Rev Hosp Jua Mex 2016; 83(4): 136-141

Ergocycle spirometric characteristics and phase II $\dot{V}O_2$ kinetics during a ramp test in Mexican female walkers and swimmers

Javier Padilla-Pérez,* Daniel Reyes-Rendón,** Iván Rubio-Gayosso,*** Omar Villanueva-Becerril****

RESUMEN

Investigamos si entre grupos femeniles de caminata (C) y de nadadoras (N) altamente entrenadas poseedoras de un mejor desempeño deportivo diferente relativo (velocidad) podrían tener valores numéricos distintos de tiempo de respuesta exponencial media de la captación pulmonar de oxígeno ($\dot{V}O_2$) de fase II (TRMexp fase II $\dot{V}O_2$) de una prueba de rampa ciclo-ergo- espirométrica (incrementada) (25 Watts . 2 min^{-1}) hasta la fatiga volitiva. El tiempo de medición directa de la respuesta de $\dot{V}O_2$ (mL . min^{-1}) al ejercicio ergométrico se transformó en segundos. Dicho curso temporal fue modelado por ordenador utilizando técnicas de regresión lineal por mínimos cuadrados sobre los datos experimentales de $\dot{V}O_2$ de la prueba de rampa. Los signos vitales se midieron en nuestros voluntarios inmediatamente después de que estuvieron en reposo sentados durante 20 min. Se obtuvieron valores ergo-espirométricos y fisiológicos pico en el momento del esfuerzo máximo a 2,240 m de altitud. La velocidad (m . s^{-1}) se calculó como la distancia del evento deportivo competitivo (m) / tiempo total utilizado (s). A pesar de las diferencias de velocidad observadas ($P < 0.05$) entre C (3.08 ± 0.17) y N (1.36 ± 0.13) la antropometría general, los signos vitales, la ergoespirometría máxima y la cinética de la fase II del $\dot{V}O_2$ respecto a la masa corporal total (mL . min^{-1} . kg^{-1}_{MCT}) resultó similar ($P > 0.05$) entre los grupos (TRMexp fase II $\dot{V}O_2$, s: C = 14.2 ± 7.5, N = 24.5 ± 19.0) al igual que la $\dot{V}O_{2\ pico}$ (mL . min^{-1} . kg^{-1}_{MCT}: C = 46 ± 13, N = 44 ± 8). Se concluye que la $\dot{V}O_2$ no sería únicamente un parámetro determinante y que otras variables biofísicas también contribuirían al éxito en la marcha y en la natación.

Palabras clave. *Deportes aeróbico y acuático, desempeño deportivo; fase II de O_2, cinética del O_2, tiempo de respuesta media exponencial.*

ABSTRACT

We search if between female groups of highly trained both walkers (W) and swimmers (S) holding different relative best sport performance (speed) could have different numeric values of P_{haseII} $\dot{V}O_2$ exponential mean response time (MRTexp) from a ramp cycle-ergo-spirometric (incremental) test (25 Watts·2min^{-1}) until volitional fatigue. The direct measurement time course of $\dot{V}O_2$ response (mL . min-[1]) to ergometric exercise was transformed in seconds. This time course was computer-modelled using linear least squares regression techniques on experimental $\dot{V}O_2$ data from the ramp test. Vital signs were measured in our volunteers immediately after they were resting for 20 min in a seated position. Peak ergo-spirometric and physiological values were obtained at the moment of maximal effort at 2,240 m of altitude. Speed (m . s^{-1}) was computed as distance of the competitive sport event (m) / total time used (s). In spite on speed differences observed ($P < 0.05$) between W (3.08 ± 0.17) and S (1.36 ± 0.13) the general anthropometry, vital signs, maximal ergo-spirometry, and $_{Phase}$II $\dot{V}O_2$ relative to total body mass (mL . min^{-1} . kg^{-1}_{TBM}) kinetics resulted similar ($P > 0.05$) between groups (MRTexp, s: FWG = 14.2 ± 7.5, FSG = 24.5 ± 19.0) as well as did $\dot{V}O_{2\ peak}$ (mL . min^{-1}. kg^{-1}_{TBM}: W = 46 ± 13, S = 44 ± 8). It is concluded that $\dot{V}O_2$ would not solely be a

* Sección de Fisiología Humana, Escuela Superior de Medicina, Instituto Politécnico Nacional, Ciudad de México.
** Sección de Estudios de Posgrado e Investigación, Escuela Superior de Medicina, Instituto Politécnico Nacional, Ciudad de México.
*** Academia de Informática Médica, Escuela Superior de Medicina, Instituto Politécnico Nacional, Ciudad de México.
**** Escuela Superior de Medicina, Instituto Politécnico Nacional, Ciudad de México.

determinant parameter and that other biophysical variables would also contribute to race walking and sport swimming success.

Key words. *Aerobic and aquatic sports, sport performance, phase II O_2, O_2 kinetics, exponential mean response time.*

INTRODUCTION

All types of aerobic exercise are assumed to affect similarly the cardiovascular and pulmonary oxygen uptake ($\dot{V}O_2$). There are few studies of swimming, but complex responses to water-based exercise suggest its potential for differential effects.[1]

Physiological testing of the female athlete has grown dramatically, particularly in assessing the physiological predictors of performance.[2] It is well established that measures of sport performance and physiological characteristics[3] are influenced by the anthropometry of the body as a whole or of its exercising segments in particular sport[4] and the physiological variable change per unit of time, like the $\dot{V}O_2$ kinetics is also important to compare groups.[5] Such information is routinely used in an exercise context to determine performance potential, recommend exercise training intensities in sports, healthy promotion, physical therapy and rehabilitation, examine the effect of exercise training[6] and to establish causes for exercise intolerance.

Competitive race walkers are able to maintain their walking gait with exercise duration apart from a systematic increase in energy cost.[7]

Swimming differs in several important aspects from walking as follows: one difference entails the expenditure of energy to maintain buoyancy while simultaneously generating horizontal movement by using arms and legs, either in combination or separately; the requirements for overcoming the drag forces that impede a swimmer's forward movement; and the amount of drags depends on the fluid medium and the swimmer's size, shape, and velocity.[4] All of these factors contribute to a significantly lower mechanical efficiency in swimming than that from running[8] and perhaps from walking. Further, significant gender differences exist in body drag, mechanical efficiency, and net oxygen consumption during swimming;[8] for example, women buoyancy accounts for about a 30% lower energy cost than men and elite swimmers swim a particular stroke at a given velocity with a lower $\dot{V}O_2$ than relatively recreational swimmers but it is unknown compared walkers. Evermore, to date, few studies of competitive female race walkers has been published. The average female person is incapable of walking at speeds $\leq 2.0 - 2.5$ meters per second, but female competition walkers' technique allows them to reach speeds $< 3.9 - 4.2$ meters per second.9 However, the $\dot{V}O_2$ kinetics of this kind of walking has not been both measured and compared with that from swimmers at an altitude of 2,240 m in female Mexicans.

Purpose

The purpose of this article was to search for more evidence-based knowledge to understand the impact of sport on the females' performance by describing differences a variety of physiological variables and $\dot{V}O_2$ kinetics between elite female walkers and swimmers.

Hypothesis

If female walkers and female swimmers holding different relative best sport performance then they could have different P_{hase} II $\dot{V}O_2$ exponential mean response time numeric values from a ramp cycle-ergo-spirometric (incremental) test.

MATERIAL AND METHODS

Ethical approval

The Review Board for Research Using Human Subjects provided ethical approval and each subject gave their informed consent.

Voluntaries

Both highly trained female six endurance walkers, from the Mexican Olympic Committee AC, holding an individually best sport performance as follows: 10 km/50 min and 38 s, 10 km/52 min and 30s, 10 km/53 min and 23 s, 10 km/52 min and 0.02 s, 10 km/ 60 min, and 10 km/56 min and 15 s, as well as six swimmers, from Club Casa Blanca AC, holding an individually best sport performance as follows: 100 m/1 min and 20 s, 100 m/1 min: 1 s and 0.63 s, 100 m/1 min and 16 s, 100 m/1 min and 10 s, 50 m/39 s, and 100 m/1 min and 19 s.

General anthropometry

General anthropometry techniques were based on those of Martin and Saller[10] and Tanner.[11] Using the Carter and Heath method[12] and the respective skin folds measured on the right side of the body with the Harpenden plicometer, we determined the body adiposity and lean body mass. Body mass index (BMI) was calculated as $T_{otal}B_{ody}M_{ass}$ (in kg)/height (in m^2). Lean body mass (LBM) was calculated as total body mass (in kg) - body adiposity (in kg).

Ramp test

The determination of peak $\dot{V}O_2$ ($\dot{V}O_{2\ peak}$) during the last minute of each workload in each of the volunteers sited, were carried out (Medical Analyzer IL404) on an computerized electrically braked cycle ergometer (Collins, Pedal Mate) spirometric open circuit system.[13] Ramp function consisted in work rate increasing at a rate of 25W • 2 min^{-1} until exhaustion at 2,240 m of altitude. For all exercise tests, subjects were asked to maintain a pedal frequency of 60 rpm. The peak work rate (WRpeak) was taken as the highest 1-s value achieved immediately before fatigue. During the forced application of the ramp-type test, this exponential response becomes a straight line with a given slope and therefore its mean response time (MRTexp) is the sum of the delay time plus the characteristic response of the system (time constant) which is the time required for, say, $\dot{V}O_2$, 63% of its total response.[14] The heart rate (HR) was monitored electronically from the resting state and minute to minute during the maximal exercise test. Respiratory rate (breaths·min-1) and blood pressure were clinically measured in our volunteers immediately after they were resting for 20 min in a seated position. Blood pressure was measured through visual, palpatory and auscultatory observations using a stethoscope and a mercury column sphygmomanometer (Boum) in the athlete. Mean arterial pressure (MAP, mmHg) was calculated from SBP (mmHg) and DBP (mmHg) (MAP = SBP + (SBP-DBP)/3). The $PulO_{2\ peak}$ (mLO_2 • $beat^{-1}$) was calculated as $\dot{V}O_{2\ peak}$ (in mL • min^{-1})/HR_{peak} (in beats·min^{-1}). $\dot{V}O_{2\ peak}$ relative either to TBM or LBM (mL • min^{-1} • kg^{-1}) was calculated as $\dot{V}O_{2\ peak}$, (mL • min^{-1}) / TBM or LBM (in kg). $R_{espiratory}E_{xchange}R_{atio}$ peak was calculated as $\dot{V}CO_{2\ peak}$, (mL • min^{-1})/ $\dot{V}O_{2\ peak}$, (mL • min^{-1}). The speed (m • s^{-1}) was computed as distance of the competitive sport event (m)/total time used (s). Power indexpeak (W • $kg^{-1}{}_{TBM}$) was calculated as peak power (in Watts) / TBM (in kg). Peak $E_{stimated}H_{eart}R_{ate}$ (beats • min^{-1}) was calculated by the Kärvonen method.[15]

Modelling

The time course of $\dot{V}O_2$ response (mL • min^{-1}) to ergometric exercise was transformed in seconds. This time course was computer-modelled using linear least squares regression techniques on experimental $\dot{V}O_2$ data from the ramp test.[16]

Statistical analysis

The Student's t-test was used to determine if the mean values of the variables of interest from the walkers and swimmers were significantly different.[17] P value < 0.05 was considered statistically significant.

RESULTS

The present study adds to the body of knowledge in this field, highlighting the complex interaction among competitive walkers and swimmer athletes sport activity effects (such as similar $_{Phase}$II $\dot{V}O_2$ kinetics, among others) and performance in these events of different sports and different durations/intensities requiring widely divergent metabolic demands and skill techniques.

The walker and swimming groups ontransient pulmonary oxygen uptake relative to total body mass ($\dot{V}O_2$, mL • min^{-1} • $kg^{-1}{}_{TBM}$) response to ramp incremental exercise test is shown in figure 1 and that $\dot{V}O_2$ (mL • min^{-1} • $kg^{-1}{}_{TBM}$) in single walker subject is shown in figure 2.

As expected, speed from best sport performance resulted slow in the aquatic sport group (swimmers) compared the aerobic sport (walkers) (Table 1). However, the general anthropometry, vital signs, maximal ergo-spirometry and P_{hase}II $\dot{V}O_2$ relative to total body mass (mL • min^{-1} • $kg^{-1}{}_{TBM}$) kinetics (MRTexp, s) resulted similar between groups (Table 1). The MRTexp from the P_{hase}II $\dot{V}O_2$ relative to total body mass was used expecting to be related with the speed achieved by our athletes, directly reflecting the body's capacity to transfer chemical energy from the enzymes and coenzymes during energy metabolism into mechanical work; however, this was not the case.

DISCUSSION

The ramp incremental exercise tests in which the external work rate is increased rapidly until the participant reaches exhaustion permits not only in the evaluation of exercise capacity in athletes and healthy volunteers but also in defining the physiological limitations to exercise performance in disease.[18] It can provide important information on the dynamic adjustment of oxidative metabolism following a 'step' increase in metabolic because the rate at which $\dot{V}O_2$ rises (i.e. the $\dot{V}O_2$ kinetics) during such exercise is another parameter of aerobic fitness, which is relevant both in health and disease and which can also be used to differentiate central *vs.* peripheral limitations to exercise performance.[18]

Competition walkers achieve high yet uneconomical rates of movement because they use a distinctive modified walking technique that constrains the athlete to certain movement patterns regardless of walking speed allowing them variations in walking economy contribute more to successful performance than in competitive running.[19] Activities with substantial drag force that resists movement like in swimming, mechanical efficiency falls considerably below 20%. Competitors in these sports focus attention on reducing drag by improving hydrodynamics through alterations in equipment and technique towards improvement in efficiency of success.

In this study, we observed similar maximal physiological characteristics in walkers and swimmers from a ramp test but walkers' speed was 1.72 s fast compared that from swimmers, that could be explained in part because walking is an aerobic sport and swimming is an aquatic one[9,19] and also one does not perform endurance exercise at $\dot{V}O_2$ max but in this work 10 km walkers and 100 m swimmers performed ergometer exercise at similar P_{hase}II $\dot{V}O_2$ kinetics. Our failing to demonstrate different P_{hase}II $\dot{V}O_2$ kinetics between walker and swimmer groups is in agreement with the lack of relationships observed between $\dot{V}O_2$ kinetic parameters and time trials over 50- and 400-m crawl, and also 100 m in swimmers by Rodríguez, *et al.*,[20] because according to them other possible explanations should be considered; for example, swimming shorter distances, may not be as dependent on systemic oxygen delivery as endurance running or cycling. There are differences in training intensity that may have played greater role in improving swimming performances6 probably increasing mitochondrial muscle efficiency, greater muscle buffering, and the ability to tolerate lactic acid production or improved oxygen flux to the exercising muscles.[20,21] For example, despite the short duration of an event of 100 m swimming performance, the aerobic energy contribution covers about 50% of total metabolic energy liberation, meaning that both aerobic and anaerobic energy processes should be developed to improve the 100 m swimming performance.[21]

CONCLUSIONS

These results indicate that of the variables observed in this study, in spite that the only biophysical difference between females walkers and swimmers best sport performance, both their physiological characteristics and P_{hase}II $\dot{V}O_2$

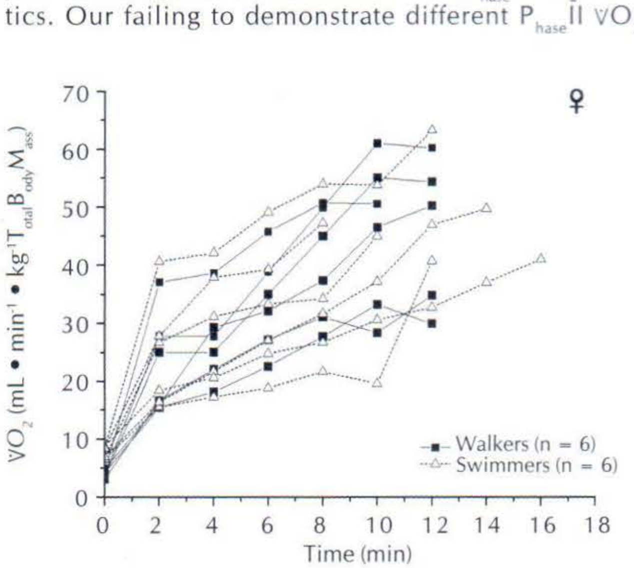

Figure 1. *Groups ontransient pulmonary oxygen uptake relative to total body mass ($\dot{V}O_2$, mL • min^{-1} • kg^{-1} $_{TBM}$) response profiles to cyclo-ergometer ramp incremental exercise test (25Watts • 2min^{-1}). Data points (symbols) are $\dot{V}O_2$ (experimental data) measured during the last minute of each workload in each of the volunteers. The six subjects maximal exercise from each group (6) are displayed.*

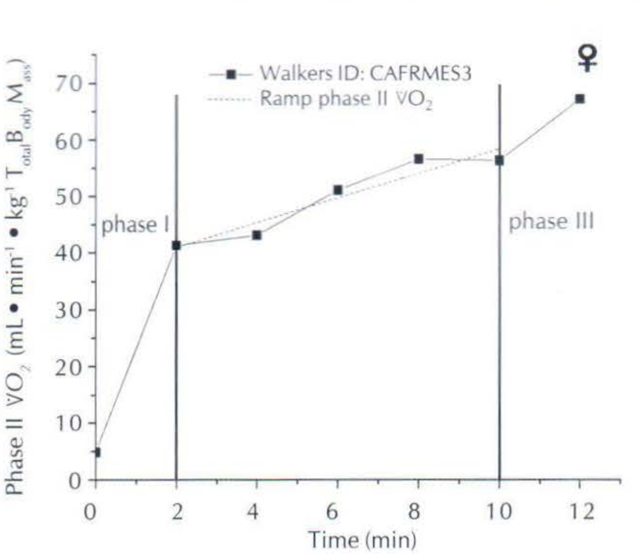

Figure 2. *Ontransient p_{hase}II pulmonary oxygen uptake relative to total body mass ($\dot{V}O_2$, mL • min^{-1} • kg^{-1} $_{TBM}$) in single walker subject to cyclo-ergometer ramp incremental exercise test (25Watts • 2 min^{-1}). Data points (symbols) are $\dot{V}O_2$ (experimental data; fine dotted line corresponds to p_{hase}II $\dot{V}O_2$) measured during the last minute of each workload in the volunteers. The six subjects maximal exercise from each group (6) are displayed. ID: subject identification.*

Table 1. Subject characteristics, physiological indices, performance level and ramp phase II $\dot{V}O_2$ kinetics.

	Walkers (n = 6)	Swimmers (n = 6)
General anthropometry		
Age, years	19.83 ± 2.32	18.67 ± 7.17
Stature, cm	159.00 ± 5.18	161.50 ± 7.53
$T_{otal}B_{ody}M_{ass}$, kg	50.08 ± 3.50	55.45 ± 9.15
$B_{ody}M_{ass}I_{ndex}$, kg • m^{-2} $T_{otal}S_{urface}A_{rea}$	31.49 ± 1:86	34.21 ± 4.11
$B_{ody}A_{diposity}$, %	14.64 ± 1.50	15.73 ± 1.90
$L_{ean}B_{ody}M_{ass}$, kg	42.74 ± 2.92	47.22 ± 6.70
Vital signs		
$H_{eart}R_{ate}$, beats • min^{-1}	65.17 ± 6.82	66.00 ± 8.30
$R_{espiratory}R_{ate}$, breaths • min^{-1}	17.67 ± 1.97	20.17 ± 4.02
$S_{iastolic}B_{lood}P_{ressure}$, mmHg	101.33 ± 4.60	109.83 ± 8.73
$D_{iastolic}B_{lood}P_{ressure}$, mmHg	64.17 ± 4.92	68.33 ± 9.83
$M_{ean}A_{rterial}P_{ressure}$, mmHg	76.56 ± 4.41	82.17 ± 8.36
Peak ergo-spirometry		
Power, Watts • 2 min^{-1}	158.33 ± 20.41	166.67 ± 51.64
$P_{ower}I_{ndex}$, W • kg^{-1}_{TBM}	3.19 ± 0.57	3.05 ± 0.97
$H_{eart}R_{ate}$, beats • min^{-1}	186.50 ± 24.80	183.33 ± 15.06
$E_{stimated}H_{eart}R_{ate}$, beats • min^{-1}	200.17 ± 2.32	201.33 ± 7.17
$\dot{V}O_2$, l • min^{-1}	2.29 ± 0.59	2.40 ± 0.53
$\dot{V}O_2$, mL • min^{-1} • kg^{-1}_{TBM}	46.17 ± 13.09	43.44 ± 8.10
$\dot{V}O_2$, mL • min^{-1} • kg^{-1}_{LBM}	54.06 ± 15.30	50.79 ± 9.14
$\dot{V}CO_2$, mL • min^{-1}	2.06 ± 0.30	2.15 ± 0.40
$\dot{V}$, e, l • min^{-1}	79.34 ± 21.42	82.03 ± 21.46
$P_{ulse}O_2$, mLO_2 • $beat^{-1}$	12.28 ± 3.20	13.27 ± 3.64
$R_{espiratory}E_{xchange}R_{atio}$	0.94 ± 0.21	0.91 ± 0.16
Best sport performance		
Speed, m • s^{-1}	3.08 ± 0.17[a]	1.36 ± 0.13[b]
P_{hase}II $\dot{V}O_2$ (mL • min^{-1} • kg^{-1}_{TBM}) kinetics		
$E_{xponential}M_{ean}R_{espnse}T_{ime}$, s	14.23 ± 7.45	24.50 ± 18.92

Values are mean ± SD. $\dot{V}O_2$: pulmonary oxygen uptake. $\dot{V}$, e: minute expired ventilation. $a \neq b$ t-$test_{2\alpha}$ ($t = 20$, $p < 0.001$).

relative to total body mass kinetics in terms of the exponential mean response time resulted similar to each other, meaning that the $\dot{V}O_2$ would not solely be a determinant parameter and that other variables would also contribute to race walking success.

ACKNOWLEDGEMENTS

We express our gratitude to all the athletes, coaches, staff and authorities of the Mexican Olympic Committee, A.C., and Club Casa Blanca (Eng. Francisco Javier Cabrera Ortíz, Escuela Superior de Ingeniería Mecánica y Eléctrica del IPN) for their cooperation and for the facilities they provided in The facilities to their worthy position.

This work was possible thanks to the experimental development of the research projects supported by the IPN (SIP: 20161606, EDD) and the Consejo Nacional de Ciencia y Tecnología (CONACyT: 23151)

Daniel Reyes Rendón is Medical Student (folium number: 2015510402) at the Escuela Superior de Medicina, Instituto Politécnico Nacional (IPN).

There are not competing interests.

REFERENCES

1. Cox KL, Burke V, Beilin LJ, Puddey IB. A comparison of the effects of swimming and walking on body weight, fat distribution, lipids, glucose, and insulin in older women–the

Sedentary Women Exercise Adherence Trial 2. Metabolism 2010; 59(11): 1562-673.
2. Burrows M, Bird SR. The physiology of the highly trained female endurance runner. Sports Med 2000; 30(4): 281-300.
3. Murphy PC, Cuervo LA, Hughson RL. A study of cardiorespiratory dynamics with step and ramp exercise tests in normoxia and hypoxia. Cardiovasc Res 1989; 23(10): 825-32.
4. Åstrand P-O, Rodahl K. Textbook of Work Physiology. 3rd Ed. N.Y. USA: McGraw-Hill; 1986.
5. Atkinson G, Davison RC, Nevill AM. Performance characteristics of gas analysis systems: what we know and what we need to know. Int J Sports Med 2005; 26(Suppl. 1): S2-S10.
6. Mujika I, Padilla S, Pyne D. Swimming performance changes during the final 3 weeks of training leading to the Sydney 2000 Olympic Games. Int J Sports Med 2002; 23(8): 582-7.
7. Brisswalter J, Fougeron B, Legros P. Variability in energy cost and walking gait during race walking in competitive race walkers. Med Sci Sports Exerc 1998; 30(9): 1451-5.
8. Toussaint HM, de Groot G, Savelberg HH, Vervoorn K, Holander AP, Van Ingen Schenau GJ. Active drag related to velocity in male and female swimmers. J Biomech 1988; 21(5): 435-8.
9. Menier DR, Pugh LG. The relation of oxygen intake and velocity of walking in competition walkers. J Physiol 1968; 197(3): 717-21.
10. Martin R, Saller K. Lehrbuch der anthropologie I. Stuttgar, Germany: Fisher, 1975.
11. Tanner JM. The physique of the Olympic athlete. London: Allen & Unwin; 1964.
12. Carter JEL, Heath BH. Somatotyping - development and applications. Cambridge: Cambridge University Press; 1990.
13. Padilla JP, Martínez EL, Olvera GS, Ojeda PC, Caudillo DP. Dinámica cardiopulmonar durante una prueba de esfuerzo máximo en atletas Mexicanos de Resistencia. Arch Inst Cardiol Méx 2000; 70: 268-84.
14. Padilla JP, Licea JM, Olvera GS, Duran LCh, Lópes JIC. Cinética del intercambio gaseoso y la frecuencia cardíaca durante una prueba de esfuerzo creciente en atletas mexicanos. Rev Inst Nal Enf Resp Mex 1999; 12(2): 87-96.
15. Karvonen MJ, Kentala E, Mustala O. The effects of training on heart rate. A longitudinal study. Ann Med Exp Biol Fenn 1957; 35(3): 305-15.
16. Hughson RL, Inman MD. Oxygen uptake kinetics from ramp work tests: variability of single test values. J Appl Physiol 1986; 61(1): 373-6.
17. Zar, JH. Biostatistical analysis. 3rd Ed. New Jersey. Englewood Cliffs: Prentice-Hall; 1996.
18. Whipp BJ, Davis JA, Torres F, Wasserman K. A test to determine parameters of aerobic function during exercise. J Appl Physiol 1981; 50(1): 217-21.
19. Hagberg JM, Coyle EF. Physiological determinants of endurance performance as studied in competitive race walkers. Med Sci Sports Exerc 1983; 15(4): 287-9.
20. Rodríguez FA, Iglesias X, Feriche B, Calderón-Soto C, Chaverri D, Wachsmuth NB, et al. Altitude training in elite swimmers for sea level performance (altitude project). Med Sci Sports Exerc 2015; 47(9): 1965-78.
21. Ribeiro J, Figueiredo P, Sousa A, Monteiro J, Pelarigo J, Vilas-Boas JP, et al. VO_2 kinetics and metabolic contributions during full and upper body extreme swimming intensity. Eur J Appl Physiol 2015; 115(5): 1117-24.

Solicitud de sobretiros:
Javier Padilla, M.D., M.Sc, Ph.D.
Sección de Fisiología
Escuela Superior de Medicina, IPN
Av. Plan de San Luis y Díaz Mirón S/N
Col. Casco de Santo Tomás, DMH
C.P.11340, Ciudad de México
Tel.: (55) 5729-6300, Ext./Fax. 62782
Correo electrónico: japadillap@ipn.mx