NUTRITION AND PHYSICAL PERFORMANCE IN SCHOOL AGE CHILDREN

NUTRITION FOUNDATION OF INDIA, NEW DELHI
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**WRONG HABITS**
- Eat a lot of these regularly
- Consume very little fish, meat or milk
- Low pulse consumption
- Eat lots of refined cereals and flours
- Eat very little fruits and vegetables

**RIGHT HABITS**
- Eat these once in a month/once in a fortnight
- Take one or more of these items everyday
- Pulse should be consumed daily
- Eat in moderation. Consume more coarse grains and less refined flour
- Eat as many fruits and vegetables as possible

Eat as many fruits and vegetables as possible
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INTRODUCTION

Nutritional status during school age is a major determinant of nutritional and health status in adult life. Globally, including in India, health hazards associated with undernutrition and micronutrient deficiencies remain major public health problems. In the second half of the previous century, the adverse effects of undernutrition and anaemia on physical performance were extensively investigated in adults. Many studies showed that undernutrition and anaemia had an adverse impact on performance and consequently led to reduction in wages for persons employed in manual labour. Lower wages led to lower purchasing power, food insecurity, lower food intake and undernutrition, thereby setting up a vicious cycle. In an attempt to improve productivity employers provided workers food in the workplace; such interventions resulted in improvement in work output only in those who were initially undernourished and who showed an improvement in their nutritional status with food supplementation. Other studies showed that iron supplementation had a beneficial impact on work capacity, especially in anaemic persons whose Hb levels improved with iron supplementation. There is very little data on the impact of undernutrition and anaemia on work output as such in children; however numerous studies have demonstrated the adverse impact of anaemia on cognitive functions, attention span and concentration. The data indicate clearly, therefore, that undernutrition and anaemia have an adverse impact on physical activity levels in children.

The past three decades have witnessed the emergence of overnutrition as a problem in school-age children in developed countries and in affluent urban segments in developing countries. In developed countries, the consumption of high-calorie food and the increasingly sedentary lifestyle have been implicated as the major factors responsible for the rising obesity rates. In India there has not been a substantial increase in energy intake among children except those in urban affluent families. The increasing obesity rates in children are attributable mainly to the substantial reduction in physical activity in the form of household chores, methods of commuting (the use of mortised conveyances instead of walking or cycling) and methods of recreation (with computer games and TV watching having replaced physical play) over the past two decades. Overweight children are at higher risk of becoming overnourished adults and thereby incurring a higher risk of developing non-communicable diseases. Anaemia and micronutrient deficiencies are widespread among both undernourished and overnourished persons. Where under- or overnutrition occurs in combination with anaemia, the adverse effects on physical performance are even greater. Overnourished anaemic children tend to curtail physical activity because they get fatigued; reduced physical activity further aggravates overweight. The Indian school system has not yet introduced a system of anthropometric assessment of nutritional status (including body fat measurement) and physical fitness tests to identify the school-age children who require interventions for improving their physical activity. There is an urgent need for initiating such programmes, with the
short-term goal of improving physical fitness and the long term-goal of reducing cardiovascular disease risk in adult life.

India is currently in the midst of a nutrition transition. There is a growing recognition that undernutrition in childhood may also increase the risk of overnutrition in adult life. A longitudinal study carried out in a Delhi cohort from birth to thirty-two years demonstrated the disadvantages of being small for age in early life and becoming obese as adults. This study measured infants at birth and at intervals of 6 months throughout childhood. The mean birth weight of this cohort was 2.9 kg, and approximately 33% of them were of low birth weight. At two years of age, 53% were underweight for age. When this same cohort was re-traced at the ages of 26-32 years, 40% were overweight (BMI >25kg/m²) and 10% were obese (BMI >30kg/m²). Approximately 16% had hypertension, 4% had type 2 diabetes and 15% had impaired glucose tolerance (IGT). After adjusting for adult BMI, plasma glucose concentrations and insulin resistance were found to be inversely related to birth weight; the incidence of IGT and diabetes in adulthood was associated with lower weight and BMI at the age of 1 year, and also with accelerated BMI gain during childhood relative to the rest of the cohort. From being below the cohort mean for BMI at 2 years of age, they were well above the mean at 30 years. The highest prevalence of IGT and diabetes was in adults who had low BMI SD scores in infancy and high SD scores at 12 years of age or later.

A longitudinal study in Delhi from birth to thirty-two years demonstrated the disadvantages being small in early life and becoming obese as adults. This study was carried out in young adults living in New Delhi, who had been measured at birth and every 6 months through childhood. Mean birth weight of this cohort was 2.9 kg and about a third were low birth weight. At two years of age 53% were underweight for age. When they were traced at the age of 26-32 years, 40% were overweight (BMI >25kg/m²) and 10% were obese (BMI >30kg/m²). About one sixth had hypertension; 4% had type 2 diabetes and 15% had impaired glucose tolerance (IGT). After adjusting for adult BMI, plasma glucose concentration and insulin resistance were inversely related to birth weight; IGT and diabetes were associated with lower weight and BMI at the age of 1 year. Childhood growth of those who developed IGT or diabetes was characterised by accelerated BMI gain relative to the rest of the cohort. From being below the cohort mean for BMI at 2 years they were well above the mean at 30 years. The highest prevalence of IGT and diabetes was in men and women who had low BMI SD scores in infancy but high SD scores at 12 years or later. These data suggest that during nutrition transition, undernutrition in childhood may increase the risk of overnutrition, diabetes and hypertension in adult life, thereby giving a new personalized meaning to the phrase 'dual nutrition burden'. The fact that, at thirty years of age half of these erstwhile undernourished children were overweight and one-sixth had hypertension, diabetes, or impaired glucose tolerance emphasizes the urgent need for identifying children who are
crossing the BMI centiles in school age and initiating interventions to increase their physical activity and make their life styles healthier.

Micronutrient deficiencies can be seen not only in undernourished children but also among overnourished children because consumption of vegetables and micronutrient-rich food stuffs are quite low in children. Obesity as well as anaemia / other micronutrient deficiencies have adverse effects on physical performance; the combination of these may have an even more adverse impact on physical performance than either of them alone.

Physical performance is defined as the ability to perform a physical task or sport at a desired level. The main determinants of performance are physical fitness and skill. Longitudinal studies have shown that the lifestyle and physical fitness during childhood and adolescence were major determinants of lifestyle, physical fitness and freedom from non-communicable diseases in adult life. Recent studies have demonstrated that maintaining physical fitness (especially cardio-respiratory fitness) and physical activity have a favourable impact on overall health. With increasing longevity and growing concern about diabetes and cardiovascular diseases affecting Indians a decade earlier than their developed-country counterparts, it is imperative that healthy lifestyles are promoted in school-age children. The focus therefore should be on increasing the use of fitness tests with a focus on cardio-respiratory function and endurance in children, and initiating appropriate intervention in those who perform poorly in these tests.

This paper presents a review of the nutritional status of Indian school-age children, the effect of nutritional status on physical performance, the impact of undernutrition and micronutrient deficiencies on physical performance, the currently used physical fitness tests, and the available limited data on physical fitness status of Asian and Indian children. It is hoped that universal access to fitness testing programmes and interventions to improve fitness in those who are identified as having sub-optimal fitness will be made available and accessible for school-age children in India; if this were done, it might be possible for the country to achieve the nutrition and health goals set in the National Health Policy, and to belie the dire projections that India will rank as the country with highest numbers of diabetics and hypertensive persons in the world.
NUTRITION TRANSITION IN SCHOOL-AGE CHILDREN

The school age group (5-18 yrs) spans the period between preschool years and adult life. Census 2001 (Figure 1) has shown that this age group forms a very large proportion of the population. Population projections (Figures 2, 3) indicate that over the next decade this age group will show by far the largest increase in numbers. It is therefore essential that over the next decade efforts should be focused on improving the health and nutritional status of school-age children, (irrespective of whether they are studying in school or are school dropouts) so that they reach adult life with optimal nutrition and health status.

Nutritional status of school age children

School age is a period of rapid growth with a growth spurt in the peri-pubertal years; on an average, ~ 80% of adolescent growth is completed in early adolescence (10-15 years). The adolescent growth spurt in girls begins at ~10 years and the peak growth velocity is at ~12 years. The adolescent growth spurt in boys begins 2-3 years later than in girls and peaks by 16-17 years. While nutritional status during infancy and childhood are major determinants of nutritional status during adolescence and adult life, adequate dietary and nutrient intake coupled with appropriate levels of physical activity can ensure optimal adolescent growth spurt; this, in turn, could
perhaps mitigate some of the adverse consequences of poor dietary intake on nutritional status during childhood.

Dietary intake

Data from NNMB\textsuperscript{2} and INP\textsuperscript{3} surveys show that over the past decade there has been some decline in cereal intake, in both urban and rural areas. Over this period there has been a substantial decline in the cost of cereals and improvement in availability of and access to cereals. The reduction in cereal intake is, therefore, not due to financial constraints. Over the same period, there has been a decline in the intake of pulses, which are a major source of protein in Indian diets. This is partly attributable to the soaring cost of pulses and the inability of the poor to purchase adequate quantities of pulses despite spending more. In spite of the impressive increase in milk output in the country, improvement in per capita intake of milk over the years has been small. The intake of vegetables and fruits also continues to be very low. Data from NNMB rural surveys suggest that dietary intake among rural populations has not undergone any major shift towards increase in intake of fat/oils, sugar and processed food. However, among urban slum dwellers there has been an increase in oil intake and some increase in sugar intake. Consumption of cereals and leafy vegetables is low in both urban and rural areas, and this contributes to the high prevalence of micronutrient deficiencies. Data from NNMB and INP surveys (using 24-hour dietary recall method) show that, in the mid-1990s, the average intake of cereals was close to the Recommended Daily Allowance (RDA) levels; the intake of pulses, vegetables and fruits was low.

NNMB surveys show that a majority of Indian children subsist on a monotonous diet consisting mainly of cereals with some small amounts of pulses and vegetables. The intake of the entire range of macro and micronutrients is lower than RDA. NNMB data have also shown that energy intake in all age groups, including in children and adolescents, improved till the 1990s and then showed a decline (Table 1). The energy gap in school-age children is lower than that in preschool children, but larger than that in adults from the same households. There are large inter-state variations in energy intake in both boys

<table>
<thead>
<tr>
<th>Ages</th>
<th>Total Dietary Energy Intake (Kcals)</th>
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<tr>
<td></td>
<td>NNMB '79 '96 '01 '05 '96</td>
</tr>
<tr>
<td>Males</td>
<td></td>
</tr>
<tr>
<td>4-6</td>
<td>1015 1154 1066 1020 1300</td>
</tr>
<tr>
<td>7-9</td>
<td>1240 1417 1294 1230 1550</td>
</tr>
<tr>
<td>10-12</td>
<td>1439 1738 1524 1423 1847</td>
</tr>
<tr>
<td>13-15</td>
<td>1618 2004 1856 1645 2185</td>
</tr>
<tr>
<td>16-17</td>
<td>1926 2369 2114 1913 2514</td>
</tr>
<tr>
<td>&lt;18\textsuperscript{a}</td>
<td>2065 2488 2225 2000 2592</td>
</tr>
<tr>
<td>Females</td>
<td></td>
</tr>
<tr>
<td>10-12</td>
<td>1394 1635 1500 1389 1482</td>
</tr>
<tr>
<td>13-15</td>
<td>1566 1848 1689 1566 2097</td>
</tr>
<tr>
<td>16-17</td>
<td>1704 2030 1856 1630 2327</td>
</tr>
<tr>
<td>&lt;18\textsuperscript{a}</td>
<td>1698 2106 1878 1738 2293</td>
</tr>
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Table 1: Time trends in energy intake of early school children and adolescents

NFI July 2009
and girls (Figure 4 and 5). Energy intake was lowest in Gujarat and highest in Andhra and West Bengal.

Nutritional Status

Data from the NNMB surveys showed that, though there has not been any substantial increase in the dietary intakes of children and adolescents, there has been some improvement in height (2.5-6 cms), weight (2-6 kg) and BMI between 1975-79 and 2005-06 (Figures 6-9). Though there has been improvement in the height and weight over the past 25 yrs, stunting and underweight are still common in rural areas. NNMB data also showed that, over this period there has been some increase in overnutrition among children and adolescents.
**Interstate differences**

Further, the data from NNMB\(^2\) showed that there are persistent (1975-2004) inter-state differences in underweight and stunting among rural children, both girls and boys. In 1989 NFI\(^4\) carried out a study to assess growth patterns of girls in affluent families in the urban areas of Delhi, Bombay, Calcutta, and Coimbatore. The mean weight and height of these girls from affluent families were lower than the mean weight and height of the NCHS standards (Figure 11,12). Delhi girls were taller and heavier than girls from Coimbatore and Calcutta.
During the past decade, there have been numerous reports about the emerging problem of overnutrition among affluent urban children and adolescents. During the past four years NFI has carried out a cross-sectional study in Delhi school children studying in government schools (predominantly from the low-income group (LIG)) and private schools (predominantly from the high-income group (HIG)) to assess the prevalence of undernutrition and overnutrition. Children from LIG were shorter and weighed less as compared to children from HIG and also as compared to CDC standards (Figures 13-16).

The prevalence of under-nutrition (< mean-2SD of weight, height and BMI CDC standards) was higher in LIG children as compared to HIG children. The prevalence of over-nutrition (> mean+2 SD of weight and BMI CDC standards) was higher in HIG children (Figure 17-22).
Data from the study also showed that children from HIG had higher body fat as compared to the US standards (Figures 23-26) (unpublished data from NFI). Numerous studies across the country have shown that the emerging problems of overnutrition among children are mainly due to changing lifestyles and substantial reduction in physical activity.
Problems faced by adolescents

Table 2: Adolescent population (%) in South-East Asia Region

<table>
<thead>
<tr>
<th>SEAR</th>
<th>10-14 yrs</th>
<th>15-19 yrs</th>
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<tbody>
<tr>
<td>Bangladesh</td>
<td>6.0</td>
<td>5.8</td>
</tr>
<tr>
<td>Bhutan</td>
<td>6.2</td>
<td>6.0</td>
</tr>
<tr>
<td>India</td>
<td>5.4</td>
<td>5.1</td>
</tr>
<tr>
<td>Indonesia</td>
<td>4.9</td>
<td>4.7</td>
</tr>
<tr>
<td>Myanmar</td>
<td>5.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Nepal</td>
<td>6.2</td>
<td>5.8</td>
</tr>
<tr>
<td>Srilanka</td>
<td>4.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Thailand</td>
<td>4.2</td>
<td>4.1</td>
</tr>
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</table>

In the current phase of demographic transition in SE Asia, adolescents constitute ~18-25% of the total population. In all the countries boys outnumber girls, though the magnitude of difference is low in Myanmar, Thailand and Sri Lanka (Table 2). The prevalence of under-nutrition and anaemia in adolescents, especially girls, continues to be high, thereby impairing their physical performance. Pregnancy in anaemic undernourished adolescent girls is associated with poor maternal and foetal outcomes. It is imperative to improve the health and nutritional status of adolescents, especially girls.

At the other end of the spectrum are the urban affluent adolescents among whom overnutrition has steeply increased because of sedentary lifestyles and intake of energy-dense junk foods. In view of the fact that overnutrition in childhood and adolescence is associated with an increased risk of developing CVD in adult life, it is essential to improve physical activity and promote balanced food intake in school children.

References

1. Registrar General of India : Population Projections http://www.censusindia.net/Projection_Report.pdf; last accessed on 20/06/09


5. Nutrition for health and development: possible action at country level
   http://searo.who.int/LinkFiles/Nutrition_for_Health_and_Development_Possible_Actions_at_the_Country_Level.pdf, last accessed on 20/06/09.
NUTRITION AND PHYSICAL PERFORMANCE

Physical performance is defined as the ability to perform a physical task at a desired level. Physical performance is determined both by non-modifiable factors such as genetics and modifiable factors such as physical activity and nutrition. Genetic inheritance has been estimated to contribute 30-50% of variation in physical fitness and performance. Heredity determines body fat and muscle content, fat distribution, and tendency to gain or lose fat or muscle\textsuperscript{1}. Muscle strength and endurance is genetically endowed to the extent of up to 65\%. Inherited variations in cardiac, vascular and respiratory systems influence sub-maximal exercise capacity and maximal performance up to 10 and 25\%, respectively\textsuperscript{3}. Substrate metabolism and hormonal actions regulating the utilization of carbohydrates or lipids during physical activity are also inborn\textsuperscript{1}.

Regular exercise and participation in sports are known to improve fitness and physical performance. The intensity, duration and frequency of physical activity-determine body weight and composition. As compared to their normal counterparts, overweight and obese children perform poorly in physical fitness tests that require propulsion or lifting of body mass, as in standing broad jumps, and also in endurance shuttle runs\textsuperscript{4}. Resistance exercise and weight training enhances muscle strength and endurance by 25 to 100\%. Good body composition – low percentage of fat and high lean mass and consistent physical activity from childhood are associated with cardiovascular fitness\textsuperscript{6}.

Nutritional status determines body composition starting as early as the intrauterine period. Barker\textsuperscript{7} and coworkers have shown that adult diseases may have their origin in the intrauterine period. Over- or under-nutrition may alter gene expressions in the fetus, resulting in developmental adaptations that may lead to permanent changes in physiology and metabolism; these changes may persist throughout life and may render the person susceptible to non-communicable diseases in adult life\textsuperscript{8}.

Adequate nutrition and exercise are essential for health, fitness and optimal physical performance. The composition and quantity of food consumed can affect body weight, physical performance, and recovery from exercise. Hence, optimal dietary intake is considered to be one of the critical determinants of physical performance\textsuperscript{5}.

Physical activity or exercise requires an adequate supply of energy to fuel exercise, repair muscles, and maintain body weight and composition. When energy intake is limited, body fat and muscle mass are utilized as fuel; reduction in muscle mass results in loss of strength and endurance. Chronic energy deficiency due to low food intake can lead to lack of adequate carbohydrates, protein, vitamins and minerals needed for physical activity. Energy excess also has a detrimental effect on performance because of increase in body weight and percentage of body fat\textsuperscript{10,11}. 

10 11
Macronutrients and physical performance

The importance of macronutrients in relation to work capacity and performance is well documented. Individuals who seek to improve their physical performance, especially athletes, may need additional intake of macronutrients — carbohydrates, lipids and fats — to provide energy required for activity and maintain structural and functional integrity. The use of macronutrients — carbohydrates, proteins and fats — as energy substrate depends on the type, intensity and duration of activity. Carbohydrate is the main energy substrate in long-duration intense activity. Maintenance of blood glucose is essential to sustain endurance. The contribution of fat as a substrate is reduced with increase in exercise intensity. Protein, an auxiliary source of fuel, contributes less than 5% of the energy needs. It is utilized to maintain blood glucose in intense and long-duration activities. The primary role of protein is to repair the damage to muscle fibres and increase muscle mass. Increase in muscle mass is associated with improved strength and resistance.

Micronutrients and physical performance

Micronutrients play an important role in energy production, haemoglobin synthesis, maintenance of bone health and immunity, building and repair of tissues, and protection of body tissues from oxidative damage. Their role in physical performance is increasingly being recognized and investigated.

Energy production

Meeting the energy needs is the first nutritional priority for optimal physical performance. B-complex vitamins - thiamine, riboflavin, niacin and pyridoxine play an important role in energy metabolism. Coenzyme thiamin pyrophosphate helps in the conversion of pyruvate to acetyl coenzyme A and of α-ketoglutarate to succinyl coenzyme A, and participates in decarboxylation of branched-chain amino acids. Thiamine may, therefore, be a potentially limiting nutrient in physical performance. Thiamine insufficiency can cause accumulation of pyruvate and increase circulating lactate; increase in lactate leads to fatigue and may hamper training and performance.

Riboflavin is needed for the mitochondrial electron transport system; coenzymes flavin mononucleotide (FMN) and flavin adenine dinucleotide (FAD) metabolize glucose, fatty acids and glycerol, and amino acids for energy. Increase in physical activity has an adverse effect on riboflavin status. Endurance training in sedentary women with adequate riboflavin intake was shown to increase glutathione reductase activity and riboflavin excretion. Conversely, marked reduction in riboflavin excretion was evident after an acute bout of treadmill running. Riboflavin also catalyzes the conversion of pyridoxine (vitamin B₆) to...
Its functional coenzyme\textsuperscript{17}. Vitamin B\textsubscript{6} functions as a coenzyme in metabolic pathways involved in substrate utilization in protein metabolism. It promotes conversion of lactic acid to glucose. Sustained aerobic exercises like running or bicycling produce short-term alterations in vitamin B\textsubscript{6} status\textsuperscript{17}.

Nicotinamide, a precursor of nicotinamide adenine dinucleotide (NAD) and NAD phosphate, is required for energy production through glycolysis, tricarboxylic acid cycle, electron transport system and pentose phosphate pathway. These co-enzymes are also involved in β-oxidation of fats and synthesis of proteins\textsuperscript{15, 21}. Niacin supplementation increases the use of carbohydrate as a substrate and reduces the availability of free fatty acids. The reports of their effects on physical performance are inconclusive\textsuperscript{22, 23}.

Since, thiamine, riboflavin, niacin and vitamin B\textsubscript{6} play an important role in energy metabolism, it is assumed that individuals with poor micronutrient status may have a reduced ability for sustained physical performance. The study by van der Beek \textit{et al} \textsuperscript{24} demonstrated the effect of multiple micronutrient deficiencies on physical performance. Twenty-four healthy men were depleted of thiamine, riboflavin, and vitamin B\textsubscript{6} over an 11-week metabolic feeding period. Vitamin depletion significantly decreased maximal work capacity (\(\text{VO}_{2\text{max}}\)) by 12 \%, onset of blood lactate accumulation by 7\%, oxygen consumption at lactate threshold by 12\%, peak power by 9\% and mean power by 7\%. Deficiencies of riboflavin and vitamin B\textsubscript{6} had a negative effect on aerobic capacity in young boys. Correction of deficiencies either through diet or supplementation was beneficial\textsuperscript{17}.

\textbf{Red blood cell formation}

Without adequate supply of oxygen, the metabolic pathways that produce energy cannot sustain energy supply to working muscles. The oxygen-carrying capacity is proportional to the haemoglobin content of blood and myoglobin in muscles. Reduction in haemoglobin is associated with reduced oxygen-carrying capacity and poor physical performance. Micronutrients essential for haemoglobin synthesis in red blood cells are iron, folate and cyanocobalamin (vitamin B\textsubscript{12}). Exercise induces increases in the turnover and metabolism of nutrients, and contributes to their loss in urine, faeces and sweat\textsuperscript{25}.

Iron plays a key role in the formation of two iron-containing proteins — myoglobin and haemoglobin. Myoglobin, a haem protein in skeletal muscle, increases the rate of diffusion of oxygen from blood to the cells. Iron deficiency lowers the amount of myoglobin in muscles, thereby decreasing the diffusion of oxygen from the RBC’s to the mitochondria\textsuperscript{26}. During exercise, there is an increased cellular demand for oxygen. Adequate oxygen transport is critical for delivery of oxygen to the working muscle and, consequently, for aerobic metabolism of energy substrates needed for muscle work\textsuperscript{27}. Iron plays the central role in energy (ATP) generation\textsuperscript{28}. Anaemia due to inadequate iron intake, and/or poor absorption and
utilization, results in reduction in muscular capacity, endurance and physical performance. 

Cynocobalamin (Vitamin B₁₂) and folic acid are essential for haemoglobin synthesis. A deficiency of either or both can lead to anaemia; the association between anaemia and poor physical performance is well documented. Supplementation of iron, vitamin B₁₂ and folic acid to those who are deficient in these micronutrients improves haemoglobin levels and physical performance. There are very few data on the effect of vitamin B₁₂ supplementation on physical performance. The connection between poor folate status and physical performance (other than through haemoglobin status) is still unexplored.

**Antioxidants**

Oxygen consumption is increased during intense exercise; the consequent increase in the generation of free radicals can induce oxidative stress. Antioxidants such as vitamins A, E, and C, and cofactors of antioxidant enzymes selenium, zinc, and chromium are essential to prevent and repair oxidative damage resulting from formation of free radicals. An optimum supply of antioxidants is considered to be essential to sustain physical activity and improve physical performance. Vitamin C plays a crucial role in facilitating the transport and uptake of non-haem iron across the mucosa and in reducing folic acid intermediates and cortisol. Vitamin C also acts as a co-factor in the synthesis of carnitine, which is required for oxidation of long-chain fatty acids, enabling the use of fat as fuel during exercise. Physical performance increases vitamin C requirements. Low intakes have detrimental effects such as fatigue, muscle weakness and increased risk of recurrent injuries to connective tissues, which may adversely affect physical training.

Vitamins A and E are antioxidants that combat free radicals after strenuous exercise. Low Vitamin A levels may increase the risk of musculoskeletal injuries. The primary role of Vitamin E is to protect poly unsaturated fatty acids (PUFA) in biological membranes against oxidative damage and to eliminate oxidative stress generated in muscles. Magnesium is considered as a limiting micronutrient in exercise and physical performance. Intense exercise results in magnesium loss, and therefore exercise increases magnesium requirement. Hypomagnesaemia results in muscle weakness, neuromuscular dysfunction and tetany. Magnesium depletion also increases the oxygen requirement for maintaining ATP production. Physical performance may be compromised in persons with poor magnesium intake and exercise-induced deficiency.

Zinc is a micronutrient with multiple roles in the body. It is a potent antioxidant, is a component of over 300 enzymes, and is involved in macronutrient metabolism, synthesis of proteins and nucleic acids, utilization of glucose, insulin secretion, and immunity. Chromium regulates the metabolism of glucose, lipids and
proteins and initiates the action of insulin at cellular level. Because of the manifold functions of zinc and chromium in the human body, they may have roles in maintaining optimal fitness and physical performance\textsuperscript{15,37}.

Summary

It is obvious that dietary intake and nutritional status are major determinants of physical performance. Strenuous physical activity as in sports training may increase the requirements for both macro- and micronutrients. Micronutrients act as key regulators of metabolism and may have a significant impact on physical performance. Micronutrient requirements may increase due to infections, loss of nutrients, increased turnover, biochemical adaptations associated with intensive physical training, increased concentration of mitochondrial enzymes that require these nutrients as cofactor, and increased need for tissue maintenance and repair. Under these circumstances there may be a need for increased dietary intake of micronutrients.

References


**NUTRITIONAL DEFICIENCIES AND WORK CAPACITY**

**Chronic energy deficiency and work capacity**

In the second half of the last century undernutrition was a major problem, especially, among poorer segments of the population in developing countries like India. Prevalence of undernutrition in childhood and adolescence was > 70%. Undernutrition during childhood and adolescence had adverse effects on the stature of adults; prevalence of undernutrition in adults was 40-60%. One of the functional impairment de-compensations associated with undernutrition is reduction in work capacity.

Five decades ago a majority of individuals from poorer segments of the population in rural and urban areas were manual labourers. They might not have worked at maximal work capacity but they did have to work at sub-maximal levels for relatively long periods of time to earn their living. Poor work capacity in occupations involving manual labour would adversely affect wages. Low wages and consequent low purchasing power, would lead to low dietary intake and undernutrition in all members of the family, thereby setting up a vicious cycle of undernutrition and poor work capacity. Between 1960-1990 several studies were carried out to assess the impact of undernutrition on work output in those occupations for which it is easy to quantitatively measure work output. In the late 1970s heart-rate monitoring was introduced as a method of assessing work capacity, and this technology widened the conditions under which impact of undernutrition on work performance could be measured.

FAO compiled, reviewed and published the available global data on dietary intake, nutritional status and work capacity in 1962. In the next two decades several investigators explored the effect of nutritional status on work capacity in adults in developing countries. Vitteri had investigated the effect of nutrition on the body composition and physical work capacity of young Guatemalan adults. He reported that maximal work capacity was directly related to body weight or lean body weight. Spurr had reported that in sugarcane cutters undertaking heavy physical activity, the work output measured in terms of the amount of sugarcane cut was related to the nutritional status of the worker as judged by body weight and height. The higher work output from the higher body weight group was mainly attributable to a higher rate of work. Spurr had also shown that maximal work capacity in poorly nourished individuals with low body weight could be improved by nutritional rehabilitation.

In India, work output in relation to nutritional status was investigated in agricultural workers and coal miners. Data from these studies showed that work output was lower in persons with lower body weight and height. However, it is difficult to assess whether the low output was related to past low dietary intake and consequent undernutrition, or to current undernutrition status. Studies carried out at the National Institute of Nutrition (NIN) in the 1970s explored the
relationship between work output and anthropometric, biochemical, and socioeconomic variables in persons engaged in sub-maximal work. Clinical and biochemical examination indicated that their current nutritional status was adequate, thereby indicating that in the immediate past and during the study they were well nourished. The workers were producing fuses, and the output was measured in terms of the number of fuses produced per day. Work output was significantly lower in those with lower body weight. Body weight, height, and lean body weight were significantly correlated with work output. The rate of work was also higher in the higher body weight group.

**Nutritional status and work capacity in school-age children**

Results of studies carried out among well nourished children and adolescents in developed countries have shown that, even among the normally nourished children, there was a relationship between body weight and work capacity. Studies among school children in developing countries indicate that undernutrition, anaemia and illness have an adverse effect on work output. Studies on nutritional status and physical work capacity at sub-maximal level in India showed that ~64% of the variation in physical work capacity at a heart rate of 170/min could be explained by the differences in current body weight, while habitual physical activity explained another 10% of the variation. Under-nutrition had no effect on work performance, when expressed in terms of unit weight. At moderate work levels, undernourished subjects attained a significantly higher heart rate for the same work load as compared to their normally nourished counterparts.

**Micronutrient deficiencies and work capacity**

Compared to the data on the effect of chronic undernutrition on work capacity, there is limited information about the impact of low intakes of vitamins/minerals and micronutrient deficiencies on physical performance. Many vitamins and minerals play key roles in energy metabolism; water-soluble vitamins are involved in mitochondrial energy metabolism. It is therefore logical to expect that there will be reduction in work capacity in the presence of micronutrient deficiencies. However, there is very little data about the impact of deficiencies of these micronutrients on work capacity. Perhaps part of the problem is that in the last century micro- and macronutrient deficiencies tended to coexist, and it was difficult to disaggregate the impact of micronutrient deficiency from the impact of under-nutrition. In the current century, when micronutrient deficiencies are seen in normally nourished or overnourished persons, it gives us an opportunity to study the impact of micronutrient deficiencies *per se*, on work performance.

**Anaemia and work capacity**

Globally, iron deficiency anaemia ranks as the number one nutritional deficiency. India has the highest prevalence of anaemia and the largest number of anaemic...
persons in the world. It is, therefore, inevitable that most of the global and Indian studies have been focused on documenting the adverse effect of anaemia on work capacity and the impact of supplementation on improvement in work capacity.

Results of some of the studies both from developed and developing countries indicate that iron deficiency, with or without anaemia, impairs muscle function and limits work capacity. Iron deficiency and iron deficiency anaemia limit maximal physical performance and submaximal endurance. Reduction in work output has been reported in farmers, plantation workers, and even in those involved in the relatively less strenuous work in a jute factory. Iron supplements improved iron status and work performance in iron deficient or anaemic persons. Supplementation of iron and other micronutrients have been reported to improve iron and Hb status and also work capacity in undernourished anaemic workers. A double-blind placebo-controlled study on the effect of iron supplementation in non-anaemic iron-depleted runners showed that iron supplementation resulted in improvement in ferritin levels and treadmill endurance times.

Several studies in school-age children in developed and developing countries have documented the fact both iron deficiency and anaemia impair work capacity; they have also explored the impact of iron supplements or multiple micronutrient-fortified beverages on iron micronutrient status, anaemia and work capacity in school-age children. A recent systematic review of the randomized controlled trials concluded that iron supplementation in children had a positive effect on physical performance as assessed by post-exercise heart rate, blood lactate levels and treadmill endurance time. Iron deficiency anaemia often coexists with chronic energy deficiency. Studies to explore the impact of energy and iron supplementation in anaemic and energy-adequate or anaemic and energy-deficient persons showed that combined deficiencies of energy and iron had a greater adverse effect on physical work capacity than energy deficiency or iron deficiency alone. Work performance improved with iron and food supplementation; improvement in performance was greater in the group that was iron- and energy-deficient and received food supplementation and iron tablets.

Anaemia and multiple micronutrient deficiencies are known to coexist. Several studies have shown poor levels of physical fitness, aerobic capacity and anaerobic threshold in children and adolescents with sub-optimal initial levels of micronutrients and improvements in these indices after supplementation with iron, vitamins B complex and vitamin C. The effect of the intake of beverages fortified with multiple micronutrients on physical performance has been investigated in the Phillipines and India. Studies on beverage-based multiple micronutrient supplements conducted in India showed an improvement in the relevant biochemical parameters. A randomized, double blind, placebo-controlled trial in Filipino schoolchildren assigned to receive either the fortified or non-fortified beverage with or without de-worming showed that consumption of a
multiple-micronutrient-fortified beverage for 16 weeks had a significant impact on iron status and iodine status, and improved the physical fitness of iron- and/or iodine-deficient Filipino school children.

Summary

Low dietary intake, and undernutrition leading to low adult body weight and low lean body weight are associated with reduced work output in adults and children. Studies that reveal these findings were carried out in populations of persons in whom body weight had excellent correlation with lean body weight, and body fat percentages were low. Under these conditions, weight or lean body weight could account for more than 50% of the variation in work output, whereas height could account only for 19% of the variation. However, when work output was computed on the basis of work per unit body mass, there were no differences in the work output.

Micronutrient deficiencies, especially iron deficiency and anaemia, had been shown to be associated with reduced work capacity in men, women and children. Iron provided through food (dietary diversification), food fortification (double fortified salt) and multiple micronutrient fortification of beverages has been shown to improve micronutrient nutritional status and work capacity.

In the past century, the focus was on studying the impact of undernutrition and micronutrient deficiencies on work capacity, because work capacity was a major determinant of wages earned in occupations based on manual labour. With increasing mechanization of transport and work domains, undernutrition and reduced work capacity may not be major determinants of earning capacity in modern society. There is an emerging problem of obesity, in which high fat mass and poor lean body mass are associated with poor work capacity and higher risk of non-communicable diseases. Micronutrient deficiencies coexist with both undernutrition and over-nutrition. There is an urgent need to intensify in-depth investigations of the adverse impact of existing and emerging nutritional problems on work performance during school age itself, introduce appropriate interventions for improving nutritional status and work performance, and lay the foundation for a healthy adult life.

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PHYSICAL FITNESS

Physical performance is defined as the ability to perform a physical task or sport at a desired level. The main determinants of performance are physical fitness and skill. Epidemiological studies have shown that the degree of physical fitness during childhood and adolescence may determine the person’s physical fitness as an adult. Continued moderate physical activity throughout life has been shown to prevent overnutrition, maintain muscle mass, reduce the prevalence of cardiovascular diseases and ameliorate the adverse effects of aging on musculoskeletal and cardiovascular systems. Over the past few decades there has been a reduction in physical activity and consequently in physical fitness levels in all segments of the population, both in developed and developing countries. Children and adolescents have also been part of this decline. It is imperative that steps are taken to arrest and reverse this decline so that these children and adolescents do not face the adverse consequences of non-communicable diseases during their adult lives.

Physical fitness tests

Physical fitness is the ability to achieve certain standards of physical activity. Several relatively simple tests have been developed and validated for assessment of different aspects of physical fitness both in adults and in children. In addition, efforts have been made to develop batteries of tests for certain core functions that determine physical fitness, and use them to assess fitness in individuals and communities. In India, these batteries of tests have been used mainly in athletes to assess suitability for sports, and in adults to assess cardiovascular disease risks. Following the reports of the decline of physical fitness in children and adolescents in the past few decades, many countries have taken up routine physical fitness testing of children. Fitness tests are valuable because, using a series of tests conducted over a short period of time, it is possible to identify those with fitness-related problems and initiate appropriate interventions. These tests might also be useful as a part of the comprehensive health-related fitness curriculum to teach children and adults about the health benefits of physical activity.

Physical fitness testing include:

- assessment of body composition (muscle mass and fat mass); adiposity is associated with risk of hypertension, diabetes, CVD and some malignancies;
- measurement of cardio-respiratory endurance (aerobic capacity); poor performance is associated with a higher risk of hypertension, diabetes and CVD;
- measurement of muscle strength (ability to exert force against resistance) and endurance; reduction in muscle strength is associated with risk of musculoskeletal injuries; and
flexibility (range of movements); reduction in flexibility is associated with risk of musculoskeletal injuries.

American Alliance for Health and Physical Education (AAHPER) developed the first battery of fitness tests which were adopted by the Presidents Council in 1966. The performance under the original battery of tests depended both on fitness and on skill. With increased emphasis on health-related fitness, the use of fitness tests related to cardio-respiratory endurance has increased and the use of components of fitness tests for assessing agility, balance and power has decreased.

Several batteries of tests have been developed to assess fitness in all its dimensions in children and adolescents. Some of the fitness test batteries that are widely used in children are EUROFIT used in European children and adolescents, and Fit Youth Today or AAHPERD (American, Alliance for Health, Physical Education, Recreation and Dance) and FITNESSGRAM in the U.S. A brief description of some of the commonly used batteries of tests for assessment of fitness is given in the accompanying Table. Assessment of physical fitness

<table>
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<th>Fitness component</th>
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<td>FITTESTGRAM</td>
<td>President’s</td>
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<td>Cardiorespiratory endurance</td>
<td>0.25-to 1-mile run</td>
<td>1-mile walk/run*</td>
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<td>Trunk strength and endurance</td>
<td>Bent knee sit-ups</td>
<td>Curl-ups*</td>
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<td>Hamstring and low back flexibility</td>
<td>Sit-and-reach</td>
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<td>Shoulder flexibility</td>
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<td>Upper body strength and endurance</td>
<td>Pull up Flexed arm hang</td>
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<td>Body composition</td>
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<td>Body mass index</td>
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<td>Trunk extensor strength and flexibility</td>
<td>Trunk lift*</td>
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<tr>
<td>Agility, endurance, power, leg strength</td>
<td>Shuttle run</td>
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<td>Leg strength</td>
<td>Standing long jump</td>
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Note: The complete names of the fitness test batteries are Chrysler/AAU Fitness Test: Prudential FITNESSGRAM; President’s Challenge Physical Fitness Test; YMCA Youth Fitness Tests; National Youth Physical Fitness Test. *Preferred test items.

using these fitness tests have been documented in American, Finnish, Greek, Spanish, Dutch, Swedish and Estonian children and adolescents. The International Council for Health, Physical Education, Recreation, Sports and Dance (ICHPERSD-Asia) has developed a battery of fitness tests specifically
designed for Asian youth\(^2\). There are very few reports of the outcomes of physical fitness tests in Asian children, partly because the importance of these tests has been realized only recently, and partly because of lack of adequate infrastructure and manpower.

Over the years, criteria have been evolved for evaluating an individual’s performance on the basis of scoring in physical fitness tests. Initially, a comparison of the individual’s performance with centile norms of the population were used for interpretation of physical fitness tests; subsequently criterion reference standards were prepared and made available for comparison. However, there are still several problems in interpretation of the results, especially in relation to assessment of physical activity and health risks. For instance, approximately 75% of boys and 50% of girls met at least four of the five FITNESSGRAM criterion—referenced standards in the National Fitness Studies I and II. However, the rates for active children were not much different from the rates for inactive children, thereby suggesting that either the standard did not differentiate between physical activity levels or that the assessment of physical activity used in these studies was susceptible to misclassification. There is an urgent need for systematic development and validation of these reference standards and elimination of snags. The use of “healthy fitness zones” is a recent innovation in criterion referenced standards for physical fitness; these take into account the public health messages regarding the importance of regular participation in moderate physical activity.

**Components of physical fitness**

*Body composition* (relative proportion of muscle, fat, water and bone in the body) is an important health-related component of physical fitness. There is an inverse relationship between percentage of body fat and performance of physical activities such as running or jumping. Optimal performance is achieved with low percentage of body fat and a high muscle mass\(^3\). Body composition is measured using field techniques such as anthropometry, fat fold measurements, and bioelectrical impedance analysis\(^3\).

*Physical fitness* refers to a full range of physical qualities *i.e.* cardiorespiratory fitness, endurance, speed of movement, agility, coordination, flexibility and muscular strength.

*Cardio-respiratory fitness or aerobic capacity* is one of the most important components of fitness. It measures the ability to carry out prolonged strenuous exercise\(^3,5\) reflecting the overall capacity of the cardiovascular and respiratory systems. The maximal aerobic capacity (\(V_O^2_{max}\)) test in the laboratory setting, is the best measure of cardiovascular fitness\(^5\). Aerobic capacity can be assessed using exercise tests that require minimal equipment. Several field tests provide reliable and valid measurements of aerobic capacity comparable to laboratory tests\(^7\). *Step test* is a field test of aerobic capacity, which requires the participant to step up and down from a platform. \(V_O^2_{max}\) determined by step tests correlate
well with treadmill and cycle ergometer tests. These tests have been validated in healthy children and adolescents between 7 to 18 years of age\(^9\). Another widely used test is the shuttle run test. This is a standardized incremental walking test that measures functional capacity by asking the individual to exercise up to a symptom-limited maximal performance. The test can be easily used in healthy children and adults\(^8\). Comparison of shuttle run tests in children and adolescents across 37 countries suggests that it may be useful as a marker of performance in different regions and ethnic populations\(^9\).

Balanced, healthy functioning of the musculoskeletal system requires that a specific muscle or muscle group is able to generate force or torque (measured as strength), resist repeated contractions over time, or maintain a maximal voluntary contraction for a prolonged period of time. This combination of strength and endurance is referred to as **muscular fitness** \(^5,6\). There is no single test to assess total body muscular endurance or muscle strength\(^4\). Muscle fitness tests are very specific to the muscle group tested, muscle velocity, type of contraction, the equipment and range of motion of the joints. The tests usually used for assessing muscle fitness in children are hand grip strength, sit-ups and standing broad jump\(^6\). **Flexibility** relates to the range of motion available at a joint. Range of motion at ease without pain or discomfort is a marker for good flexibility. It is an important attribute in sports and even for carrying out routine activities effortlessly. Flexibility is specific to each joint of the body. The equipments used to measure flexibility are goniometer and flexometer. There is no general measurement for flexibility. The most common field test is the sit-and-reach test\(^4\).

**Agility** is the ability to rapidly change the position of the entire body in space with speed and accuracy. One of the tests to assess agility is sprints. **Balance** relates to the maintenance of equilibrium while stationary or moving. **Coordination** is the capability to use senses such as sight and hearing, along with body parts performing motor tasks smoothly and accurately. There are no tests to measure overall balance and coordination, but situation-specific tests are available.

Speed and reaction times are the two most commonly assessed skill-related fitness components. **Speed** is the capacity to perform a movement within a short period of time. There are many different types of speed, such as running speed, swimming speed, and speed of hand or foot movement. Speed assessment is highly specific to different body parts and human movement activities. Sprints and shuttle runs are widely used to assess speed. **Reaction time** is the time elapsed between stimulation and the subsequent response to it. Reaction time is influenced by heredity. It declines with age, conditions of fatigue, and distractions.

**Use of physical fitness tests**

Physical fitness is a key marker for health at any age; but fitness tests are not being widely used as a part of assessment of health status either in adults or in children. In the U.S., studies on physical fitness of children got a fillip following
the reports in the 1950s that the physical performance of American children was worse than that of European children. It has been demonstrated that:

- there is a global decline in physical activity in children, adolescents and adults over the past few decades;
- there has been a sharp decline in physical activity in the past two decades among adults and children in developing countries;
- physical activity in childhood and adolescence continue to be major determinants of physical activity in adults and;
- low levels of physical activity have been related to the emerging problem of overnutrition, and also increase the risk of developing CHD, diabetes, CVD and osteoporosis in adulthood; and
- low levels of physical activity are associated with higher CHD and perhaps also all-cause mortality in both men and women.

These findings resulted in increasing the global interest in the area of physical fitness and fitness testing for better health. Reviews of available data on physical fitness, mainly from the developed countries, indicate that there has been a global decline in physical fitness. Performance data under cardiovascular endurance tests indicate that there has been a 4-5% decline per decade since the 1970s. However, there has been no decline in the outcomes in power and speed tests.

Asia is the population giant among all continents; the continent has witnessed a steep increase in overnutrition and associated health hazards in the past two decades. There is abundant data on time trends in nutritional status in different segments of the Asian population. However, there is very little data on the changing physical activity and physical fitness levels in different Asian countries over time. A meta-analysis of available data on secular changes in outcomes of power, speed and cardiovascular endurance tests in 23.5 million 6-19 year old children from seven Asian countries tested between 1917 and 2003 showed that, overall, the pattern of decline in physical fitness in Asian countries is similar to the reported data from developed countries. However, among Asian countries themselves, the pattern of decline was not similar. In children in China, Singapore and Japan the rate of decline in physical fitness since 1970 was half the global rate of decline, whereas in children from Hong Kong and South Korea the decline was twice that of the global rates. The decline in power and speed tests have been slow and comparable to the global figures.

There is very little data from India on time trends in physical fitness tests in children and adolescents. Fitness tests have been used for selection and monitoring of athletes in sports academies. A few studies have reported the aerobic and anaerobic performances of trained and untrained school children and compared them with international standards. Grip strength in school children has been reported to significantly correlate with height, weight, mid arm
circumference, triceps skin fold, arm fat and arm muscle measurements\textsuperscript{14}. With increasing awareness about the importance of physical fitness in school children, it is hoped that adequate data will be generated in this important area.

References

SUMMARY

Six decades ago, a majority of Indian citizens were poor, worked at manual jobs, had low dietary intake, and were undernourished and anaemic. There was excellent correlation between weight and lean body mass as they had very low body fat.

Research studies from the 1960s to the 1980s showed that:

- even in persons with adequate food intake and normal nutrition, there was a direct relation between body size and work output;
- work output, whether during strenuous, moderate or light work, was lower in undernourished and/or anaemic persons in all age groups and both sexes.

Reduction in work output results in reduction in earnings and consequently in purchasing power; this leads to lower dietary intake and further aggravation of undernutrition, setting up a vicious cycle. Research studies have demonstrated that food supplementation to undernourished persons and iron supplementation to anaemic persons lead to amelioration of undernutrition, and reduction in anaemia, respectively; work output improved with reduction in the incidence and severity of undernutrition and anaemia. Based on these findings many industrial firms provided food to the workers at work site. There is no data on the impact of these on productivity. Over the past three decades there has been increasing mechanisation and automation in the industrial, agricultural and transport sectors; because of the overall reduction in occupational physical activity, it is not possible to assess the impact of nutrition interventions on productivity in the industrial and agricultural sectors.

A steep reduction in physical activity in general is the major factor responsible for the increasing incidence of overnutrition in the past two decades. In urban affluent segments of the population, the consumption of calorie-rich junk food with very little micronutrient content has also contributed to the rise in overnutrition, often in association with anaemia. In Indians, diabetes and cardiovascular diseases (CVD) occur a decade earlier than in populations in developed countries, and the prevalence of both diseases is rising rapidly. Physical activity improves fitness and reduces the risk of developing obesity, diabetes and cardiovascular diseases. Anthropometric assessments of overnutrition and cardio-respiratory endurance tests are increasingly being used to screen both adults and children so as to identify at-risk individuals and provide appropriate interventions; they are also used to monitor improvement over time.
A battery of physical fitness tests are being used in developed countries for assessing physical fitness in children. So far, in India, these tests have been used mainly for selecting children with good physical fitness, training them in sports and monitoring their progress. With the increasing popularity of athletics and sports, the number of persons engaged in strenuous physical activity in pursuit of excellence in their sports is rising. The available data indicate that macronutrient as well as micronutrient requirements are higher in these persons. Their nutrient requirements have to be met through increased dietary intake of natural food and/or fortified food and/or supplements. Infections and debilitating illnesses are other conditions that are associated with increased nutrient requirements, and these too can be met through food and/or supplements.

India is undergoing rapid socioeconomic, nutritional and health transition; rapid transitions always bring challenges as well as opportunities. With improved availability of infrastructure and manpower, an increasingly aware population may access facilities for screening and identification of both overnutrition and undernutrition in childhood itself. Schools provide a platform for mounting these activities and providing appropriate interventions to modify the dietary intake and physical activity patterns. By making optimal use of this opportunity to introduce school-age children to more healthy lifestyles, India may be able to combat the dual nutrition burden and the health hazards associated with it more effectively.