Micronutrients: interaction between physical activity, intakes and requirements

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Abstract

The present literature review examines the following questions: (a) What is the evidence that micronutrient requirements are increased in physically active people? (b) Is there an association between physical activity and micronutrient intake? (c) Are there any significant differences between indices of micronutrient status between physically active and inactive people? The available data suggest that micronutrient requirements are increased in physically active people because of increased losses through sweat, urine and faeces, and an increased need for defence against free radicals. However the evidence is controversial, and it is not possible to make any quantitative estimations. Micronutrient requirements in moderately active people are not likely to be very much above the levels recommended for the general population. The intake of micronutrients increases with increasing energy intake. Therefore, physically highly active people (athletes) have higher micronutrient intakes than untrained subjects. However, moderate physical activity does not necessarily affect daily micronutrient intake. The available indices of micronutrient status do not support the belief that micronutrient status is compromised in highly trained athletes, even without use of dietary supplements. Hence, there are no reasons to believe that the situation would be different in people who are only moderately active. The results suggest that micronutrient status is adequate for health and functional performance in physically active people who follow a normal, mixed Western diet.

Keywords
Diet
Vitamins
Minerals
Trace elements
Nutritional status
Exercise

Key messages

- Micronutrient requirements are likely to be increased in physically highly active people, but not significantly in moderately active individuals.
- According to the available data, the increased micronutrient requirements are counterbalanced by increased dietary intakes in physically active people.
- Given that an individual follows a balanced diet, moderate or high physical activity is not a reason for vitamin and mineral supplementation.

Introduction

Adequate nutritional status means sufficiency of host nutriture to permit cells, tissues, organs, anatomical systems or the host him/herself to perform optimally the intended, nutrient dependent function[1]. The role of micronutrients in nutritional status is extremely important and versatile. For instance, micronutrients are needed for immune function, integrity of cell membranes, sperm production, nervous function, muscle contraction, and brain and muscle metabolism. Inadequate micronutrient status increases susceptibility to diseases, affects cognitive capacity and decreases physical performance.

A basic characteristic of physical activity is energy expenditure caused by muscle contractions. Most micronutrients participate in these physiological processes[2]. Many vitamins of the B-complex group (e.g. thiamin, riboflavin, vitamin B_6, niacin, biotin and pantothenic acid) act as cofactors for enzymes regulating glycolysis, citric acid cycle, oxidative phosphorylation, β-oxidation (breakdown of fatty acids) and amino acid degradation. Folic acid and vitamin B_{12} are needed for heme synthesis. Ascorbic acid activates an enzyme regulating carnitine biosynthesis[3]. Carnitine is necessary for fatty acid transportation from cell cytosol into mitochondria. Finally, antioxidant vitamins (mainly vitamins C and E) participate in the buffer system against free radicals produced by increased energy turnover[4].

Several minerals and trace elements, such as magnesium, iron, zinc and copper, act as enzyme activators in glycolysis, oxidative phosphorylation and in the system responsible for maintenance of acid-base equilibrium. Minerals (electrolytes) also affect muscle

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contraction. After stimulation by the action potential, calcium, released from the sarcolemma, triggers contraction. Further, the action potential stimulation depends on the balance between intracellular potassium and extracellular sodium[5].

Micronutrient status is a function of balance between nutrient losses and intake. In general, physical activity is regarded to be positive for nutritional status. However, the theses regarding the association between physical activity and micronutrient status are slightly different. In many instances, physical activity and especially strenuous athletic training is believed to be harmful for nutritional status. Consequently, there is a widespread belief that physically active people need micronutrient supplements to ensure adequate nutritional status[6].

The present review examines the following questions: (a) What is the evidence that micronutrient requirements are increased in physically active people? (b) Is there an association between physical activity and micronutrient intake? (c) Are there any significant differences between indices of micronutrient status between physically active and inactive people?

Although the main emphasis of the present review is on the interaction of diet and moderate activity, many conclusions need to be extrapolated from studies with athletes as subjects. The relationships between physical activity, micronutrient intakes and prevention of chronic diseases (osteoporosis, cardiovascular-heart diseases, hypertension, cancer) are covered by Branca, Hardman, Hill, Margetts and Rauramaa in this issue.

Factors potentially affecting micronutrient requirements in physically active people

Physical activity increases energy expenditure. As mentioned, several vitamin- or mineral-dependent enzymes are involved in human energy metabolism. In his review, van der Beek[7] proposed that high metabolic activity might increase the turnover of several vitamins of the B-complex group. Indeed, some old data support the above view: Sauberlich *et al.*[8] found that thiamin requirements in male subjects were 30% higher when daily energy intake was 15.1 MJ. (3600 kcal), compared with 11.7 MJ. (2600 kcal). However, an energy-related requirement for thiamin has also been questioned[9].

Vitamin losses through sweat are minimal, even in physically active people[10]. However, sodium losses, particularly, may be significant[11–17] (Table 1). The losses of magnesium[11–14,17], iron[11,18–23] and zinc[11,21] through sweat may also be meaningful, compared with the daily needs for body, after intestinal absorption is accounted for[24,25]. However, the interpretation of the data is difficult, because of several problems in sweat analyses. For instance, the composition of sweat varies with the collection site[19,21]. Moreover, it is uncertain whether a short sampling period represents long-term conditions[26]. The large variation between different studies, as illustrated in Table 1, reflects the above mentioned methodological problems.

In addition to sweating, micronutrients may be lost in urine or faeces. On a day of physical exercise, Deuster *et al.*[27] found elevated (22%) magnesium excretion. Similarly, higher (21–76%) excretion of magnesium[28] and zinc[29,30] was found in trained athletes compared to controls. Moreover, several investigators have found iron in urine[23,31] or faeces[23,32–35] after strenuous endurance running. However, it is likely that iron excretion is much less during moderate training.

Free radicals are unstable, reactive and potentially harmful chemical substances with unpaired electrons in their outer orbitals[36]. An excessive production of free radicals or an insufficient protection against them has been linked to ageing, cancer, and athlerosclerosis[37].

Table 1 Sodium, magnesium, iron and zinc losses by exercise-induced sweating in males: ranges of concentrations found in different studies

	Concentration	Losses per litre, % of needs[1]	Recommendation, mg/d	Bioavailability, %[2]	References
Sodium					
mmol/L	24.3–60.9				
mg/l	560–1400	25–64	2300[2]	95	11–17
Magnesium					
mmol/L	0.12–1.48				
mg/l	3.0–36.0	3–34	350[3]	30	11–14,17
Iron					
μmol/L	0.5–9.0				
mg/l	0.03–0.5	3–50	10[3]	10	11,18–23
Zinc					
μmol/L	19.2–22.9				
mg/l	0.6–1.5	17–42	12[3]	30	11,21

[1]Need for the body after intestinal absorption is accounted for.
[2]Recommended daily amounts of vitamins & minerals (from diet) in Europe, ref. 24.
[3]Nordic Nutrition Recommendations (from diet) for adult males, ref. 25.

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Results from animal studies suggest an exercise-induced free radical production and a concomitant lipid peroxidation[4,36,37].

In humans, exercise-induced free radical formation or lipid peroxidation can not be measured directly[36]. Indirect evidence of lipid peroxidation during physical exertion includes increased penthane exhalation in the breath[4,38–4] and elevated malondialdehyde in serum and erythrocytes[4,41,42]. However, not all studies show an exercise-induced increase in indices of lipid peroxidation[40,43,44]. The interpretation of these data is somewhat problematic. A major limitation in the above analyses is that they neither indicate the source or timing of lipid peroxidation[45] nor permit quantitative correlation of peroxidation[46].

Scavenger enzymes and antioxidant vitamins build up a protection system against free radical attack. Mena *et al.*[47] showed that highly trained athletes indeed have higher activities of several scavenger enzymes, but the effects of moderate training are apparently much smaller[48]. An increased need for endogenous defence against free radicals might raise the requirements for zinc and copper (in Zn_2Cu_2-superoxide dismutase) and selenium (in glutathione peroxidase) in physically active people. Further, more antioxidant vitamins than usual might also be needed[4,36,37].

In conclusion, it is biologically plausible to conjecture that physical activity may increase the requirements of micronutrients at least through sweating, losses in urine and perhaps in faeces, and through increased free radical production. Nevertheless, the data are insufficient to allow any quantification of the needs in moderately active people, or in athletes.

Dietary intake – a balancing factor?

Increased nutrient losses and turnover might be counterbalanced by increased dietary micronutrient intake, which has been observed in response to the amount of training[49] and energy intake[7,50]. Micronutrient intakes in male athletes are usually above the recommendations and significantly higher than in untrained subjects[49,51–56]. There are, however, occasional reports of marginal vitamin B_6 and E intake in male athletes[54]. Vitamin intakes in female athletes are typically above the recommendations, but not very much higher than in untrained females[28,30,33,53,57–61]. Several studies have found low iron[28,30,53,57–61], zinc[30,59,62] and copper[28] intakes in both female athletes and controls. However, these results may at least partly be explained by underreported dietary intake[63].

In a very large study comprising 439 Dutch athletes, van Erp-Baart *et al.*[64] regressed the intake of calcium and iron against energy intake. The regressions showed that a 100% increase in energy intake was associated with a 70-80% increase in iron, and an 80-90% increase in calcium intake. Similar calculations from two Finnish studies are presented in Table 2[49,65]. Also these results suggest that micronutrient intakes are positively associated with energy intake, but that the increase in micronutrient intakes are not as large as the increase in energy intake.

Judged by the weakest correlation coefficients in Table 2, the association between energy and vitamin C intake seemed to be weaker than the association between energy and other nutrients. This finding may be as a result of food items rich in vitamin C (fruits, vegetables) having a low energy density. Therefore, variation in fruit and vegetable consumption affects vitamin C, but not energy intake. The intake of other micronutrients seems to be more closely related to energy intake.

Health-enhancing, moderate physical activity, as recommended by an expert panel[66], increases the daily energy expenditure by no more than 10%. As the increase in micronutrient intake is assumed to be even lower, and because of a wide between-person variation of daily intake, it is not surprising that moderate

Table 2 Pearson product moment correlations for dietary energy vs. micronutrient intake in male (n=571, ref. [49]) and female (n=39, ref. [65]) subjects and predicted (from linear regression formulae) intake of micronutrients at a low and high energy intake

Nutrient	Correlation	Predicted intake		
Males	R	10 MJ	20 MJ	Δ%[1]
Thiamin	0.85	1.9	3.5	85
Riboflavin	0.76	2.5	4.6	84
Vitamin C	0.58	155	315	110
Magnesium	0.82	405	740	83
Iron	0.80	18	31	72
Zinc	0.86	14	25	79
Females	R	7 MJ	14 MJ	Δ%[1]
Thiamin	0.77	1.2	2.0	74
Riboflavin	0.66	1.6	2.7	69
Vitamin C	0.35	116	166	43
Magnesium	0.72	277	444	60
Iron	0.77	12	20	67
Zinc	0.70	10	16	60

[1]Δ% = higher (%) micronutrient intake at higher energy intake (compared with lower intake).

physical activity does not clearly relate to higher intake of micronutrients[65,67].

Indices of micronutrient status in physically active people

Vitamin A (β-carotene)

Serum concentration for β-carotene, the provitamin for retinol, is more responsive to changes in dietary intake than retinol. Takatsuka *et al.*[68] reported that hard physical activity was associated with lower β-carotene concentrations in Japanese men and women. The results in this cross-sectional study were adjusted for age, BMI, diet, smoking, serum cholesterol and serum triglycerides. Guilland *et al.*[54] found comparable β-carotene levels in athletes and in controls.

Vitamins of the B-complex group

Using erythrocyte glutathione reductase activation coefficient (E-GRAC) as an indicator of riboflavin status in females, Belko *et al.*[69] reported a 15% increase in daily riboflavin requirement during increased moderate physical exercise. Two subsequent studies by the same group[70,71] seemed to support the finding.

In a more recent study, Soares *et al.*[72] examined riboflavin status in male subjects with initially marginal E-GRAC results. Because of worsened indicators of riboflavin status during an 18-day exercise-period, the authors suggested increased riboflavin needs because of increased physical activity. The interpretation is not straightforward, however, because the exercise period was followed by a 13-day maintenance period without any improvements in blood or urine chemistry. The authors suggested a carry-over effect.

We have investigated the effects of a 24-week fitness-type exercise program on indices of nutritional status in previously untrained female students[65]. The frequency of weekly exercise sessions increased gradually from two to six. The reported dietary intake was essentially unchanged throughout the study period. Indicators for thiamin and riboflavin status were unchanged throughout the study. Erythrocyte aspartate aminotransferase activation coefficient (E-ASTAC, an indicator of vitamin B_6 status) increased in exercise and decreased in control groups. Increased E-ASTAC might have indicated marginally impaired vitamin B_6 status in the exercise group. However, changes in E-ASTAC of this magnitude (from 2.02 to 2.11) are not likely to affect functional capacity[73,74].

The effects of varying training volume on erythrocyte transketolase activation coefficient (E-TKAC, an indicator for thiamin status) have been studied in Finnish cross-country skiers[53]. Despite very strenuous training in August and November, and clearly lighter in February and in May, E-TKAC showed no seasonal variation.

Cross-sectional studies comparing athletes and untrained controls do not give much evidence to support a view of impaired vitamin B status in physically active people. Guilland *et al.*[54] found higher E-TKAC in athletes than in untrained controls, whereas Fogelholm *et al.*[49,53] found both lower and comparable E-TKAC in athletes. Keith & Alt[58] found higher E-GRAC in female athletes, but Guilland *et al.*[54] reported levels comparable to the controls. Only Guilland *et al.*[54] reported E-ASTAC values for both athletes and untrained controls; no difference was observed.

Vitamin C

To my best knowledge, only four studies have reported data on vitamin C status in physically active people and untrained individuals. Serum ascorbic acid concentrations were the same[49,54,75] or higher[76] in athletes than in controls. The pooled mean concentrations for serum or plasma ascorbic acid in the above studies were 59 and 56 $\mu mol \cdot L^{-1}$ for athletes ($n = 533$) and controls ($n = 193$), respectively. These levels correspond to a sufficient body pool of about 1500 mg[77].

Vitamin C is needed for immunologic functions. An interesting aspect of interaction between vitamin C, physical activity and health is related to the proposed connection with upper respiratory tract infections (URTI). Several studies suggest that strenuous physical activity increases the risk for URTI during the first week or two after exercise[78–80]. In his meta-analysis, Hemilä[81] identified three placebo-controlled studies that examined the effects of vitamin C supplementation on URTI in subjects under acute physical stress. The pooled rate ratio of URTI was 0.50 (95% confidence interval 0.35–0.69) in favour of the group receiving vitamin C (600–1000 mg daily). Hence, these studies suggest a positive effect of vitamin C supplementation during and after strenuous physical activity. Nevertheless, these data do not tell anything about the need of supplementary vitamin C during moderate training.

Vitamin E

Kitamura *et al.*[82] reported that physical activity was positively associated with plasma α-tocopherol concentration in Japanese men. In a recent, albeit small ($n = 41$) study, habitual levels of physical activity did not affect plasma α-tocopherol levels[83]. Similarly, Tiidus *et al.*[48] did not find moderate training to influence vitamin E concentration in the muscle.

Only a few studies have compared plasma α-tocopherol levels between athletes and controls. Guilland *et al.*[54] reported similar results, but Karlsson *et al.*[84] found lower levels in athletes than in controls. Nevertheless, in the latter study, the ratio between athletes' and controls' α-tocopherol concentration was precisely the same as the ratio between athletes' and controls' free cholesterol concentration in plasma.

Because α-tocopherol is transported in lipoproteins together with cholesterol, dissimilar blood lipid profiles in athletes and controls might explain the difference found by Karlsson *et al.*[84].

Several studies have shown that α-tocopherol supplementation reduces breath pentane excretion[39] and serum malondialdehyde (MDA) concentration (determined as thiobarbituric acid reactive substances, TBARS)[39,42,56,85] during exercise. Both breath pentane and serum MDA were used as indicators of lipid peroxidation. Nevertheless, the significance of these results on health remains uncertain. Finally, most studies have not supported the hypothesis that vitamin E attenuates exercise-induced muscle damage[86].

Minerals and trace elements

The effects of physical activity on iron status have probably been studied more than the effects of activity on other micronutrients together. One evident reason for the interest is the well-known associations of blood haemoglobin concentration and physical performance[87]. Iron excretion through sweat, urine and faeces is believed to be increased from normal levels, although contrasting evidence has also been presented (see earlier in this review). In contrast, iron absorption may be slightly improved by physical activity[35,88].

The effects of moderate physical training on indices of iron status in previously untrained women have been examined in some controlled interventions. Two studies[65,89] were six months by duration, while the third[90] was shorter (12 weeks). All the above studies concluded that a regular, moderate training program did not have any negative effects on the measured indices of iron status. In contrast, regular physical activity (not athletic training) was associated with better iron status (as measured by serum ferritin) in a cross-sectional survey in Finland[91]. The results were controlled for several variables, including menstruation (volume and frequency), age, dietary habits and use of micronutrient supplements. The above results indicate that moderate physical activity is not a risk factor for iron deficiency.

In an analytical review[87], I have pooled the available data on iron status in athletes and controls, published between 1980 and 1994 (Table 3). The results show slightly lower serum ferritin concentrations in runners, regardless of sex, and also in other female athletes, compared to controls. However, the difference between males and females is much greater than the difference between physically active and inactive subjects. More recent studies have not brought any new insight into the above view[92–94]. However, iron deficiency anaemia, expressed as blood haemoglobin concentration below the lower reference limit, is rare in both physically active people and untrained controls[87,94].

The pooled mean serum magnesium and zinc concentrations were not different between athletes and untrained controls in studies published between 1980 and 1994[87]. In agreement with the above conclusion, we have also reported approximately similar erythrocyte magnesium levels between male endurance athletes and controls, whereas erythrocyte zinc concentration was even higher in athletes[51]. The latter finding might be related to increased amount of intracellular zinc-dependent enzymes, such as superoxide dismutase[59]. The recent hypothesis that very high magnesium doses (3 g/day) attenuate lipid peroxidation and improve performance in athletes[95] need further studies.

In a controlled intervention, a 24-week fitness-type exercise program, with progressively increasing training frequency, did not affect serum or erythrocyte magnesium content in previously untrained young women[65]. Likewise, no changes were observed in serum zinc concentration, but erythrocyte zinc concentration increased throughout the study. In an uncontrolled 12-week intervention, Dolev *et al.*[96] reported unchanged serum and erythrocyte, but increased mononuclear cell zinc concentrations in male military recruits.

In studies published between 1980 and 1994, the pooled mean results on plasma copper concentration tended to be higher for females than for males: 16.3 and

Table 3 Summary of studies presenting serum or plasma concentration of magnesium, ferritin or zinc in athletes and controls (data from ref. [87])

	Concentration in serum/plasma		Number of subjects		
	Athletes	Controls	Athletes	Controls	Groups
Serum/plasma magnesium (mmol/l)	0.84	0.85	516	251	7
Serum ferritin, female runners (μg/l)	25	31	251	160	9
Serum ferritin, females, other sports (μg/l)	25	30	180	239	7
Serum ferritin, male runners (μg/l)	63	98	240	220	6
Serum ferritin, males, other sports (μg/l)	83	71	614	400	9
Serum/plasma zinc , females (μmol/l)	12.3	12.8	81	69	4
Serum/plasma zinc, males (μmol/l)	13.5	13.7	587	244	7

15.1 μmol · L^{-1} for female athletes and controls, and 14.7 and 14.1 μmol · L^{-1} for male athletes and controls, respectively[87]. As seen from the above results, the plasma copper concentration tended to be slightly higher in physically active subjects. Data on other trace elements are scarce. Anderson *et al.*[97] reported similar plasma chromium concentrations in athletes and untrained controls. A competitive sailing crew had lower serum selenium concentration than controls[52]. Nevertheless, even the sailing crew's results were clearly within the reference range for selenium. Hence, the available indices of magnesium, zinc, copper, chromium and selenium do not suggest compromised status in physically active people.

Conclusions

The present review examined three questions on the interaction between physical activity, micronutrients and health. The main endpoint for health was micronutrient status, as measured by biochemical indices from blood. The following conclusions may be drawn:

1 The available data suggest that micronutrient requirements are increased in physically active people. The evidence is, however, controversial, and it is not possible to make any quantitative estimations. The main reasons for increased requirements seem to be increased losses through sweat, urine and faeces, and an increased need for defence against free radicals. Nevertheless, it may be conjectured that micronutrient requirements in moderately active people are not significantly above the levels recommended for the general population.

2 Micronutrient intake increases with increasing energy intake. Therefore, physically highly active people (athletes) have higher micronutrient intakes than untrained subjects. Female athletes in aesthetic events (e.g. gymnastics, ballet) have often reported low nutrient intakes, but the results may be biased because of underreporting. Moderate physical activity, already with known positive effects on health, do not necessarily affect daily micronutrient intake.

3 The available indices of micronutrient status do not support the belief that micronutrient status is compromised in highly trained athletes, even without use of dietary supplements. Hence, there are no reasons to believe that the situation would be different in people who are only moderately active. The use of static, rather than functional, indices of micronutrient status may be regarded as a limitation in the above conclusion[1,87]. However, the fact that micronutrient supplementation is not generally associated with enhanced physical performance (a non-specific, functional indicator of nutritional status) supports the view of adequate micronutrient status in physically active people who follow a normal, mixed Western diet[87].

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