administered orally to the subjects (daily for a period of 15 days in the case of prolonged supplementation). Riboflavin requirement is also known to increase with physical exercise, although estimates vary considerably. In line with other workers, the present investigator administered an oral dose of 10 mg per day of riboflavin. Pyridoxine requirement is difficult to determine, but it is known that physiological stresses increase the requirement manifold. A dose of 20 mg per day of the vitamin, the same as applied by many other workers, was administered to the subjects of the present study.

The procedure adopted in this investigation consisted in the following main steps:

1. The collection of athletes was made taking into consideration their similar athletic activity and range of physical characteristics. They were normal healthy athletes with no history of cardiopulmonary disorder or liver and kidney diseases.

2. The subjects were acclimatized in the laboratory conditions and the selected doses of the three vitamins and the corresponding placebos were administered to the respective groups of swimmers in a double blind protocol.

3. Administration of the respective vitamins and placebos was made 1 hour before the testing procedure to study any instantaneous effects and also daily
for a continuous period of 15 days to study any possible prolonged effects.

4. The pre- and post-supplementation data for each vitamin and placebo group were analyzed using the standard statistical procedure.

The Physical Fitness Index (PFI) was measured by the Harvard Step Test as modified by Sloan (1959) for women. The blood haemoglobin concentration was measured by the cyanomethamoglobin method (Harold et al., 1980). The maximal oxygen uptake was determined by the bicycle ergometer method, the expired gas having been collected in a 150 L Douglas bag. Similarly, for measurement of the endurance time and blood lactic acid and blood pyruvic acid concentrations, the subjects exercised on a magnetic brake bicycle ergometer at a fixed workload of 1200 kg·m min⁻¹ till exhaustion. Blood samples were collected from anticubital veins before exercise, at 3rd min of recovery and then at 20th min of recovery, and blood lactic acid was determined by the Barker Summerson method (1941) modified by Strom (1949) and blood pyruvic acid was determined by 2,4 dinitrophenylhydrazine method (Friedmann and Haugen, 1943).

All the various aspects of the investigation have been discussed in this dissertation in its five chapters as follows:

Chapter I includes brief histories of the vitamins, their constitution and physiological properties, the concept of physical exercise and the relationship between exercise and thiamine, riboflavin and pyridoxine.

Chapter II is a survey of literature on the effects of these vitamins on physical fitness and other parameters dealing with the respiratory and cardiovascular systems.
Chapter III presents the findings of the investigation relating to the effects of these vitamins on the Physical Fitness Index and blood haemoglobin concentration.

Chapter IV gives the results of the studies relating to maximal oxygen consumption, pulmonary ventilation and related cardiopulmonary parameters.

Chapter V deals with the findings on endurance capacity and blood lactic acid and blood pyruvic acid concentrations.

In general, exposure of the girl swimmers to the B vitamins - B₁, B₂ and B₆ - have produced in them effects of varying measure. Among the parameters of study the significant (P/0.01) decrease of the mean pre-exercise heart rate (by 2.1 beats min⁻¹) following daily supplementation of 50 mg of thiamine for a period of 15 days can possibly be explained by increased activity of acetylcholine at the nerve endings due to thiamine supplementation. Similar results from pyridoxine exposure, significant (P/0.05) decrease by 1.7 beats min⁻¹, may be due to the influence of metabolism of the pacemaker cells of the heart, and also certain hormone releasing factors which may in turn be related to the decrease of the pre-exercise heart rates. Riboflavin exposure has caused only slight and non-significant decrease of the pre-exercise heart rate.

Riboflavin and pyridoxine supplements, on the other hand, have caused significant (P/0.05) increase of the haemoglobin concentrations of blood (5.78% and 7.77% respectively). No significant change has, however, been effected by thiamine exposure in this regard. Riboflavin may be related to amino acid metabolism and, therefore, possibly to formation of blood protein.
(Spector et al, 1943) to produce the observed result. The increase due to pyridoxine may be ascribed to the fact that this vitamin (B6) directly helps in the biosynthesis of haemoglobin. Increased haemoglobin concentration in men and women fencers under influence of pyridoxine supplementation has been recorded by Van Dam (1978) also. Since the haemoglobin content of blood is related to the oxygen transport to the tissues (Åstrand and Rodahl, 1986), supplementation of riboflavin and pyridoxine may, therefore, have been helpful in the present case for enhancement of the aerobic capacity of the girl swimmers by increasing their haemoglobin concentration.

The higher PFI scores of the subjects following both instantaneous (P < 0.01) and prolonged (P < 0.02 and P < 0.05) supplementation of all the three vitamins (9.34% and 5.18% for thiamine, 9.75% and 2.33% for riboflavin, 10.80% and 3.35% for pyridoxine) may be due to faster recovery of the heart rates consequent upon vitamin exposure. It may have been caused also by the decline of the pre-exercise heart rates following application of the vitamins in the human organisms and the special conditions under which endurance athletes have to perform high turnover rates of the energy metabolism, an increase in body core temperature and sweat loss (Van Dam, 1978). The findings of the present investigation are in agreement with the findings of Gounell (1940), Van Dam (1978) and Vander Beek et al (1988). So it may be stated that supplementation of B vitamins (B1, B2 and B6) may be beneficial for improving the physical fitness capacity of athletes.

The significant increase of the maximal oxygen uptake (\( \dot{V}O_{2\ max} \)) as effect of both instantaneous (3.27%, \( P < 0.01 \)) and prolonged (9.01%, \( P < 0.001 \)) exposure to thiamine in the present study may be related to the increase of the pulmonary
ventilation and of the functional capacity of the circulation. The reason for similar increase (2.27% and 6.49%; \( P < 0.05 \) and \( P < 0.01 \)) due to pyridoxine exposure (both instantaneous and prolonged) is not clear, but it is possible that the increase of the pulmonary ventilation as also the improvement of the circulatory efficiency have influenced this effect. Increased haemoglobin concentrations may have some role in this regard and may have augmented the \( O_2 \) transport to the tissues, the oxygen uptake by tissues having increased consequently. Riboflavin exposure has caused only slight and non-significant increase.

The maximal pulmonary ventilation of the subjects has also increased (9.56% and 8.95%) significantly (\( P < 0.05 \) and \( P < 0.01 \)) following instantaneous and prolonged thiamine supplementation in the present study. Thiamine, in the form of TPP, possibly facilitates the aerobic metabolism by oxidizing the pyruvate via the TCA cycle and this leads to production of \( CO_2 \). An increased \( pCO_2 \) stimulates the pulmonary ventilation directly and also indirectly through its effect on \( H^+ \) concentration. Additionally, this influence may be mediated through stimulation of the peripheral chemoreceptor (Åstrand and Rodahl, 1986). Similar increase (5.94% and 9.04%; \( P < 0.02 \) and \( P < 0.01 \)) following instantaneous and prolonged pyridoxine exposure may be due to the fact that pyridoxal phosphate catalyzes the decarboxylation reaction of different amino acids which in turn may have a role in elevating the \( pCO_2 \) level in blood and this may stimulate the pulmonary ventilation. Riboflavin supplementation has produced only slight and non-significant increase.

The significant decrease of the pre-exercise and maximal heart rates (3.38% and 2.75%; \( P < 0.05 \) and \( P < 0.01 \)) as a result of both instantaneous and
prolonged administration of thiamine to the subjects is an effect which is possibly mediated through the action of thiamine on vagal discharge to the heart. Gautier (1950) observed that thiamine was formed in the heart muscle upon stimulating the vagus. Thus thiamine acts directly on the heart muscle and lowers the heart rate by modulating the neuronal discharge. In the case of pyridoxine also the pre-exercise heart rate has decreased significantly (2.64% and 1.76%; \( P < 0.05 \) in either case), so also the maximal heart rate (1.91% and 2.86%; \( P < 0.05 \) in either case) as a result of instantaneous and prolonged supplementation. This vitamin may reduce the heart’s rhythmicity by influencing the stroke volume and thus changing the pre-exercise and maximal heart rates as observed in the present study.

The finding that in the present case both thiamine and pyridoxine supplements (instantaneous and also prolonged) have increased significantly the mean values of \( O_2 \) pulse (7.28% and 12.48%; \( P < 0.01 \) and \( P < 0.001 \) for thiamine; 4.41% and 9.96%, \( P < 0.01 \) in either case for pyridoxine) over the control values leads to the conclusion that both these vitamins help increase the cardiovascular efficiency by modifying the \( O_2 \) pulse. The increase in \( O_2 \) pulse is indicative of increased stroke volume. This is corroborated by the fact that there has been decrease of the pre-exercise and the maximal heart rates owing to administration of these vitamins.

In brief, the present study indicates that all the girl athletes showed some significant improvement of their aerobic capacity after supplementation of thiamine and pyridoxine, and this reveals the beneficial effects of these B vitamins on the maximal aerobic capacity. In view of the very little information available in India on women’s physiological response to exercise,
this valuable finding of the present study is likely to be helpful to enriching the idea of exercise physiologists and others.

The significantly increased endurance times of the thiamine treated subjects (6.02% and 8.47%; $P < 0.05$ and $P < 0.01$ respectively for instantaneous and prolonged effects) and the strong correlation of these values before and after both instantaneous and prolonged supplementation may be caused by increase in local blood flow in the muscles. Another cause may be the increase of $O_2$ uptake by the muscles. It is also possible that delay in muscular fatigue increases the endurance time. Thus thiamine plays a significant role in enhancing the endurance capacity. A higher "fatigue threshold" may also be involved in increasing the muscular endurance (Åstrand and Rodahl, 1986).

The pre-exercise blood lactic acid concentration has decreased significantly (13.19%, $P < 0.01$) compared to the control values after thiamine supplementation. The concentration increases during and after exercise and the maximal value is usually obtained in the early period of recovery. The values in the 3rd minute of recovery are higher than those of late recovery, both in the control and in the vitamin treated groups. But in the case of prolonged exposure the post-exercise (in the 3rd min and 20th min of recovery) lactic acid concentrations have decreased (19.83% and 13.9%; $P < 0.001$ and $P < 0.02$) compared to the control values. This decrease may be due to removal of the lactic acid from the blood. The possible role of thiamine in this regard may be to prevent the conversion of pyruvic acid to lactic acid, which means that pyruvic acid, with the help of thiamine, is routed to the aerobic process.

Prolonged consumption of thiamine has caused decline of the pre-exercise as also post-exercise (28.57%, $P < 0.02$ and 40.38%, $P < 0.05$ for the 3rd min and
20th min of recovery period) blood pyruvic acid levels, a fact corroborated by the findings of some other investigators, including Vitchikova (1958). Instantaneous supplementation of thiamine does not produce any significant changes. In the case of riboflavin exposure the pre-exercise and post-exercise blood lactic acid as well as blood pyruvic acid concentrations do not show any significant changes compared to the mean values of their control groups. Similar is the case with the pyridoxine exposure. There is a positive significant correlation between lactic acid concentrations and pyruvic acid concentrations in both the pre-exercise \((r = 0.74)\) and post-exercise blood samples \((r = 0.72)\) after prolonged supplementation of thiamine, which fact indicates that the thiamine exposure helps reduce lactic acid and pyruvic acid at the same time. Riboflavin has no direct role in influencing the enzyme system for metabolism of pyruvic acid. For this reason, perhaps, excess doses of riboflavin supplementation do not reduce the concentration of blood pyruvic acid in rest and in exercise conditions.

In general, B vitamins are essential in metabolism of carbohydrate and amino acids, the formation of nucleic acids for RNA and DNA. Thiamine is, in its physiologically active form, the co-carboxylase, which is essential for the breakdown of dextrose and is thus of great significance for any endurance performance with caloric demands. Water soluble vitamins cannot cause any harm. Fat soluble vitamins can be stored in the body, but excessive dosage has been found to be toxic. But it is true that B vitamins play an important role in many of the reactions that make energy available for muscular work. Excess amounts of these vitamins cannot be stored in the body and are excreted in the urine.
Therefore, it has been observed in the present study that all the girl athletes showed significant superiority in physical performance after supplementation of B vitamins during investigation with the bicycle ergometer in our laboratory, which indicates the beneficial effects of B vitamins on their athletic performance.

CONCLUSION

In India information on girls' physiological responses to exercise is rather scarce. In fact, little information is available till date on the performance capacity of girl athletes following supplementation of B vitamins. It has been known that most water soluble vitamins are involved in mitochondrial energy metabolism. However, the influence of vitamin supplementation over mitochondrial metabolism is largely unknown. In this study, the principal argument for B vitamins supplementation is the increased B vitamin requirement of athletes. Theoretically, an increased requirement can be caused by decreased absorption by the gastro-intestinal tract, increased excretion in the sweat, urine and faeces, increased turnover as well as biochemical adaptation to training.

In summary, it may be stated that possible beneficial effects of supplementation of B vitamins have been studied in female athletes after exercise and the supplementation has been found to improve the physiological performance as revealed by:

1. Increase of the Physical Fitness Index, endurance capacity and maximal aerobic capacity.
2. Decrease in post-exercise heart rates.

3. Decrease in blood lactic acid and blood pyruvic acid concentrations.

So, if there is no evidence of illness or deficiency in any specific vitamins, a well balanced diet should provide the quantities of B vitamins required for good health and physical performance.

In conclusion, it may be stated, therefore, that intake of B vitamins, especially thiamine (Vitamin B₁), before starting an exercise, game or athletic contest would be helpful for greater physical endurance for longer periods of time and for better physical performance of the athletes.

So, it is expected that the results of this study would furnish information which may be useful in the field of exercise physiology and in achieving better physical performance after training in the athletic institutes of our country.
REFERENCES


