Calculating an Equation to Estimate the Maximum Oxygen Uptake in Lifeguards

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Abstract

The aim of this study was to derive an equation that validly and reliably estimates the VO_2 reached in the IPTL, a maximum stress test for lifeguards. From the results obtained in the first part of the research, a multiple linear regression model was identified. A "stepwise" procedure was established as a variable selection method, where the VO_{2IPTL} was selected as the dependent variable and the maximum time reached in the IPTL (s), the percentage of muscle mass (%) and weight of the participant (kg), as independent variables. This procedure generated a regression model where a high correlation was observed between the 3 independent variables and the dependent variable ($R^2 = 0.84$; $p < .01$). From this model, an equation could be generated that allows estimating the VO2max reached in the IPTL. The analysis of the results suggested that the IPTL was a valid and reliable test to estimate VO_2 simply which would allow, in the long term, analysis of changes in lifeguards physical conditioning.

Keywords: regression equation, lifeguard, maximum oxygen uptake, physical fitness

Introduction

One of the main objectives of maximum stress tests is to analyse cardiorespiratory capacity. For this purpose, it is necessary to know the maximum oxygen uptake (VO_2max), that is, "*the maximum capacity of the organism to take up, transport and use oxygen during physical exercise*" (López-Chicharro and Fernández-Vaquero., 2006, p.409). In the case of athletes, these tests fully respect the specificity of the sport requirements involved. The field of lifeguarding is no exception (Salvador et al., 2014). There are two main types of maximum stress tests: "direct" tests where VO_2 is obtained through gas-analysers, and "indirect" tests which estimate VO_2 without the use of an analyser.

In recent decades, incremental tests have been designed to measure oxygen uptake in the swimming pool (Veronese-da-Costa et al., 2013). The protocols for measuring VO_2 in swimmers have improved in recent years. The use of portable analysers continues to cause significant changes in the movement within the water, hence the results obtained may lack validity (Chaverri et al., 2016). Other techniques have been used to calculate VO_2 in the aquatic environment without the need to include any material which alters the swimming technique (Prieto et al., 2010). In the first part of this line of research inquiry (Ruibal-Lista et al., 2019), the maximum nature of the IPTL was demonstrated, a maximum and specific incremental test for lifeguards. In this second part of the line of inquiry, the main objective has been to obtain an equation allowing us to calculate the VO_2 achieved in the previously-identified test.

Method

Participants

An intentional sample of 20 professional lifeguards were included in our study. The inclusion criteria were to have official qualification and a profesional experience of at least two years. All participants signed an informed consent document on the conduct of the tests and the subsequent use of the data obtained. In addition, the study was approved by the local ethics committee.

Design and Procedures

A maximum effort test was performed in the laboratory consisting of an incremental test on a treadmill (Excite Med-Run, TecnhoGym ©) with velocities of 0.4 to 25 km/h and slope of 0 to 18%, with a constant slope of 1%. The protocol began at a speed of 5.4 km/h and 1% of constant slope. The test increased at 0.33 km/h every 20 seconds, simulating a ramp test. During the test an analysis of heart rate, expired gase,s and lactic acid concentration was carried out.

The new test (IPTL) was carried out in a glass-sided pool 25 m long, 20 m wide and 2 m deep. All pool trials were performed one week after laboratory testing on two consecutive days in the same time of day (10:00 am – 2:00 pm) and under the same circumstances (water temperature = 27.8 – 27.9 ° C and relative humidity = 26.9 – 27.0%). The protocol of the Incremental Test Pool for Lifeguards (ITPL) consisted of repeatedly swimming a distance of 25 meters at a pre-established and progressive rhythm using an acoustic start signal at both ends of the glass pool.

The values of HR recorded were taken into account and from there the VO_2 was calculated in the pool test ($VO_{2MaxITPL}$). This calculation was carried out through the HR/VO_2 ratio obtained during the maximum test in the laboratory (TestLab) (linear relation $y = bx - a$) (Prieto et al., 2010). Where Y is the dependent variable (value to be obtained) (i.e., the VO2 to be determined), X is the value of the independent variable (already measured) (i.e., the HR recorded during the pool test), a & b are constant values and r^2 is the linear correlation of this equation.

After statistical analysis and obtaining results as previously reported (Ruibal-Lista et al., 2019), a multiple linear regression model was applied to data obtained from the testing. Bearing in mind the anthropometric variables and those measured in the IPTL (independent variables), we proposed to estimate the VO_2 achieved (dependent variable). To choose the variables for the regression model, a stepwise regression procedure was used. To determine the degree of validity of the model, the empirical data assumptions of linearity, independence, normality, homoscedasticity, and non-collinearity were analysed among the independent variables. This regression model sought to find out to what extent the oxygen uptake (dependent variable) could be explained by the

values of the other measured independent variables and in turn to obtain a valid and reliable predictive equation of VO_{2IPTL}.

Results

A stepwise multiple linear regression model was applied to the data after the Shapiro-Wilk formula demonstrated that all the variables showed a normal distribution. The stepwise regression method was established using a variable selection approach, where the VO_{2IPTL} was chosen as the dependent variable and maximum time reached in the IPTL (s), percentage of muscle mass (%), and participant weight (kg) as independent variables.

Table 1

Results of the variables introduced in the regression model

Variable	Mean	SD
Maximum time IPTL (s)	700	106.87
Muscle mass (%)	44.06	2.49
Weight (kg)	75.68	5.99

The model with the three variables was the one that best determined the oxygen uptake in the IPTL. The variance accounted for by the model was 84.1% (R^2) (Table 2).

Table 2

Regression[a] model summary

Model	R	R^2	R^2 corrected	SEM	Durbin-Watson
1	.642	.412	.339	4.262	
2	.824	.680	.588	3.365	
3	**.917**	**.841**	**.762**	**2.560**	**1.944**

1. Predictor variables: (Constant), Maximum time reached in the IPTL(s)
2. Predictor variables: (Constant), Maximum time reached in the IPTL (s), Percentage of muscle mass (%)
3. Predictor variables: (Constant), Maximum time reached in the IPTL (s), Percentage of muscle mass (%), Participant weight (kg)

[a] Dependent variable: Oxygen uptake reached in the IPTL (ml·kg·min^{-1})

Table 3 shows that the significance of F in the selected model was equal to .008 which indicated that the model explained the dependent variable at alpha < 0.05. Therefore, we concluded that there was a significant predictive correlation among variables X1 to X3 (independent) and variable Y (dependent).

Table 3

ANOVA of the regression^a model

Model	Sum of Squares	df	Root mean square	F	Sig.
1 Regression	102.044	1	102.044	5.616	.045
Residual	145.352	8	18.169		
Total	247.396	9			
2 Regression	168.107	2	84.054	7.421	.019
Residual	79.289	7	11.327		
Total	247.396	9			
3 Regression	208.061	3	69.354	10.579	.008
Residual	39.335	6	6.556		
Total	247.396	9			

1. Predictor variables: (Constant), Maximum time reached in the IPTL(s)
2. Predictor variables: (Constant), Maximum time reached in the IPTL (s), Percentage of muscle mass (%)
3. Predictor variables: (Constant), Maximum time reached in the IPTL (s), Percentage of muscle mass (%), Participant weight (kg)

^a Dependent variable: Oxygen uptake reached in the IPTL (ml·kg·min^{-1})

Table 4 shows the model coefficients. We observed that all variables contributed significantly to explain the dependent variable (VO$_{2IPTL}$).

Table 4

Regression^a model coefficients

Model	Unstandardised coefficients		Standardised coefficients	Correlations		t	Sig.
	B	SEM	Beta	Partial	Semi Partial		
1 (Constant)	21,091	10.253				2.057	.074
Time IPTL	.035	.015	.642	.642	.642	2.370	.045
2 (Constant)	-24.801	20.655				-1.201	.269
Time IPTL	.031	.012	.583	.715	.579	2.706	.030
% muscle mass	1,092	.452	.520	.674	.517	2.415	.046
3 (Constant)	-79.930	27.306				-2.927	.026
Time IPTL	.025	.009	.472	.750	.452	2.775	.032
% muscle mass	1.689	.420	.805	.854	.654	4.017	.007
Total weight	.436	.176	.498	.710	.402	2.469	.049

Dependent variable: Oxygen uptake reached in the IPTL (ml·kg·min^{-1}).

Based on these results, the regression equation took the following expression:

$$VO_{2IPTL} = 0.025 \cdot Time_{IPTL}(s) + 1.69 \cdot muscle_{mass}(\%) + 0.436 \cdot weight_{total}(kg) - 79.93$$

The knowledge of the residuals provided the necessary information to study compliance with the regression model assumptions. The residual independence hypothesis was confirmed by applying the Durbin-Watson statistics (Table 2) since the values obtained ranged from 1.5 to 2.5 (1.944).

The linearity was checked by means of the graphic analysis of the scatter plot of the dependent variable (VO_{2IPTL}) and each of the independent variables (i.e.g, total time, muscle mass and body weight). As can be seen in the following three graphs, a degree of linearity could be observed in all three independent variables graphed against VO_{2IPTL}. The linear correlation coefficients between the dependent variable and each of the independent variables were: (VO_{2IPTL} & $Time_{IPTL}$: R=.750; p=.032), (VO_{2IPTL} & $Muscle_{Mass}$: R^2=.854; p=.007; VO_{2IPTL} & $Weight_{Total}$: R^2=.710; p=.049).
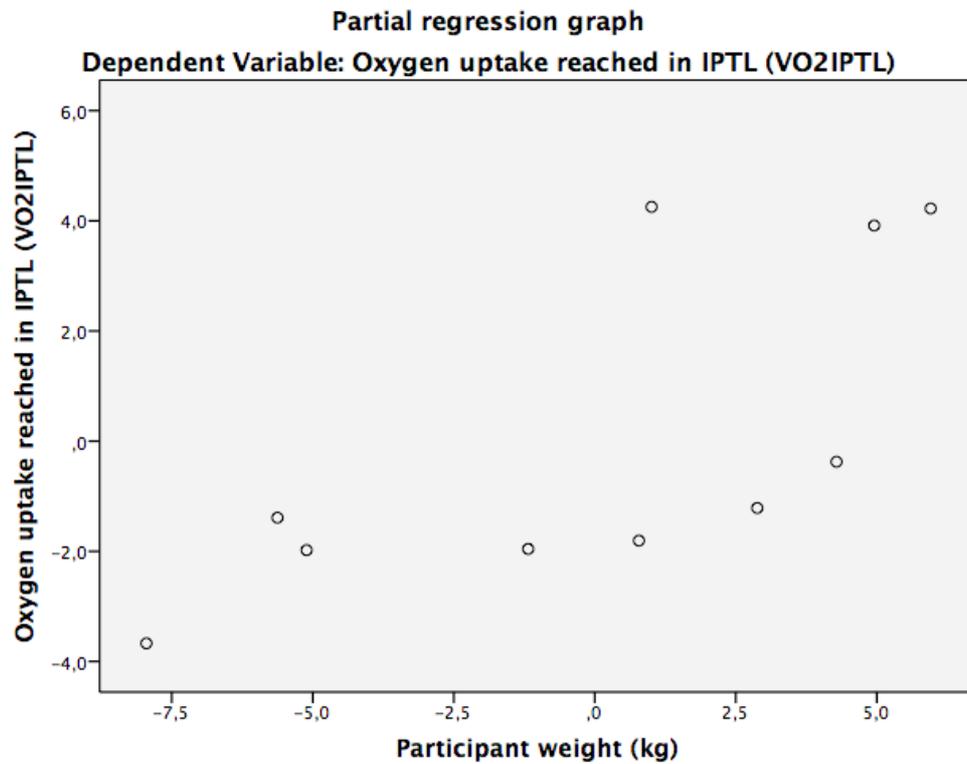
Figure 1
Partial regression between VO_{2IPTL} and the percentage of muscle mass
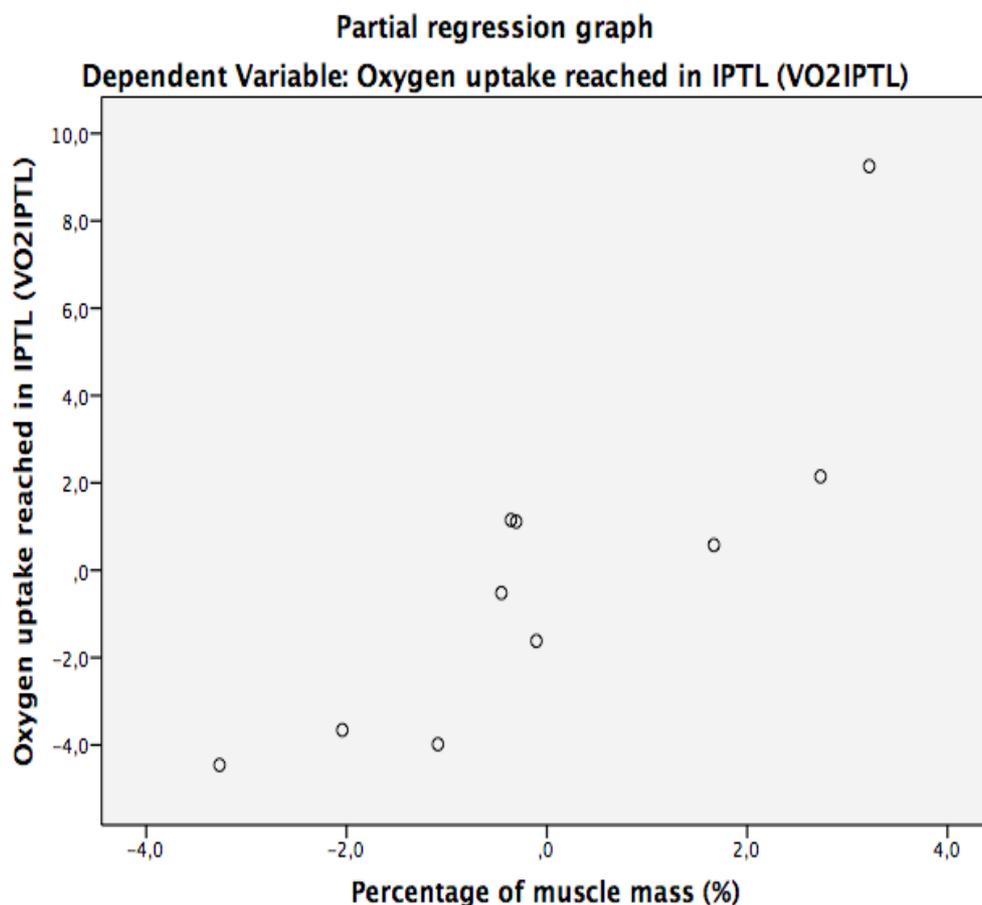
Legend: *Partial regression graph. Dependent variable: Oxygen uptake reached in IPTL (VO_{2IPTL}). Oxygen uptake reached in IPTL (VO_{2IPTL}). Percentage of muscle mass.*

Figure 2
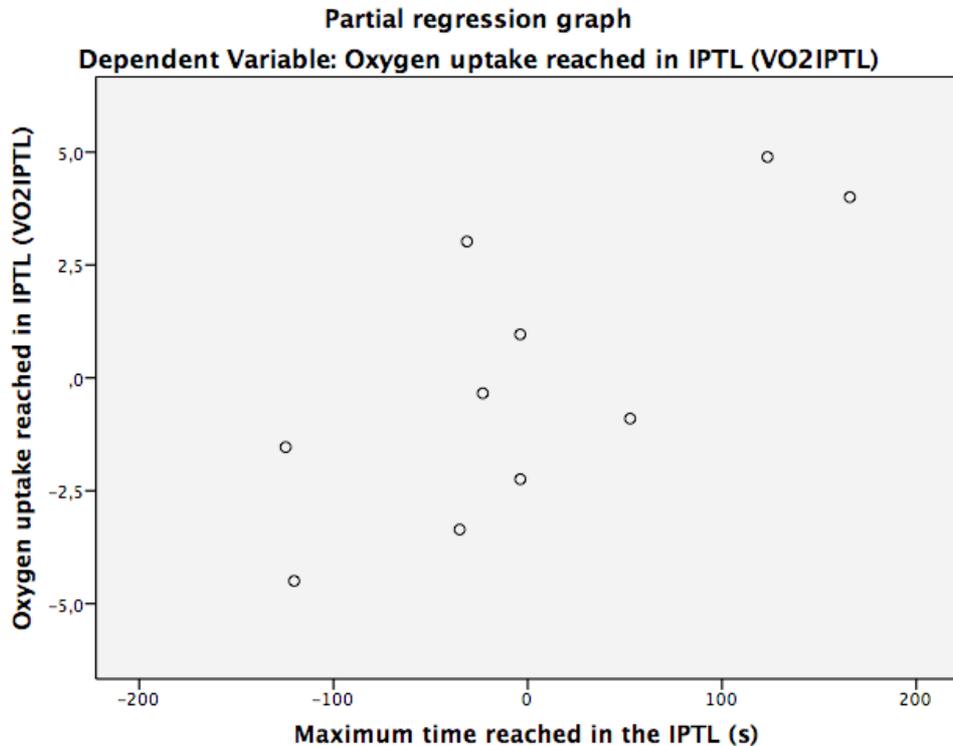
Partial regression between VO$_{2IPTL}$ and total weight

Partial regression graph

Dependent Variable: Oxygen uptake reached in IPTL (VO2IPTL)

Legend: *Partial regression graph. Dependent variable: Oxygen uptake reached in IPTL (VO$_{2IPTL}$). Oxygen uptake reached in IPTL (VO$_{2IPT}$L). Maximum time reached in the IPTL (Incremental pool test for lifeguards).*

Figure 3

Partial regression between VO$_{2IPTL}$ and the maximum time reached in the pool test (IPTL)

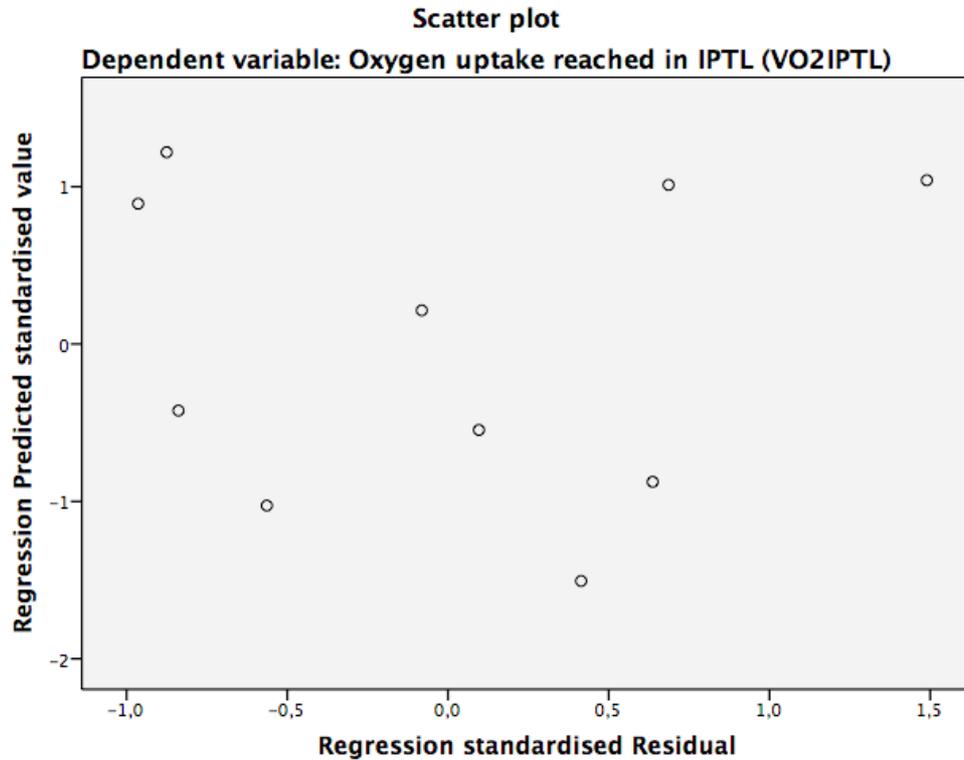
Legend: *Partial regression graph. Dependent variable: Oxygen uptake reached in IPTL (VO2IPTL). Oxygen uptake reached in IPTL (VO2IPTL). Participant weight (kg).*

To confirm the linearity, it was also observed that in the graph (Figure 4) of the predicted values, depending on the standardised residuals for the dependent variable (VO$_{2IPTL}$), there was no tendency in the distribution of the residuals. Figure 4 also confirmed the hypothesis of homoscedasticity, since the residuals were randomly distributed in a strip of three parallel lines that ranges between +2 and -2 typical deviations.

Figure 4

Predicted values based on the standardised residuals for the muscle dependent variable

Legend: *Scatter plot. Dependent variable: Oxygen uptake reached in IPTL (VO2IPTL). Regression Predicted standardised value. Regression standardised Residual.*

The normality hypothesis was confirmed in the following normal probability plot, where the points approximate on the plot diagonal. Also, the Z Kolmogorov-Smirnov test values were (Z = .608; p = .853).

Figure 5
Normal P-P plot of regression Standardised Residual
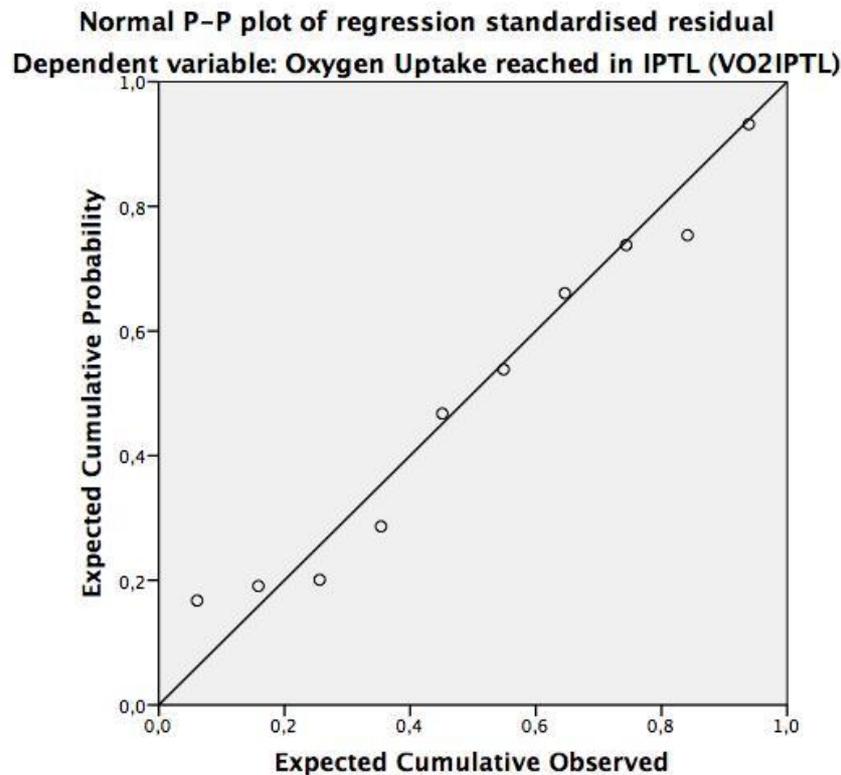
Legend: *Normal P-P plot of regression standardised residual. Dependent variable: Oxygen uptake reached in IPTL (VO_{2IPTL}). Expected cumulative probability vs. Observed cumulative probability*

Finally, to confirm the principle of non-collinearity between independent variables, the following indicators were taken into account:

- There was no significant correlation between independent variables included in the model (Time$_{IPTL}$ & Muscle$_{Mass}$: R=0.404; p=.753; (Muscle$_{Mass}$ & Weight$_{Total}$: R=-.547; p=.102; Time$_{IPTL}$ & Weight$_{Total}$: R=0.158; p=.663).

- The F test evaluating the general adjustment was significant (p=.008) as well as were each one of the partial regression coefficients (Time$_{IPTL}$: p=.032; Muscle$_{Mass}$: p=.007; Weight$_{Total}$: p=.049) (Table 13).

- Tolerance level values were high (they were far from 0.01): Time$_{IPTL}$=.918; Muscle$_{Mass}$=.660; Weight$_{Total}$=.652).

Discussion

After analysing the results obtained, we demonstrated that the IPTL was a valid test to estimate VO_2 in a simple way with respect to specific technical physical requirements for lifeguards. In indirect tests, the estimation of VO_2 was based on equations or nomograms. These took into account the time of effort endured,

the distance reached in a specific test, body weight or stroke length, among other variables (Veronese-da-Costa et al., 2013; Koutlianos et al., 2013).

All estimates have errors, which are called "standard errors from the mean" and result from the equation on which the estimate was performed. Errors from the mean are usually expressed in units of the estimated variable (McArdle et al., 2004). With this degree of error, it might seem that the indirect tests were of little value, but this is not really the case. There are several studies in the field of swimming in which, thanks to an indirect test, an equation has been achieved to estimate VO_2 in the water environment. Costill et al (1985) analysed 39 swimmers trained in a pool during a maximal test of freestyle swimming. They carried out a measurement of VO_2 for 20 seconds after the test. The results were compared with other variables measured during the test and it was observed that the best parameter to estimate VO_{2max} was the lean mass of the swimmers (R=0.88). This estimate increased significantly by including the stroke rate (R=0.97).

Recently, an incremental test was proposed, called the "Progressive Swim Test" (Veronese-da-Costa et al., 2012). It consists of performing a repeated series of 25 metres where, through an acoustic signal, time is reduced 1 second every two series of 25 metres. The first two series of 25 must be carried out in 28:30, the following two in 27:30 and so on until completing 800 metres, the total distance of the test. Once the test was completed, the authors verified its validity test to estimate VO_{2max} (Veronese-da-Costa et al., 2013). The sample included 22 swimmers divided into two groups. In one group, the VO_{2max} was analysed directly and in the other one, it was measured indirectly. During the test, the investigators found that the maximum time reached, the body weight, and the maximum heart rate reached were significantly correlated with the VO_{2max} of the swimmers (R^2=0.63; p<.01).

In our case, the best parameter to estimate the VO_2 in the pool was the time reached within the test (R^2=0.64; p=.032), which, together with the percentage of muscle mass and total body weight, generated a valid equation (R^2=0.84; p =.008) to estimate the VO_2 reached in the IPTL. Reilly et al (2006b), on the other hand, verified that only the energy consumption during the transfer of a drowning victim required a high degree of effort for the lifeguard, finding values close to 70% $VO_{2max.}$

Prieto et al (2010) claimed that the effort in a rescue of 110 metres with waves meant reaching 85% of VO_{2max}. Their study concluded that the minimum level of aerobic capacity (VO_{2max}) to be able to meet the quality standards in water rescue must be 43 ml.kg.min^{-1}, similar to that needed in other rescue groups such as firefighters (Bilzon, 2001 in Prieto et al., 2010).

Limitations

The multiple linear regression model of this study made up of three independent variables resulted from a relatively small sample that may or may not be generalizable. Further study would be advisable to verify the validity of said regression model with a partial sample or with a different and larger sample.

It addition, while the current study focused on the accuracy, or validity, of the regression analysis, there was no test of the consistency or reliability of the study. In order to determine the actual reliability of the equation, additional testing using multiple trials or test-retest or standard error of measurement needs to be calculated in a future study.

Conclusions

In this study to develop a valid regression equation to calculate oxygen uptake among lifeguard, we observed that the length of time reached in the test, the percentage of muscle mass, and the total weight of participants generated a statistically valid model to estimate the oxygen uptake reached in the IPTL (VO_{2IPTL}) ($R^2=0.84$; $p=.008$). Repeatedly calculating this variable over time among lifeguards should allow facility managers to analyse the physical condition of lifeguards as well as the effectiveness of any endurance training programmes they may be undertaking during their lifeguard service.

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