ASSESSMENT OF VENTILATION DURING SWIMMING USING BACKWARD EXTRAPOLATION OF THE VENTILATION RECOVERY CURVE

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Abstract:

The purpose of the present study was to ascertain whether the backward extrapolation method can be used to calculate the pulmonary ventilation (V_E) appropriate in two different breathing conditions during swimming: with and without reduced breathing frequency. Five trained swimmers swam 400 m front crawl at Onset of Blood Lactate Accumulation (OBLA) velocity taking a breath every stroke cycle (normal breathing – NB). Then they repeated 400-m front crawl at NB velocity and with NB stroke frequency taking a breath every second stroke cycle (restricted breathing – RB). The measures included the parameters of blood acid-base status (pH, Po_2, Pco_2, $[HCO_3^-]$) and pulmonary ventilation (V_E). Pulmonary ventilation during swimming was obtained by the backward extrapolation method (V_{Ee}) and by a theoretical model (V_{Et}). There was no significant difference between V_{Ee} and V_{Et} in NB. But the paired *t*-test showed a significant ($p<0,05$) difference between these two parameters in RB. Pco_2 was also significantly higher after RB than after NB. It may be concluded that the backward extrapolation method could be used to determine the V_E during swimming without reduced breathing frequency. If exertion is caused by hypercapnia and/or acidosis (reduced breathing frequency during swimming) then the backward extrapolation method is questionable.

Key words: *swimming, pulmonary ventilation, backward extrapolation, reduced breathing frequency*

ATEMMINUTENVOLUMEN-BEURTEILUNG WÄHREND DES SCHWIMMENS MITTELS DER RÜCKWÄRTS-EXTRAPOLATION DER VENTILATIONSKURVE NACH DEM SCHWIMMEN

Zusammenfassung:

Das Ziel dieser Studie war, zu bestimmen, ob die Methode der Rückwärts-Extrapolation das Atemminutenvolumen (V_E) in zwei verschiedenen Atmungszuständen während des Schwimmens errechnen kann: mit oder ohne reduzierter Atmungsfrequenz. Fünf professionelle Schwimmer schwammen 400 m Kraul bei OBLA-Geschwindigkeit und atmeten ein bei jedem Zyklus (normale Atmung - NB). Danach wiederholten sie 400 m Kraul bei NB-Geschwindigkeit und mit NB-Armzugfrequenz und atmeten ein bei jedem zweiten Zyklus (beschränkte Atmung - RB). Messungen umfassten die Parameter des Säure-Basen-Status im Blut (pH, Po_2, Pco_2, $[HCO_3^-]$) und das Atemminutenvolumen (V_E). Das Atemminutenvolumen während des Schwimmens wurde durch die Methode der Rückwärts-Extrapolation (V_{Ee}) und durch das theoretische Modell (V_{Et}) erlangt. Die gepaarten T-Tests zeigten einen bedeutenden ($p<0,05$) Unterschied zwischen V_{Ee} und V_{Rt} bei RB. Es gab aber keinen bedeutenden Unterschied zwischen diesen beiden Parametern bei NB. Pco_2 war auch bedeutend höher nach RB als nach NB. Daraus kann man erschließen, dass die Methode der Rückwärts-Extrapolation bei der Bestimmung der V_E während des Schwimmens ohne reduzierter Atmungsfrequenz angewendet werden könnte. Wenn die Anstrengung durch Hyperkapnie und/oder Azidose (reduzierte Atmungsfrequenz während des Schwimmens) verursacht wurde, ist die Anwendung der Methode der Rückwärts-Extrapolation fraglich.

Schlüsselwörter: *Schwimmen, Atemminutenvolumen, Rückwärts-Extrapolation, reduzierte Atmungsfrequenz*

Introduction

One of the major problems when measuring pulmonary ventilation (V_E) directly during pool or flume swimming is that the use of measuring equipment will increase swimming resistance and alter body position during the test. This thereby increases the energetic costs of swimming. To overcome this problem the measuring should be performed with minimal influence on the swimming and physiological response. Therefore, V_E values may be measured during recovery and with the use of backward extrapolation it may be possible to calculate V_E during swimming. The backward extrapolation method seems to be valid in order to calculate the VO_2 during the on-land activities (Leger, Seliger, & Brassard, 1980; Sleivert & Traegar-Mackinnon, 1991) and during the swimming (Montpetit et al., 1981, Costill, Maglischo, & Richardson, 1992).

During swimming the pulmonary ventilation is limited by the stroke technique. The breathing frequency has to be in accordance with the stroke rate. It may be assumed that during front crawl swimming with normal breathing every stroke cycle, the need of pulmonary ventilation matched its real (actual) values. In contrast, during front crawl swimming with restricted breathing (breath every second, third or fourth stroke cycle), the stroke technique may not permit the increase of pulmonary ventilation which should match its needs.

Dicker, Lofthus, Thorton and Brooks (1980) and Town and Vanness (1990) measured V_E directly during flume swimming with normal and restricted breathing. They concluded that V_E decreased due to restricted breathing. This increased the Pco_2 in addition it may have significantly influenced on the acidosis and therefore on the swimmer's exertion (Dicker et al., 1980). Increased Pco_2 and acidosis, which are two of the most important breathing control factors, may influence on V_E immediately after swimming. It is questionable whether V_E values measured during recovery are valid to determine V_E during front crawl swimming with restricted breathing.

The purpose of the present study was to ascertain if backward extrapolation method can be used to calculate the V_E appropriate in two different breathing conditions, during swimming: with and without reduced breathing frequency.

Methods

Subjects

Five trained swimmers (age 22 ± 2 years, height 184 ± 8 cm and weight 80 ± 6 kg) volunteered to participate in this study.

Procedures

The swimmers swam 5 × 200 m front crawl step test to define OBLA velocity. The swimming velocity of the first step was 1.09 m/s. From step to step the swimming velocity was increased by 0.1 m/s. Breaks during each exercise step were 3 minutes. OBLA criterion (Onset of Blood Lactate Accumulation) is defined by a [LA] value of 4 mmol/l (Maglischo, 1990) and it is one of the possible criteria for the anaerobic threshold (Ušaj & Starc, 1990). It was evaluated on the basis of lactate concentration – swimming velocity curves.

After the step test swimmers had to swim 400-m front crawl at OBLA velocity taking a breath every stroke cycle (normal breathing – NB). Following that they had to swim 400 m front crawl taking a breath every second stroke cycle (restricted breathing – RB). Velocity and stroke rate of 400 m front crawl with RB were defined with 400-m front crawl with NB, since we knew that the swimmers could reduce their swimming velocity and/or increase their stroke rate, when the need to breathe became critical during swimming with reduced breathing frequency (Town & VanNess, 1990).

Blood collection and breathing measurements

During a break between each exercise in the front crawl step test a blood sample (10 ml) was taken in order to determine the lactate concentration ([LA]). [LA] was analysed with the use of the Dr. LANGE fotometer (Germany).

The measurements before and after the 400-m front crawl with different breathing frequencies included the parameters of blood acid-base status (pH, Po_2, Pco_2, $[HCO_3^-]$), [LA], pulmonary ventilation (V_E) and stroking characteristics. Capillary blood samples (60 – 80 ml) were collected in the third minute after each session of swimming from a hyperemizied ear lobe for pH, Po_2, Pco_2, $[HCO_3^-]$ analysis using an ABL5 (Radiometer Copenhagen) instrument. V_E was measured with the use of a K2 (Cosmed, Italia) instrument before and 5 minutes after each swim by applying the breathing mask to the face of a swimmer while he sat near the swimming pool. Care was taken to instruct the swimmers and assistants in order to reduce to a minimum the time of the first measurement (maximum 14 seconds after the cessation of swimming). Lung capacity, maximum inspiration and maximum expiration were measured with the use of a BIOPAC (USA) spirometer in the laboratory. Stroke rate, inspiratory time (T_I), expiratory time (T_E), number of inhalations per whole distance (Ni) and breathing frequency during swimming were obtained by analysing video film shots.

Data processing and analysis

The V_E was obtained by means of backward extrapolation of the V_E recovery curve at time zero of recovery (V_{Ee}; (Leger, Seliger, & Brassard, 1980)) and by the theoretical model (V_{Et}).

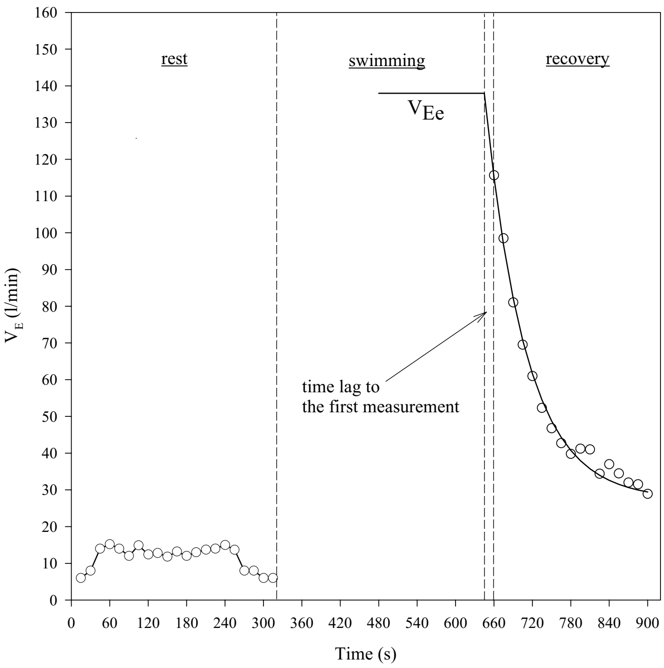

Figure 1. Typical V_E recovery curve for one swimmer. Collection of expired air started maximally 14 seconds after the cessation of swimming.

To describe the kinetics of V_E during 5 minutes recovery, the response data for each swimmer were fitted by using monoexponential model (Figure 1). The function used was of the form:

$$V_E(t) = V_{Ee} + a_r \cdot \left(1 - e^{-\frac{t}{\tau_r}}\right) \quad \text{(Equation 1)},$$

where V_E was the time-dependent variable during recovery, V_{Ee} was the end of swimming level of V_E, a_r was the amplitude coefficient and t_r was the time constant. The best-fit estimates were obtained by the least-squares method.

The theoretical model was composed by analysing video film shots and by measuring lung capacity in the laboratory. V_{Et} was described by the following equation:

$$V_{Et}(l/\min) = V_T(l) \cdot f(\min^{-1}) \quad \text{(Equation 2)},$$

where V_T was the tidal volume during swimming estimated by forced expiratory and inspiratory volume and time available for breathing during swimming, and *f* was the breathing frequency during swimming.

Statistics

The values were represented as means ± standard deviations (SD). The paired *t*-test was used to compare the data between swimming in two different conditions. All the statistical parameters were calculated using the graphical statistics package Sigma Plot (Jandel, Germany).

Results

Table 1. OBLA velocity (V_{OBLA}), measured NB (V_{NB}) and RB velocity (V_B) and measured NB and RB stroke rate (SR_{NB}, SR_{RB}) for each subject and mean values (MV) with standard deviation (SD)

SUBJECT	V_{OBLA} (m/s)	V_{NB} (m/s)	SR_{NB} (min^{-1})	V_{RB} (m/s)	SR_{RB} (min^{-1})
1.	1.21	1.19	29	1.20	29
2.	1.46	1.44	31	1.44	31
3.	1.20	1.21	24	1.21	24
4.	1.34	1.33	31	1.33	32
5.	1.43	1.43	32	1.43	31
MV ± SD	1.33 ± 0.12	1.32 ± 0.12	/	1.32 ± 0.11	/

As expected the swimming speeds and stroke frequencies did not change between the two different breathing conditions. Only one subject could not finish 400 m front crawl with RB. Because of fatigue he could swim only 300 m.

Table 2. Parameters of blood acid-base status (pH, Po_2, Pco_2, $[HCO_3^-]$) after NB and after RB

	pH		Pco_2 (kPa)		Po_2 (kPa)		$[HCO_3^-]$ (mmol/l)	
Breathing conditions	NB	RB	NB	RB	NB	RB	NB	RB
MV ± SD	7.27 ± 0.03	7.26 ± 0.05	4.8 ± 0.3*	5.4 ± 0.2*	11.3 ± 0.4	12.4 ± 1.0	18 ± 3	17 ± 2

*significant difference ($p<0.05$)

Legend:

NB = normal breathing

RB = restricted breathing

Table 3. Respiratory parameters (inspiratory time - T_I, expiratory time - T_E, number of inhalations per whole distance – Ni, tidal volume - V_T) and V_{Et} obtained by analysing the video film shots and by measuring lung capacity in the laboratory and V_{Ee} obtained by backward extrapolation of the V_{Ee} recovery curve at time zero of recovery. Values are mean ± SD

Breathing conditions	T_I (s)	T_E (s)	Ni (per whole distance)	V_T (l)	V_{Et} (l/min)	V_{Ee} (l/min)
NB	0.72 ± 0.1	1.29 ± 0.2	124 ± 9	5.67 ± 0,9	139 ± 21,2	120 ± 19,2
RB	0.72 ± 0.1	3.30 ± 0.5	74 ± 9	5.64 ± 0,6	83 ± 16,2 *	126 ± 24,6*

*significant difference ($p<0.05$)

Pco_2 was significantly higher after RB than after NB ($p<0.05$). Other parameters did not change significantly in response to reduced breathing frequency during swimming (Table 2).

No significant differences between V_{Ee} and V_{Et} in NB conditions were found (Table 3). There was no difference in T_I between the two different breathing conditions. According to the reduced breathing frequency during swimming T_E, Ni and V_{Et} decreased under RB conditions compared to NB conditions. V_{Et} decreased by 40%. But V_{Ee} increased by 5% under RB conditions in comparison with NB conditions. A significant difference was found between V_{Ee} and V_{Et} after RB ($p<0.05$) (Figure 2).

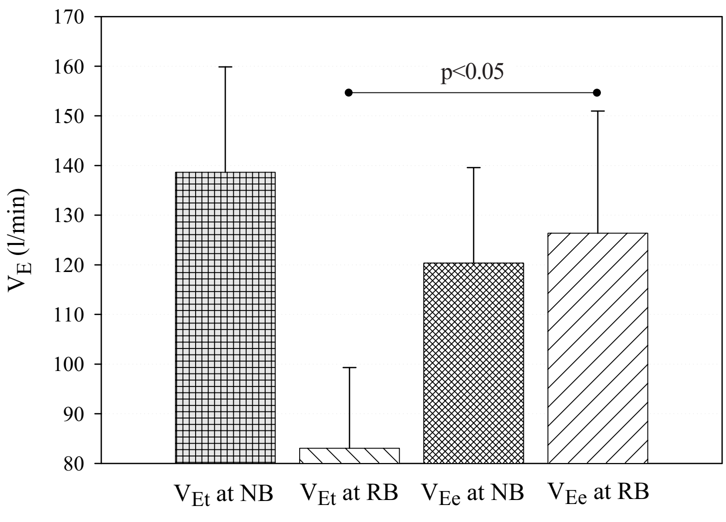

Figure 2. Comparisons V_{Et} and V_{Ee} values between two different breathing conditions.

Discussion and conclusions

Town and VanNess (1990) reported that V_E decreased by 50% under RB conditions compared to NB conditions. A similar decrease in V_E obtained by the theoretical model (V_{Et}) was also obtained in this study. But data from the backward extrapolation method did not show this V_E response to restricted breathing. The V_{Ee} even increased under RB conditions. These results indicate that increased Pco_2 under RB conditions altered V_E immediately after swimming. Therefore, the time from the end of swimming to the start of measuring (maximum 14 seconds) was too long for the swimmers to maintain their "swimming" V_E (which was restricted during swimming). V_E during swimming under NB conditions was not as restricted as under RB conditions. Changes in Pco_2, pH and Po_2 after swimming under NB conditions were too small to influence the V_E immediately after swimming.

V_E reduction during swimming with restricted breathing was compensated by an increasing tidal volume (V_T) (Dicker et al., 1980; Town & VanNess, 1990). To maintain V_E while in the water, trained swimmers utilise a greater V_T during swimming than when running or walking at submaximal efforts (Holmer et al., 1974). In the present study the estimated V_T used in the theoretical model of V_E was almost the same in both conditions. That is about 5.6 l, which is considerably higher than the value (2.9) obtained for maximal free swimming by Holmer and associates (1974).

It may be concluded that the methods for measuring V_E during swimming were incomplete. If exertion is caused by hypercapnia and/or acidosis and backward extrapolation method is being used then, an error can occur. If the tidal volume is not precisely estimated, an error can occur in the valve of V_E (V_{Et}). The first method was suggested in exertion with a lower velocity and usual breathing. Both methods can be used in exertion with higher velocity and restricted breathing: data from the recovery phase were shown by the first method, however the second was more precise.

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PROCJENA VENTILACIJE TIJEKOM PLIVANJA NAKNADNOM EKSTRAPOLACIJOM VENTILACIJSKE KRIVULJE OPORAVKA

Sažetak

Uvod

Jedan od osnovnih problema koji se javlja pri izravnom mjerenju plućne ventilacije (V_E) tijekom plivanja u bazenu ili u malom bazenu sa suprotnim protokom vode, veže se uz uporabu opreme za mjerenje koja povećava otpor tijela i mijenja položaj tijela prigodom testiranja. Uslijed toga se povećava energetska potrošnja za vrijeme plivanja. Kako bi se prevladao taj problem, mjerenje bi trebalo provoditi uz najmanji mogući utjecaj na plivanje i fiziološki odgovor plivača. Stoga, se vrijednosti V_E mogu mjeriti za vrijeme oporavka, a uz pomoć naknadne ekstrapolacije mogu se izračunati vrijednosti V_E koje su bile aktualne za vrijeme plivanja. Metoda naknadne ekstrapolacije pokazala se dobrom za izračunavanje parametara VO_2za vrijeme aktivnosti na tlu (Leger, Seliger i Brassard, 1980; Sleivert i Traegar-Mackinnon, 1991), kao i za vrijeme plivanja (Monpetiti, Leger, Lavoie i Cazorla, 1981; Costill, Maglischo i Richardson, 1992). Svrha ovog istraživanja bila je utvrditi izračunava li metoda naknadne ekstrapolacije ispravno V_E u dvama različitim uvjetima disanja za vrijeme plivanja: sa i bez reduciranja frekvencije disanja.

Metode

Ispitanici i postupak. Pet treniranih plivača plivalo je 400 m kraul na razini anaerobnog praga (OBLA) uzimajući zrak pri svakom zaveslaju (normalno disanje, *normal breathing*, NB). Potom su ponovili dionicu 400 m kraul istom brzinom i frekvencijom zamaha, ali ovaj put uzimajući zrak kod svakog drugog zaveslaja (ograničeno disanje, *reduced breathing*, RB). Izmjereni su parametri acido-baznog statusa (pH, Po_2, Pco_2, $[HCO_3^-]$) i plućna ventilacija (V_E). Plućna ventilacija utvrđena je na osnovi naknadne ekstrapolacije V_E krivulje oporavka u nultoj točka oporavka (V_{Ee}) (Leger et al., 1980) i pomoću teorijskog modela (V_{Et}). Teorijski model sastavljen je na temelju snimaka i laboratorijskog mjerenja plućnoga kapaciteta.

Rezultati i rasprava

Nije utvrđena statistički značajna razlika između V_E i V_{Et} na razini normalnog disanja (NB). Međutim, *t*-test za zavisne uzorke pokazao je značajnu razliku između tih parametara pri ograničenom disanju (RB) ($p<0.05$). Također je utvrđeno da je razina Pco_2 bila znatno viša nakon plivanja uz ograničeno disanje nego nakon plivanja uz normalno disanje.

Town i suradnici (1990) izvješćuju da V_E opada i do 50% u uvjetima RB u usporedbi s plivanjem u uvjetima NB. Sličan pad V_E u ovom istraživanju dobiven je i prema teorijskom modelu (V_{Et}). Došlo je čak i do povećanja V_{Ee} u uvjetima RB. Takvi rezultati pokazuju da povećanje Pco_2 u uvjetima RB dovodi do povećanja V_E neposredno nakon plivanja. Zbog toga je vrijeme od završetka plivanja do početka mjerenja (maksimalno 14 sekundi) plivačima bilo predugo za zadržavanje 'plivačke' V_E (koja je bila ograničena za vrijeme plivanja). V_E za vrijeme plivanja uz normalno disanje nije bila toliko smanjena kao u uvjetima RB. Promjene u pH, Po_2 i Pco_2 nakon plivanja u uvjetima NB bile su premalene da bi mogle utjecati na V_E neposredno nakon plivanja. Smanjenje V_E za vrijeme plivanja uz RB bilo je kompenzirano povećanim dišnim volumenom (V_T) (Dicker i sur., 1980; Town i sur., 1990). Kako bi se zadržala V_E u vodi, plivači su koristili veći V_T za vrijeme plivanja nego za vrijeme trčanja ili hodanja uz submaksimalan napor (Holmer, Stein, Saltin, Ekblon i Åstrand, 1974). U ovom istraživanju procijenjeni V_T korišten u teorijskom modelu V_E bio je gotovo jednak u oba uvjeta disanja (oko 5,.6 l), što je znatno više od vrijednosti (2,9 l) dobivene za potpuno slobodno plivanje u bazenu (Holmer i sur., 1974).

Zaključak

Može se zaključiti da se metoda naknadne ekstrapolacije može koristiti kako bi se odredio V_E za vrijeme plivanja bez redukcije frekvencije disanja. Ako je iscrpljenost uzrokovana nagomilavanjem CO_2 (reducirana frekvencija disanja za vrijeme plivanja), tada je upotreba metode naknadne ekstrapolacije upitna.