Coll. Antropol. 39 (2015) 3: 575–582
Original scientific paper

Changes of Respiratory Exchange Ratio in Children and Adolescents: A Longitudinal Study

Željko Jeleč[1], Branka R. Matković[2], Ana Lebo[3], Dražen Jeleč[4] and Andro Matković[5]

[1] »Dr. Ivo Pedišić« General Hospital, Sisak, Croatia
[2] University of Zagreb, Faculty of Kinesiology, Zagreb, Croatia
[3] PLIVA Croatia Ltd, Zagreb, Croatia
[4] Roche d.o.o., Zagreb, Croatia
[5] »Merkur« University Hospital, Clinical Department of Diagnostic and Interventional Radiology, Zagreb, Croatia

A B S T R A C T

We conducted a longitudinal study to examine changes in the respiratory exchange ratio (RER) during progressively increasing body exertion in children and adolescents of female sex. In this analysis we only included 23 examinees for which we had all yearly measurements from examinee's age 9 years until 18 years of age. The data were analyzed according to the chronological and biological age. According to both criteria, the highest RER values were recorded at moments of maximum exertion and they did not increase with age. We found the highest RER values were in the year of the menarche. We interpret these results as related to the effect of estrogen. The beginning of sexual development involves a gradual increase in estrogen plasma concentrations. At one point serum levels of estrogen reach a level high enough to allow for maximum RER values, i.e. causing the optimum anaerobic capacity of the examinee. This threshold estrogen value varies between individuals.

Key words: *children, respiratory exchange ratio, substrate utilization*

Introduction

Respiratory exchange ratio (RER) is a ratio determined by dividing the amount of produced (exhaled) carbon dioxide and consumed (inhaled) oxygen. The same value measured at the cellular level represents the respiratory quotient (RQ). By determination of RER values, it is possible to estimate which of the main energy substrates is being utilized while performing certain task, *i.e.* physical activity.

Furthermore, RER values change depending on the type of energy substrate being metabolized, and they usually vary from 0.7 (indicating fat as the energy substrate which is predominantly utilized) to 1.0 (indicating carbohydrates as the energy substrate predominantly utilized). Unlike fat and carbohydrates, proteins play a minor role in energy metabolism, and their respective RER value is usually around 0.8.

Respiratory quotients for fat and proteins are lower than respiratory quotient for carbohydrates, largely due to the fact that major part of oxygen entering the metabolic processes together with fat and proteins is being used for binding with excess hydrogen atom, present in the molecules of those compounds. Thus, there is relatively less carbon dioxide produced compared to the amount of oxygen utilized. In persons with a normal, balanced diet, the mean RER value is 0.825[1].

Currently, there is lack of published studies that evaluate the changes of RER in children and adolescents during a longer period of physical activity. Furthermore, the results from the majority of research studies carried out are rather contradictory. Martinez and Haymes examined RER values in young girls (8 to 10 years) comparing them with women (20 to 32 years). They concluded, because the RER values were lower in girls, that girls rely more than women on fat utilization during 30-min run on treadmill run at 70% VO_2 max after a 12-hour fast. Some other studies conducted on boys and adult males also have reported lower RER values in boys than in adults during submaximal exercises. On the other hand, Rowland and

Received for publication March 23, 2014

Rimany or Macek and his co-workers did not find lower RER values in children compared with adults[2-6].

Despite the fact that RER have some limitations when used to establish substrate utilisation[7] it is extensively used to describe substrate oxidation in children. Based on different studies published to date it is the general consensus that the lower values of RER observed in children indicates that the children utilize more fat for energy at a given exercise intensity[8-10].

Thus, the aim of this study was to determine the respiratory exchange ratio (RER) changes during progressive exercise on the treadmill stress test in girls of nine to eighteen years old. RER values will be analyzed separately for each chronologic and biologic age and differences with respect to RER between these age groups will be sought.

Materials and Methods

The present study used a sample of subjects from the population of healthy school children from Zagreb. The sample comprised 50 girls who were 8 years old at the time of enrolment into the study. The group of children was then followed up from the time they were 8 to 18 years and represented a chronologically homogenous group of girls. This was achieved due to the fact that the measurements were scheduled each year on the subjects' birthday or very close to that date. However, at the end of the study the final sample consisted of 23 girls. Their biological age was determined by the age of menarche. The subjects underwent standardized progressive exercise test on a treadmill during which RER was measured. The test took place between 10.00 and 13.00. Before it the girls were allowed to eat their usual breakfast, at least two hours before the exercise. The girls were asked not to perform any strenuous exercise 36 hours before the testing.

The measurements were divided into several stages: at rest, walking on the straight surface, four different levels of exercise workload (depending on the slope and speed on a treadmill) and after a 10-minute recovery period.

Initially, each test consisted of walking for four minutes on the straight surface, at the speed level of 1.6 km/h. This phase was followed by a 3 minute warming up period on a treadmill with 10% slope and at a speed level of 4.8 km/h. After completing the warming up period, the subjects were instructed to move to the next phase, which was the first level of exercise workload and consisted of running at a speed level of 8 km/h at the slope of 12%. The second level of exercise workload that followed next was at a speed level of 9.6 km/h and at a slope of 14%, the third consisted of a speed level of 12.8 km/h at a slope of 16%, while the fourth level included a speed level of 12.8 km/h and the slope of 18%.

The subjects were exposed to each of the four exercise levels for two minutes. During the three-minute warming-up phase and the four workload levels (2 minutes each), the consumed oxygen (VO_2), exhaled carbon dioxide (VCO_2) and respiratory exchange rate were recorded at 30-second intervals. We have chosen intervals of two minutes because it is well documented that the achievement in steady state may occur more quickly in children compared with adults[11].

The data obtained were analyzed by the standard statistical procedures in order to evaluate their basic characteristics: arithmetic mean, standard deviation and range between the minimal and maximal value. In addition, differences between the obtained RER values relative to chronologic age were analyzed by means of one-sided analysis of variance (ANOVA) with repeated measures (dependent variables), while for the biological age analysis of independent samples was used.

Results

During each annual measurement, which lasted 11 minutes in total provided the subject completed all phases of the stress test, respiratory exchange ratio (RER) was recorded every 30 seconds. By using this design, a total of 22 RER values were obtained during each annual mea-

TABLE 1
DIFFERENCES IN RER FOR VARIOUS PHASES WITHIN ONE ANNUAL MEASUREMENT, IN 10 CONSECUTIVE FOLLOW-UP YEARS, RELATIVE TO SUBJECT'S CHRONOLOGICAL AGE

	F	p
M 1	6.71	0.0001
M 2	5.96	0.0001
M 3	6.10	0.0001
M 4	5.81	0.0001
M 5	7.82	0.0001
M 6	6.15	0.0001
M 7	8.16	0.0001
M 8	5.29	0.0001
M 9	4.35	0.0001
M 10	4.03	0.0001
M 11	3.97	0.0001
M 12	8.65	0.0001
M 13	13.30	0.0001
M 14	14.49	0.0001
M 15	12.57	0.0001
M 16	17.14	0.0001
M 17	14.11	0.0001
M 18	12.40	0.0001
M 19	8.58	0.0001
M 20	3.90	0.001
M 21	3.56	0.01

M 1 – M 21 – phases within one annual measurement
F – F-ratio, p – statistical significance

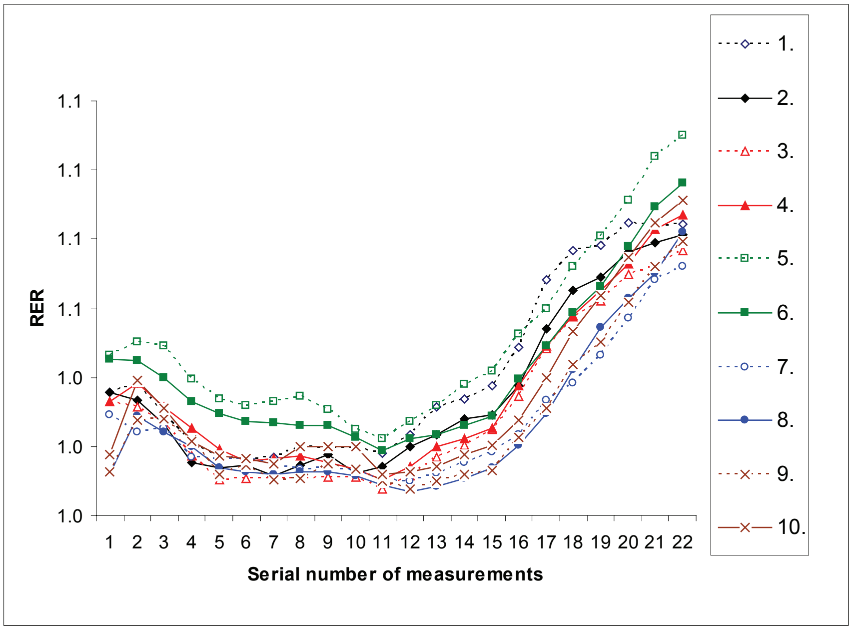

Fig. 1. Changes in RER relative to exercise workload (serial number of measurements, 1-22) and to subject's chronological age (linear plots 1-10). Linear plot designated as 1 represents the lowest chronological age (9 years), while the linear plot designated as 10 represents the highest chronological age (18 years).

surement. The results are presented both in figures and tables.

From the linear plots provided in the figures below, it can be seen that RER values initially declined mildly, reaching the lowest point in the phase 11 that corresponds to the second level of workload (5.5 minutes after the start of the test), i.e. the speed of 9.6 km/h and the slope of 14%. Following that point, RER values increased and reached the maximal value at the peak of exercise workload, *i.e.* in the last stage of measurement (Table 1, Figure 1).

From the shape of the linear plots provided, it can be concluded that RER values increased relative to an increase in the workload level to which subjects were exposed, however this increase was irrespective of the subject's chronological age.

Furthermore, by using a one-sided analysis of variance, a statistically significant difference was found between all phases of each individual measurement, regardless of the exercise workload. However, these differences were greater as the workload increased.

Figure 2 displays the relationship between mean values of RER for each given biological age and a phase of measurement. Similar to observed RER changes relative to chronological age, we observed a similar pattern in relation to biological age, with the initial discrete decline of RER values that occur with increased workload. The RER values declined until approximately half way through each measurement, and again started to rise from that point onwards, with a rising trend that lasted until the end of the test, *i.e.* until subjects reached maximal workload level. Interestingly, the RER value was the highest in the year of menarche (designated as year 0). Furthermore, the lowest RER value was recorded in subjects who had earlier onset of menarche.

Table 2 shows statistically significant differences across different age groups relative to biological age. The level of statistical significance was higher at the higher workload level.

The present longitudinal research showed that the maximal RER values were recorded at the maximal workload level, which was the expected outcome. Notably, this rising trend observed in RER values during the 11-minute measurement was not constant. In the earlier phases of each measurement, i.e. at the lower workload level, the finding of the initial decline in RER values can be explained by adjustment of subjects to experimental conditions under which the measurements were taken. The described mild decline in RER values was recorded during the first 5.5 minutes of the measurement (point 11 in the figures), which corresponds to the second level of exercise workload in which the subjects ran at the speed of 9.6 km/h and slope of 14%. Following this decline, the RER values started to increase proportionally with the increase in the level of exercise workload, and finally, at the point of peak exercise, the RER values exceed 1 for each chronological age. This finding can be attributed to lactic buffering and to shifting to anaerobic metabolism, which produces excess carbon dioxide as a by-product of bicarbonate system.

Furthermore, the lower RER values obtained at the beginning of each measurement can be explained by the lower workload level and subsequent utilization of fat as

TABLE 2
DIFFERENCES IN RER FOR VARIOUS PHASES WITHIN ONE ANNUAL MEASUREMENT, IN 10 CONSECUTIVE FOLLOW-UP YEARS, RELATIVE TO SUBJECT'S BIOLOGICAL AGE

	F	p
M 1	3.91	0.0001
M 2	2.22	0.022
M 3	2.25	0.02
M 4	1.99	0.042
M 5	1.49	0.151
M 6	1.79	0.07
M 7	1.81	0.068
M 8	0.95	0.487
M 9	2.69	0.006
M 10	2.48	0.01
M 11	1.72	0.086
M 12	2.11	0.031
M 13	2.48	0.01
M 14	3.50	0.0001
M 15	2.39	0.014
M 16	1.83	0.065
M 17	3.55	0.0001
M 18	7.88	0.0001
M 19	11.27	0.0001
M 20	18.47	0.0001
M 21	10.71	0.0001

M 1 – M 21 – phases within one annual measurement
F – F-ratio, p – statistical significance

the main energy substrate in the initial phases of the test. As the workload level increased, a corresponding increase in RER values was observed, in line with the metabolic shift to carbohydrates as the main energy substrate.

The above described changes in the mean RER values occur in each individual chronological age, however, an age-dependent increase in RER values was not observed. Namely, the highest RER value observed did not correspond to the highest chronological age. Interestingly, the highest RER value recorded during the study was in the fifth year of follow-up evaluation, which corresponds to the chronological age of 13 years.

In accordance with the previous findings, data analysis with one-sided ANOVA with repeated measures showed a statistically significant difference was found across all phases of individual measurements, regardless of chronological age (Table 1). This difference, however, increased with the increase in exercise workload level.

Similarly to analysis of chronological age, the processed and analyzed results relative to biological, i.e. physiological age of each subject demonstrate that for each age group the highest recorded RER value occurred at the maximal exercise level.

Same as in previous analysis, the rising trend in RER values was not constant; and followed a mild decline in mean RER values at the beginning of serial measurements. A subsequent constant increase started 5.5 minutes after the beginning of the measurements and continued to rise proportionally with the increase in the level of workload.

The initial decline, same as in analysis related to chronological age, can be explained by the adjustment time needed by subjects to adjust to experimental conditions in which measurements were taken. At the peak exercise level, RER values exceeded the value of 1 for each biological age, due to reasons explained earlier.

Figure 2 clearly demonstrates that the highest mean RER values were recorded in the year of menarche, whereas the lowest recorded values occurred in subjects of highest biological age, i.e. those subjects who had the earliest onset of menarche.

Discussion and Conclusions

In agreement with the previous findings and as expected, the obtained results demonstrated that increasing the exercise workload, energy metabolism shifted from predominant utilization of fat to a more significant utilization of carbohydrates. In particular, this shift became obvious in the year of menarche, with the maximal RER values recorded in that period. Thus, maximal utilization of carbohydrates as energy substrate occurred in the year of menarche, and increased proportionately with the increase in the level of workload.

In line with previous knowledge, the first occurrence of menstruation – menarche, is a relatively late stage of sexual maturation of a child and it usually occurs 2.3 years after the start of breast development, which according to Tanner indicates the beginning of sexual maturation. Typically, menarche occurs after the rapid growth spurt has been completed, i.e. 1 to 1.5 years following the peak velocity of growth.

According to Jenner et al.[12], who are cited in Borer's book »Advanced exercise endocrinology«[13], serum estradiol level starts to increase rapidly in the Tanner stage 2 of sexual maturation in girls. According to Tanner classification[14], the onset of menarche corresponds to transition between the Tanner stage 4 and Tanner stage 5, i.e. to the complete sexual maturity as judged by the breast development. Serum estradiol level increases from 37 pmol/l in Tanner stage 2 to approximately 220 pmol/l in Tanner stage 5 of sexual maturation[12], leading to a conclusion that this is the threshold concentration that needs to be achieved for menarche to occur. Serum estrogen levels in sexually mature women vary and usually are in the range of 10 to 400 pg/ml or 37 to1,468 pmol/l, depending on the phase of the menstrual cycle[15]. It should be noted, however, that estrogen effect depends not only on the serum concentration of this hormone, but also on other fac-

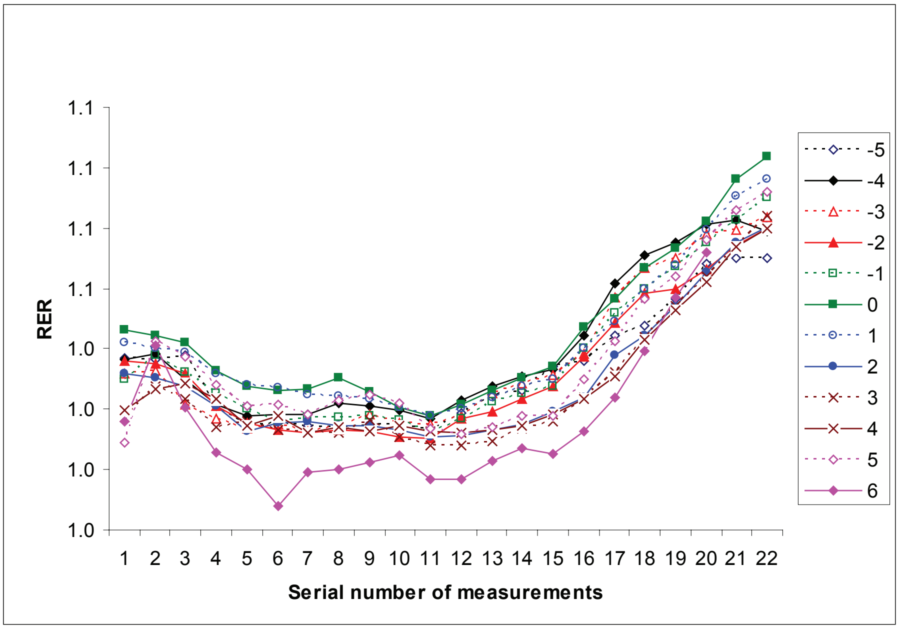

Fig. 2. Changes in RER relative to exercise workload (serial number of measurements, 1-22) and to subject's biological age (linear plots designated 5-6).

tors, such as the concentration of globulin to which estrogen binds, receptors and serum levels of other hormones.

In addition, it can be concluded that highest mean RER value achieved occurred after the estrogen level reached a certain level, a level that correlates well with the onset of menarche. This threshold concentration of serum estrogen varies considerably between individuals, but according to Jenner[12], its mean value is 220 pmol/l.

Apart from its effect on sexual organs, estrogen has an effect on other organs and physiological processes as well. It is well established that estrogens increase osteoblast activity in bones and that exposure to estrogen also causes epiphyseal and diaphyseal fusion of long bones. Likewise, estrogens contribute to mild elevation of total capacity of body metabolism and lead to a specific body composition, with larger amounts of fat deposited into subcutaneous tissues, resulting in the characteristic female body shape.

Significant amounts of sexual hormones, thus also estrogen, stimulate the secretion of growth hormone and thereby indirectly influence the growth process. According to Prader[16], there is a possibility of estrogens exerting anabolic effects, but only in conjunction with the growth hormone. Spadano et al.[17] found that resting metabolic rate is elevated at the time of menarche compared to 4 years after menarche and the authors suggested that this finding is positively correlated with the increased effect of growth hormone.

There are also findings in of elevated blood glucose level and impaired glucose metabolism caused by estrogens in susceptible patients. Some of the effects of progesterone on central nervous system lead to increased sensitivity of respiratory center to carbon dioxide[18].

Each of the above mentioned estrogen effects could be the cause and explanation of the results of this research. Osteoblast activity in bones, elevation of total energy expenditure, indirect effect on growth through stimulating secretion of growth hormone and possible anabolic effect can all lead to maximal RER values. Progesterone effect, evident in increased sensitivity of the respiratory centre to carbon dioxide, could lead to higher intensity of respiration, increased carbon dioxide release, which in turn leads to elevated RER values.

A question that remains to be partially unanswered is what caused the RER values to be maximal in the year of menarche, while in the years that precede and follow menarche, the increase in RER values does not correspond to age. As mentioned earlier, menarche is a relatively late event in pubertal development and its onset occurs after the growth spurt has been finished. Increased production and secretion of estrogen and progesterone is being registered during a longer time interval and it is not limited only to the year of menarche[19].

According to Guyton[1], increased secretion of estrogen occurs in puberty, with cyclic changes occurring during menstrual cycles, and further increase in secretion of estrogen is recorded during first few years of reproductive like. After that phase, gradual decline in secretion of estrogen occurs and eventually its cessation, i.e. menopause. Lee et al.[20] report on progressive increase in LH, FSH and estradiol levels during puberty and peaking at the time of menarche. After menarche, LH and FSH levels maintain at the levels seen in mature women, whereas estradiol concentration during luteal phase of menstrual cycle is slightly lower than expected.

Physical exercise of moderate to high intensity, to which a person is exposed during a limited time interval, is closely linked with the increased concentration of sexual hormones in plasma. In adult women, increase in plasma estrogen concentration is directly proportional to the intensity of physical stress and is more pronounced in luteal phase than in follicular phase of menstrual cycle. Increase in progesterone concentration is recorded only in luteal phase[21].

Increase in plasma concentration of sexual hormones related to physical stress can be explained by stress caused by haemoconcentration, slower degradation of hormones by the liver due to decreased hepatic perfusion, secretion of hormones from adrenal cortex and increased secretion of gonadal hormones due to catecholamine effect. Comparing the results of this research with those of other authors in the scientific literature, we observed a number of regular changes.

With the sexual maturation and under the influence of gonadotropins which increasingly start to be secreted at the beginning of puberty, estrogen plasma levels starts to rise. It was observed that estrogen levels as seen in the year of menarche increase anaerobic capacity of the subject *i.e.* make the subject more capable of enduring physical stress. Exposure of such a subject to physical stress of moderate to high intensity leads to increase in estrogen plasma concentration and to all positive estrogen effects on tissues and organs.

Within this context, it should be noted that an increased level of LDL (low density lipoproteins) and lower concentration of HDL (high density lipoproteins) can be explained by lower concentration of estrogen in menopause. Hormone replacement therapy with estrogen results with an increase in total HDL[22].

It can be concluded from this analysis that a better toleration of physical stress enables subjects to engage in physical activity of higher intensity. As an increase in estrogen level is directly proportional to the intensity of the physical stress, an increase in estrogen level will be greater, and thereby its positive effects.

Vihko and Apter[23] found in a research of 200 female subjects that subjects with the early onset of menarche maintain their higher levels of estradiol into the adult age (followed up until the age of 25 years) when compared to others. Likewise, it was found that subjects with the earlier onset of menarche also had higher levels of FSH and estradiol before the onset of menarche. Similar conclusions were made by Apter and Vihko[24] in his research carried out on 84 subjects.

Based on results of Vihko and Apter, as well as on results of the present research, a hypothesis can be made that in competitive sport in younger age groups better results are achieved by sportswomen with an earlier onset of menarche. Age groups are formed according to chronological age leading to a diverse biological ages seen in one such age group. This leads to a certain advantage of children with older biological age, due to described positive estrogen effect.

Conversely, based on the plethora of published studies, it can be concluded with a high degree of certainty that estradiol lowers, i.e. inhibits gluconeogenesis and glicogenolysis, while at the same time shifting metabolic process to increased utilization of lipids. This is caused by either a direct estrogen effect on enzyme activity[25,26] or indirectly, through effects of cortisol, growth hormone, catecholamines, glucagon and insulin[27,28]. Tarnopolsky et al.[29] came to a conclusion that women who are under physical stress at 75% $VO_{2\,max}$ oxidize significantly more lipids and less carbohydrates and protein in comparison to men. Bunt[30] cites an increase of both resting and labor metabolism caused by estradiol.

Wilmore et al.[31] studied the RER changes during physical stress in eumenorrhoeic and amenorrhoeic female runners. Measurements were taken during bicycle ergometer test and treadmill tests at three different intensities of exercise. During measurements at the treadmill at all three exercise levels, slightly higher RER values (of 0.02) were obtained in amenorrhoeic subjects. At bicycle ergometer test similar results were obtained, with RER values in eumenorrhoeic women being slightly higher only at the maximal exercise level. Interestingly, the results of the above mentioned studies are opposite to the results of the present research. A possible explanation lies within the fact that the above studies are carried out in adult women, whereas this study was carried out in pediatric population, including adolescents.

Besides positive changes in terms of increased levels of sexual hormones that develop after physical exercise and last for a shorter period of time, a delay of onset of menarche from one to several years was observed in girls who are actively engaged in sport activities. In particular, this is observed in ballet dancers, female athletes and female gymnasts. According to Frisch et al.[32] found that each year of training before the anticipated onset of menarche delays its onset for 5 months.

There are at least four different mechanisms reported as possible causes of development of primary amenorrhoea in sportswomen: specific energy depletion, changes in the stored body fat content, increased level of inadequate sexual hormones and increased level of stress hormones. Most likely, there is a combined effect of all these factors. A young sportswoman with amenorrhoea who also has eating disorder and osteoporosis is said to suffer from sportswomen triad syndrome.

However, there are completely opposite views on this issue. The fact that sports with the most prominent delay of menarche (dancing, gymnastics, running) require a specific physical constitution of sportswomen may lead to a conclusion that the observed delay of menarche could be result of screening by the trainer[33]. Some authors[34] argue that physically predisposed girls, who better meet the needs of a certain sport, are selected from the group of young sportswomen. These girls often had gentle constitution and usually were sportswomen of lower biological age.

In comparison to the most relevant and most cited research that investigated RER changes in females[2,5], the present study had one significant change. Subjects of this research were exposed to progressive physical exercise. In Rowland's research[5], measurements were carried out at the constant intensity of physical exercise of 63% $VO_{2\ max,}$ while the research from Martinez and Haymes[2] was conducted at two directions, also with the constant intensity of physical exercise: relative (70% $VO_{2\ max}$) and absolute (7.2 km/h). Likewise, the maximal duration of each individual measurement in this research was 11 minutes, while at Martinez' and Rowland's research it was 30 and 40 minutes, respectively.

This was a longitudinal research, i.e. the same cohort of female subjects were followed up during a period of 10 years, whereas in the previous two studies single measurements were undertaken in two different age groups, and the results later compared.

This research enrolled 23 female subjects who were followed up from the age of 9 to 18 years. In the research conducted by Martinez et al. there were two groups of 10 subjects with the mean age of 9.1 and 24.4 years. Rowland and Rimany[5] and Bonen et al.[27] conducted their research in two groups of 11 (mean age was 11.4 years) and 13 subjects (mean age was 27.1 years). Influence of chronological age on RER values was detected only in the study from Martinez et al. at the same level of relative workload, with the RER values being lower in younger research subjects. At the same level of absolute physical exercise and in the other two research studies, influence of subject's chronological age on RER changes was not found.

The two main and most relevant conclusions following the analysis and review of the obtained results of the present study are as follows: i) the highest mean RER value obtained was at the maximal exercise level, irrespective of the subjects' age; ii) the highest mean RER value was recorded in the year of menarche. The RER during the treadmill walking and running was not age dependent, not chronologically nor biological. The lowest RER values were found, in all years, around 40 to 60% of aerobic capacity which is in agreement with the findings of Jeukendrup and Wallis[35] who showed that peak fat oxidation rates occur between 40 and 50% of VO2max in untrained women.

REFERENCES

1. GUYTON AC, HALL JE, Medicinska fiziologija. (Medicinska naklada, Zagreb, 2012). — 2. MARTINEZ LR, HAYMES EM, Med Sci Sports Exerc, 24 (1992) 975. — 3. ASANO K, HIRAKOBA K, Respiratory and circulatory adaptation during prolonged exercise in 10- to 12-year old children and adults. In: IMARINEN J, VALIMAKI I (Eds) Children and Sport (Berlin, Springer-Verlag, 1984). — 4. EYNDE B, VAN GERVEN D, VIENNE D, VUYISTEKE-WAUTERS M, GHESQUIRE J, Endurance fitness and peak height velocity in Belgian boys. In: OSSEID S,CARLSEN K (Eds) Children and Exercise XIII (Champaign, Il, Human Kinetics, 1989). — 5. ROWLAND TW, RIMANY TA, Pediatr Exerc Sci, 7 (1995) 183. — 6. MACEK M, VAVRA J, NOVOSADOVA J, Eur J Appl Physiol, 35 (1976) 299. — 7. RIDDELL MC, J Appl Physiol, 117 (2008) 725. — 8. BOISSEAU N, DELAMARCHE P, Sports Med, 30 (2000) 405. — 9. RIDDELL MC, JAMNIK VR, ISCOE KE, TIMMONS BW, GLEDHILL N, J Appl Physiol, 105 (2008) 742. — 10. TIMMONS BW, BAR-OR O, RIDDELL MC, J Appl Physiol, 103 (2007) 995. — 11. ROWLAND TW, Children's Exercise Physiology (Champaign, Il, Human Kinetics, 2005). — 12. JENNER MR, KELCH RP, KAPLAN SL, GRUMBACH MM, J Clin Endocrinol, 34 (1972) 521. — 13. BORER KT, Advanced exercise endocrinology. (Human Kinetics, Champaign (IL), 2013). — 14. TANNER JM, Sequence and tempo in the somatic changes in puberty. In: GRUMBACH MM, GRAWE GD, MAYER FE, The control of onset of puberty (John Wiley and Sons, New York, 1974). — 15. MARTIN CR, Exercise physiology. (Oxford University Press, New York, 1978). — 16. PRADER A, Biomedical and endocrinological aspects of normal growth and development. In: BORMS J, HAUSPIE R, SAND A, SUSANNE C, HEBBLINCK M, Human growth and development. (Plenum Press, New York, 1984). — 17. SPADANO JL, BANDINI LG, MUST A, DALLAL GE, DIETZ WH, Am J Physiol Endocrinol Metab, 286 (2004) 456. — 18. GENUTH SM, Spolne žlijezde. In: BERNE RM, Levy MN Fiziologija. (Medicinska naklada, Zagreb, 1993). — 19. KIRCHENGAST S, BAUER M, Coll Antrop, 31 (2007) 419. — 20. LEE PA, XENAKIS T, WINER J, MATSENBAUGH S, J Clin Endocrinol Metab, 43 (1976) 775. — 21. BONEN A, LING WY, MACINTYRE KP, NEIL R, MCGRAIL JC, BELCASTRO AN, Eur J Appl Physiol, 42 (1979) 15. — 22. SCHAEFER E, FOSTER D, ZECH L, LINDGREN FT, BREWER HB, LEVY RI, J Clin Endocrinol Metab**,** 57 (1983) 262. — 23. VIHKO R, APTER D, J Steroid Biochem, 20 (1984) 231. — 24. APTER D, VIHKO R, Clin Endocrinol (Oxf), 22 (1985) 753. — 25. DURSTINE JL, HASKELL WL, Exerc Sport Sci Rev, 22 (1994) 477. — 26. SCHAEFER EJ, LAMON-FAVA S, SPIEGELMAN D, DWYER JT, LICHTENSTEIN AH, MCNAMARA JR, GOLDIN BR, WOODS MN, MORRILL-LABRODE A, HERTZMANK E, GORBACH SL, Metabolism, 44 (1995) 749. — 27. BONEN A, HAYNES F, GRAHAM T, J Appl Physiol, 70 (1991) 1917. — 28. BEMBEN D, BOILEAU R, BAHR J, NELSON R, MISNER J, Med Sci Sports Exerc, 24 (1992) 434. — 29. TARNOPOLSKY MA, ATKINSON SA, PHILLIPS SM, MACDOUGAL JD, J Appl Physiol, 78 (1995) 1360. — 30. BUNT J, Med Sci Sports Exerc, 22 (1990) 286. — 31. WILMORE J, WAMBSGANS K, BRENNER M, BROEDER C, PAIJMANS I, VOLPE J, WILMORE K, J Appl Physiol, 72 (1992) 15. — 32. FRISCH RE, GOTZWELBERGEN AV, MCARTHUR JW, ALBRIGHT T, WITSCHI J, BULLEN B, BIRNHOLZ J, REED RB, HERMANN H, J Am Med Assoc, 246 (1981) 1559. — 33. ROGULJ N, PAPIĆ V, ČAVALA M, Coll Antrop, 25 (2001) 611. — 34. KLENTROU P, Ann Nestle Eng, 64 (2006) 85. — 35. JEUKENDRUP AE, WALLIS GA, Int J Sporta Med, 26 (2005) S28.

B. R. Matković

University of Zagreb, Faculty of Kinesiology, Horvaćanski zavoj 15, Zagreb, Croatia
e-mail: branka.matkovic@kif.hr

PROMJENE OMJERA RESPIRACIJSKE IZMJENE KOD DJECE: LONGITUDINALNA STUDIJA

S A Ž E T A K

Cilj ovog istraživanja bio je utvrditi kretanje omjera respiracijske izmjene (RER) tijekom progresivnog opterećenja na pokretnom sagu kod djevojčica u dobi od devet do osamnaest godina. RER se analizirao za svaku kronološku i biološku dob te su se analizirale razlike između pojedinih dobnih kategorija. Istraživanje je provedeno na uzorku izabranom iz populacije školske djece grada Zagreba. Skupina od 50 djevojčica prvi puta je testirana kada su imale 9 godina i praćene su do svoje navršene 18. godine, a u konačni uzorak uzete su u obzir samo one ispitanice koje su redovito, svake godine pristupile mjerenju. Iz objektivnih ili subjektivnih razloga (bolest, promjena mjesta stanovanja) broj ispitanica je smanjen tako da u konačnoj obradi uzorak iznosio 23 ispitanice. Kako bi sve ispitanice bile izjednačene u odnosu na kronološku dob, kao dan mjerenja uziman je rođendan djeteta te su mjerenja izvođena tijekom čitave školske godine i ponavljana svake godine na dan što bliži rođendanu ispitanice. Biološku dob utvrđena je datumom pojave menarhe. Sve ispitanice podvrgnute su progresivnom maksimalnom testu opterećenja na pokretnom sagu. Pomoću aparature Ergopneumotest kontinuirano je određivan primitak kisika te oslobađanje ugljičnog dioksida na osnovu čega je izračunata vrijednost RER. Dobiveni rezultati obrađeni su standardnim statističkim postupcima kako bi se utvrdile njihove osnovne deskriptivne karakteristike. Razlike između dobivenih vrijednosti RER u odnosu na kronološku dob analizirane su metodom jednosmjerne analize varijance za ponovljena mjerenja (zavisne podatke), dok je kod biološke dobi primijenjena analiza za nezavisne uzorke. Dva glavna i najvažnija zaključka proizašla iz analize i pregleda dobivenih rezultata sadašnjeg istraživanja su kako slijedi: i) najviša dobivena srednja RER vrijednost je zabilježena na maksimalnim razinama opterećenja, nevezano za dob ispitanica; ii) najviša dobivena srednja RER vrijednost je zapažena u godini menarhe. RER vrijednost, zabilježena tijekom hodanja ili trčanja na pokretnoj traci, nije bila ovisna niti o kronološkoj niti o biološkoj dobi. Najniže RER vrijednosti su, za sve dobi, zabilježene između 40 i 60% aerobnog kapaciteta ispitanica što je u suglasnosti s rezultatima prijašnjih istraživanja koja su pokazala da su najviše stope oksidacije masti između 40 i 50% maksimalnog VO2 u netreniranih žena.