Physical Performance of Migrant Schoolchildren with Marginal and Severe Iron Deficiency in the Suburbs of Beijing [1]

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Objectives To investigate relationship between iron deficiency of different degrees and physical performance and habitual activity of migrant schoolchildren at the age of 11-14 years. **Methods** Ninety one randomly selected schoolchildren were divided into three groups according to their iron status. Iron status including hemoglobin (Hb), serum ferritin (SF), serum iron (SI) and sTfR was determined. Physical performance tests included maximum oxygen consumption (VO_2max) and maximum work time. Energy expenditure (EE) and daily physical activity were estimated by recording 24-h heart rate (HR). Dietary intake was assessed with frequency questionnaires, and physical activity level was estimated with frequency and physical activity questionnaires. **Results** Severe iron deficiency (IDA) impaired the aerobic capacity and habitual physical activity. When fat-free mass (FFM) was considered, VO_2max (VO_2max/FFM) was significantly lower in the iron-marginal group than in the iron-adequate groups among girls (P=0.02), but such a deference was not found among boys (P=0.28). Aerobic activity and EE at leisure were significantly lower in the severe iron deficient group than in the marginal iron deficient and iron adequate groups. Net HR at leisure time was correlated with Hb, log SF, body weight, and FFM (P<0.05). **Conclusion** The functional effect of iron deficiency on physical performance and habitual physical activity rely on the degree of current iron deficiency. Severe iron deficiency significantly impairs both aerobic capacity and habitual physical activity. Iron-marginal deficiency impairs VO_2max/FFM in girls, rather than in boys.

Key words: Iron deficiency anemia; Iron deficiency; Maximum oxygen consumption; Heart rate; Energy expenditure; Physical activity; Children of migrant workers

INTRODUCTION

Urbanization has stimulated migration of population from rural to urban areas of China in in the past 20 years. As new dwellers in cities, migrant people, especially migrated children have become a vulnerable population group in terms of health and nutrition care because of their bad living conditions. Most of the migrant children are therefore considered suffering from a poor nutrition status and badly need nutrition improvement during the critical period for a better growth and development. Iron deficiency (ID) and iron deficiency anemia (IDA) are major global mutrition problems. ID could be classified into three degrees based on its severity: severe ID, moderate ID, and mild ID. Maginal ID without anemia is characterized by normal hemoglobin (Hb) levels and abnormal values of iron status[1].

IDA affects physical capacity by reducing the availability of oxygen from tissues, which, in turn, reduces maximal work capacity, endurance, productivity, energy expenditure, and voluntary activity[1-4]. As iron plays an essential role in oxygen transportation, iron depletion may impair aerobic physical performance. In iron depletion without anemia, the hemoglobin value is above a specified cutoff point for anemia and the oxygen carrying capacity of blood is not expected to be compromised. However, impairment of the ability to use oxygen may still exist. Animal studies have shown that iron deficiency without anemia can reduce endurance capacity and spontaneous physical activity[5-10]. It has been reported that iron depletion without anemia can decrease VO_2max in young women after control of fat-free mass (FFM)[11]. Thomas *et al.* have reported that ID can reduce the endurance capacity of untrained women by increasing energy expenditure (EE) and percentage of maximal oxygen uptake[12-13].

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It has been shown that iron supplementation significantly enhances maximal work capacity and endurance capacity[14]. To cope with the problem, this study was conducted in a school for migrant children located in the suburbs of Beijing, China, and designed to investigate the effect of ID of different stages on physical performance and habitual activity in school students at the age of 11-14 years.

SUBJECTS AND METHODS

Subjects

A total of 543 school students (328 boys and 215 girls) at the age of 11-16 years voluntarily underwent a screening test of IDA and ID[15]. Volunteers who were unhealthy or consumed medicine/nutrient supplements were excluded. Subjects were selected randomly according to their iron status and by doing physical exercises. All the physical exercises were asked to be finished in 3 days, and 91 students who were finally selected after the test were divided into three groups: deficient group with 15 boys and 15 girls (both Hb and serum ferritin levels were below normal range), marginal group with 16 boys and 15 girls (Hb level was within normal range, but SF level was lower than normal range) and adequate group with 15 boys and 15 girls (both Hb and SF levels were within normal range). The study protocol was reviewed and approved by the Ethical Committee of the Institute of Nutrition and Food Hygiene, Chinese Center for Disease Control and Prevention. Volunteer forms were obtained from each subject and their guardian.

Measurements

Iron status measurements Hb was measured as previously described[16]. Blood samples were taken from the antecubital vein of fasting subjects and centrifuged at 3000 rpm for 20 min and stored at –20 ℃ for determination of of serum iron (SI), SF, and sTfR. SI was detected with RANDOX SF kit (RANDOX Company, England) using an auto-biochemical analyzer (SYNCHRON CX4PRO/BECKMAN, BECKMAN CO., USA) following the standards and calibrating reagents provided by RANBOX Company[17], SF was detected by flame atomic absorption spectrophotometry[18], and sTfR was detected by ELISA at 450 nm, corrected at 540 nm, using a Bio-Rad microplate manager spectrophotometer (R & D Sysem, Inc., America).

Body size and composition Body weight and height were measured to the nearest 0.1 kg and 0.1 cm, respectively. The weight of clothes was determined separately and substracted from the total weight. Body fat and FFM were assessed by densitometry (Institute of Sports Sciences under the State Sport General Administration) as previously described[19]. Body density and percentage of body fat were estimated from skinfolds using the two site equations (bicep and subscapular)[20-21].

Physical performance Physical performance was assessed by Motion Function Evaluation and Technical Analysis Key Laboratory of Capital Institute of Physical Education, Beijing, China, with an electrically braked bicycle ergometer (Corival, Lode BV, Groningen, Netherlands). All physiological and performance tests were conducted at a temperature of 19-21 ℃. The foot-bar position of the kayak ergometer was adjusted to resemble the paddler's own kayak prior to each test. Ventilation of oxygen (VO_2) and carbon dioxide (VCO_2) was measured using a portable cardiopulmonary breath-by-breath calorimetry system (MetaMax 3B, Cortex Biophysik, Leipzig, Germany). Heart rate (HR) was calculated continuously throughout the test with a Polar heart rate monitor (Polar A1, Polar Electro, Kempele, Finland). The mechanically braked ergometer has a digital readout of the pedal revolutions per minute. Concentrations of oxygen and carbon dioxide in expired air and volume of expired air were directed to the computer for breath-by-breath on-line calculation of O_2 consumption (VO_2), CO_2 production (VCO_2), respiratory exchange ratio (RER, VCO_2/VO_2) and minute ventilation.

Subjects were instructed not to eat or drink soda or any beverage containing caffeine within 3 hours before the test. Testing was started with a 3-min warm-up at 50 W and a pedaling rate of 60 rpm. The workload was increased by 25 W every 3 min until VO_2 stopped increasing or the subject could no longer maintain a rate of 60 rpm. VO_2max was achieved if two of the following criteria were met: VO_2 <150 mL with an increase in workload, RER >1.10, or maximum HR (HRmax)=within normal range ±10 beats of age-predicted maximum (220-age in yr)[22-23]. Maximum oxygen uptake (VO_2max) was determined as the highest 30-s value obtained during the test.

Twenty-four hours heart rate monitoring Minute-by-minute HR was recorded in free-living situations. The HR monitor consists of a transmitter snapped into a chest electrodes and a light weight receiver worn at the waist. The transmitter detects the heart signal and sends an electrical impulse to the circuitry of the pulse monitor where each HR interval is timed. HR and time are recorded in memory every 60 seconds. Each subject was fitted with the HR monitor (RS 400, Polar Electro, Kempele, Finland) early in the morning until it was removed by the subject at the same time next day. All the subjects were asked to participate in their normal daily activities. Two observers were selected from the teachers and trained to use the HR monitor and record fall in the physical-activity diary. During the observed day, they regularly checked whether the HR monitor functioned normally.

The average net HR was cacluated as follows: HR minus baseline HR divided by the number of valid data points. Baseline HR was calculated by averaging the lowest HR and all HRs within 3 beats of the lowest HR. The number of total minutes spent at or above 60% heart rate reserve (HRR) using predicted HRmax (220-age) was also computed as aerobic activity, which served as an index of activity at or above the aerobic training threshold. The figure depicts typical telemetry data collected for each child[24]. Physical education class, music class and practice course were excluded. EE was calculated as previously described[25].

Queationnairs Dietary information was obtained using a validated food frequency questionnaire with reference to the food records provided by the school cafeteria for resident students. For non-resident students, dietary information was obtained using a food frequency questionnaire filled in by their parents. The intake of dietary iron and other nutrients was calculated from the Chinese Food Composition Tables[26].

Physical activity level was assessed with a frequency questionnaire to obtain a physical activity score for each subject. Questions included types of activities, intensity or number of times of participation per week, number of workouts to a sweat per week, and duration of each episode. The activity level of the subjects was measured by summing the products of intensity scores and amount of time spent each week participating in all activities reported. The validity of this method was supported by the correlation between physical activity and VO_2max (r=0.499, P=0.013)[11,27]. The physical activity data showed a skewed distribution, and statistical analysis was performed on logarithmically transformed data.

Statistical Analysis

Data were examined to verify normality of distribution. One-way analysis of variance was used to test groups. Then, unpaired t test was used to determine difference between groups. Statistical significance was indicated, and $P<0.05$ was considered statistically significant. Data were expressed as $\bar{x}\pm s$. All statistical analyses were performed using SAS verson 8.01.

RESULTS

Some characteristics of the subjects are given in Table 1. The age of the subjects in the three groups was similar. No significant difference was found in weight, height, BMI, percentage body fat or FFM for both genders among the 3 groups, neither was in non-resident students.

TABLE 1

Body Size and Composition in Study Groups ($\bar{x}\pm s$)

	Boys			Girls		
	Adequate (n=15)	Marginal (n=16)	Deficient (n=15)	Adequate (n=15)	Marginal (n=15)	Deficient (n=15)
Age (y)	13.27±0.80	13.00±0.97	12.67±0.90	12.60±0.63	12.80±1.01	12.80±0.77
Weight (kg)	44.87±5.20	43.42±6.92	43.24±6.10	41.24±6.10	42.71±8.12	41.45±9.02
Height (cm)	154.87±5.50	153.65±6.97	151.73±6.76	152.07±4.24	153.00±7.63	153.45±7.22
BMI (kg/m^2)	18.67 ±1.52	18.36±2.38	18.67±1.60	17.77±2.03	18.15±2.58	17.43±2.67
Body Fat (%)	17.84±2.02	17.66±2.83	17.54±1.71	18.63±1.77	18.40±2.06	18.50±2.93
FFM (kg)	36.79±3.69	35.60±4.67	35.60±5.26	33.48±4.42	34.73±5.86	33.56±6.14

Note. BMI= body mass index; FFM= fat-free mass; deficient=both Hb and serum ferritin levels were below normal range; marginal= Hb levels were within normal range, but SF levels were lower than normal range; adequate= both Hb and SF levels were within normal range.

The general hematological data in three groups are shown in Table 2. Because the distribution of SF values was skewed, statistical analysis of SF and sTfR was carried out on logarithm transformed values. The Hb value of the marginal group was in normal range, although it was 5% lower than that of the adequate group. The SF values were lower in the deficient group than in the marginal group. However, no significant difference was found in SF value between the two groups.

TABLE 2

Evalutation of Hematological Status in the Subjects with Deficient, Marginal, or Adequate Iron ($\bar{x} \pm s$)

	Boys			Girls		
	Adequate (*n*=15)	Marginal (*n*=16)	Deficient (*n*=15)	Adequate (*n*=15)	Marginal (*n*=15)	Deficient (*n*=15)
Hemoglobin (g/L)	139.40±3.78	131.94±3.53**	112.13±5.83**	135.87±5.51	128.20±4.07**	113.00±5.26**
Serum Ferritin (μg/L)	42.33±15.04	10.74±1.91**	4.98±1.67**	39.41±13.64	9.54±1.54**	4.65±1.58**
sTfR (nmol/L)	21.68±3.83	29.29±4.71**	36.94±8.30**	22.64±3.54	26.56±4.29*	35.26±6.48**
Serum Iron (mg/L)	0.88 ±0.09	0.81±0.05*	0.75±0.12**	0.86±0.07	0.80±0.05*	0.73±0.12**

Note. $^{**}P<0.01$, $^{*}P<0.05$ *vs* adequate group (unpaired *t* test).

In order to observe the effect of anemia or iron deficiency without anemia on physical performance, we compared the combination values of the marginal, adequate, deficient and marginal groups. Physical responses are presented in Table 3. No significant difference was found in VO_2max and VO_2max/W (VO_2max/weight) between the iron-marginal and iron-adequate groups. However, there was a significant difference in VO_2max/FFM for girls (P=0.024) but no such a dirrerence was found for boys (P=0.28) between the two groups. Severe iron deficiency significantly affected all physical performance measurements except for HRmax. Maximum work time of iron-deficient subjects was significantly lower in iron-marginal and iron-adequate subjects.

TABLE 3

Physical Performance Associated with Deficient or Marginal Iron Status ($\bar{x} \pm s$)

		Deficient *vs* Marginal and Adequate		Marginal *vs* Adequate	
		Marginal + Adequate	Deficient	Adequate	Marginal
VO_2max (L/min)	Boys	1.63±0.20	1.29±0.25**	1.68±0.16	1.58±0.23
	Girls	1.54±0.19	1.25±0.25**	1.57±0.14	1.51±0.23
VO_2max/weight ($mL \cdot kg^{-1} \cdot min^{-1}$)	Boys	37.22±4.33	30.25±5.47**	38.03±5.86	36.46±2.04
	Girls	37.08±4.02	30.42±4.32**	38.49±4.10	35.57±3.52
VO_2max/FFM ($mL \cdot kg^{-1} \cdot min^{-1}$)	Boys	45.24±4.86	36.72±4.56**	46.23±6.50	44.30±2.41
	Girls	45.48±4.54	37.28±4.84**	47.27±4.51	43.69±3.94*
Maximum Work Time (mins)	Boys	14.07±1.40	11.51±1.40**	14.52±1.22	13.66±1.46
	Girls	13.75±1.40	10.39±1.90**	14.21±1.08	13.28±1.56
HRmax ($beat \cdot min^{-1}$)	Boys	201.81±2.55	201.33±2.94	202.47±2.00	201.19±2.90
	Girls	201.73±2.94	201.33±3.75	201.80±3.63	201.67±2.16

Note. VO_2max=maximum oxygen consumption; FFM=fat-free mass; HRmax=maximum heart rate. $^{**}P<0.01$ *vs* iron marginal and adequate groups (unpaired *t* test); $^{*}P<0.05$ *vs* iron adequate group (unpaired *t* test).

Recordings of 24-hour HR are present in Table 4. No significant difference was found in net HR or EE at work (at class). However, during leisure time, iron-deficient subjects spent less time on aerobic activity (10.77 min for boys, 10.05 min for girls), and net HR (22.57±4.20 beats/min for boys, 22.86±4.58 beats/min for girls), and their EE was also significantly lower. The iron-adequate groups spent much more time on aerobic activity in leisure time. The results obtained from physical questionnaires also showed that sport and leisure indexes were significantly higher in the iron-marginal and iron-adequate groups then in the iron-deficent groups. The subjects in the iron-deficent groups were less active than those in the other two groups, and preferred to spend more time on rest or on non-sport activities, like watching TV, sleeping, and feeling fatigues (Table 5). Correlations between net HRL (net HR at leisure time) and Hb, log SF, sTfR, body weight, FFM, and sport activity level are shown in Table 6. Hb, log SF, sTfR, and sport index were correlated with net HRL (*P*<0.05).

TABLE 4

Probability of Differences in Physiological Characteristics of the Subjects with Deficient or Marginal Iron Status

	Boys		Girls	
	Deficient *vs* Marginal+Adequate	Marginal *vs* Adequate	Deficient *vs* Marginal+Adequate	Marginal *vs* Adequate
Net HR of Work (min)	0.6481	0.8263	0.6004	0.7484
EE of Work (kJ/d)	0.1573	0.9410	0.8170	0.9865
Net HR at Leisure (beats/min)	0.0002	0.4888	0.0001	0.3313
EE at Leisure (kJ/d)	0.0254	0.5009	0.0093	0.3384
Aerobic Activity Time (mins)	0.0055	0.4895	0.0084	0.4892

Note. VO_2max=maximum oxygen consumption; HR=heart rate; EE=energy expenditure.

TABLE 5

Probability of Differences in Habitual Physical Activity Associated with Deficient or Marginal Iron Status

Physical Activity Index	Boys		Girls	
	Deficient *vs* Marginal +Adequate	Marginal *vs* Adequate	Deficient *vs* Marginal + Adequate	Marginal *vs* Adequate
Work	0.8933	0.9807	0.7621	0.8163
Sport	0.0022	0.9005	0.0061	1.0000
Leisure	0.0060	0.8790	0.0014	0.8597

TABLE 6

Correlations between Net HR at Leisure Time and Selected Characteristics

	Boys		Girls	
	r	*P*	*r*	*P*
Hemoglobin	0.460	0.0013	0.637	<0.0001
Log Serum Ferrritin	0.412	0.0044	0.522	0.0002
Log sTfR	-0.307	0.0383	-0.504	0.0004
Body Weight	0.118	0.437	-0.084	0.5827
FFM	0.132	0.3836	-0.091	0.5513
Sport Index	0.686	<0.0001	0.311	0.0377

Note. FFM=fat-free mass.

DISCUSSION

This study was to examine the effect of different iron deficiency stages on adaptation to physical activity in schoolchildren. SF and Hb concentrations were used to identify subjects with depleted iron stores and IDA. It has been reported that marginal iron deficiency without anemia can impair aerobic adaptation, endurance, habitual activity and productivity[3-4, 12-14, 28-29]. In our study, VO_2max in the marginally iron-depleted but nonanemic subjects was not significantly lower than in the iron-adequate subjects and there was some difference between the boy and girl subjects. FFM is probably a better determinant of VO_2max than body weight because lean body tissues use most oxygen consumed during exercise whereas fat mass is inactively metabolized[11,30]. As for VO_2max/FFM between the iron-marginal and iron-adequate groups , there was a significant difference in girls, but no such difference in boys (*P*=0.0236). The possible explanation for such a difference is that boys in the iron-marigial group had a lower percentage of body fat (17.68±2.21) than girls (18.51±2.26) (Table 1). IDA affects physical capacity by reducing available oxygen from tissues, which, in turn, affects cardiac output and reduces the efficiency of oxygen exchange in muscle and myoglobin[28]. Our study also showed that the maximum work time for the iron-deficient group was significantly lower than that for the iron-marginal and iron-adequate groups (*P*<0.0001), which was approximately 18% lower both in boys and girls. The maximum work time for iron-marginal group was slightly lower than for iron-adequate group, but the difference was not signigicant.

There is a good agreement between 24-h HR and oxygen uptake[31]. HR is linearly associated with energy expenditure. A whole-day HR monitoring is an objective and nonobtrusive method for measuring physical activity (*r*=0.50, *P*<0.001)[24]. The percentage of HRR is an indicator of $\%VO_{2R}$[32-33]. We excluded the high energy demand classes like physical education class, music class, and practice course when calculating the net HR and EE at work. The subjects had a same scheme at work (similar energy demand according to the time table). No significant difference was found in net HR and EE of boys and girls at work among the three groups (TABLE 4). Occupations such as clerical work, driving, domestic or office work, study and others with a university education do not requir high oxygen uptake. Such workloads can be easily supported by individuals even with low levels of Hb. Even severe anaemic individuals could meet energy demands with few or no adaptive changes[34]. Compaired with that of the iron-marginal and iron-adequate groups, the net HR of the iron-deficient group at leisure time was significantly lower and the subjects in the iron-deficient group spent less time on aerobic activity, suggesting that they were more inactive than those in the iron-marginal and iron-adequate groups. Habitual physical activity can be determined by physical activity at work or at leisure time, and sports at leisure time[27]. In this study, the net HR at leisure time was negatively related to the leisure index (*r*=-0.354, *P*<0.0157 for boys; *r*=-0.20, *P*<0.19 for girls) and positively related to the sport index (*r*=0.69, *P*<0.0001 for boys; *r*=0.311, *P*<0.0377 for girls) (Table 6). The aerobic activity time was correlated with Hb value (*r*=0.49, *P*<0.001 for boys; *r*=0.60, *P*<0.0001 for girls).

In summary, severe iron deficiency results in anemia and impairs physical performance and habitual physical activity. Marginal iron deficiency might decrease VO_2max/FFM in girls. Further study is needed to observe the long-term effect of iron deficiency.

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