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Original article

Cardio respiratory response: Validation of new modifications of Bruce protocol for exercise testing and training in elite Saudi triathlon and soccer players

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A B S T R A C T

The Bruce protocol is the traditional method used to assess maximal fitness level, although it may have limitations, such as its short duration and large work rate increases, with very high levels of exertion that consist of speed/incline combinations. Modifications have been added to elicit similar maximal fitness achievements. The authors of this experimental trial have proposed a new treadmill protocol that allows optimal test duration in conjunction with peak oxygen consumption 'VO2max', and with appropriate patient comfort and safety during both exercise testing and training.

Subjects: Twenty-two elite Saudi players, comprising eleven Saudi triathlon athletes, and eleven Saudi elite soccer players, BMI, body fat mass percentage, body fat free mass percentage. cardiovascular parameter; including, absolute and relative "VO2max" as well as maximal heart rate "HR max", were assessed during a graded treadmill running modified protocol, using a Quark Cardio Pulmonary Exercise Testing Unit (CPET).

Results: Descriptive statistics were used to obtain the anthropometric characteristics, including comparisons between the means, independent sample *T*-test and a regression analysis, to test the association of the protocol duration and the corresponding, dependent variables.

Conclusions, clinical relevance: It is often difficult to achieve a high cardiorespiratory response, VO2max, without an association to high values of HR max, and peak perceived exertion. This may lead to cardiovascular risk. Our new modifications can provide a practical, valid alternative protocol to be used comfortably both during exercise testing and training, rather than performance testing only, to achieve high VO2max with minimal cardiovascular stress.

1. Introduction

Triathlon is a multiple-stage competition involving the completion of three continuous and sequential endurance disciplines. While many variations of the sport exist, triathlon usually includes swimming, cycling, and running in quick progression over different distances. Triathletes compete for the fastest overall course completion time, including timed 'transitions' between those distinct swimming, cycling, and running segments. Triathlon has become a popular and rapidly increasing sport, in particular in the shorter events, for example, the Olympic separation (1500 m, 40 km, 10 km) or the sprint marathon (500 m, 20 km, 5 km). Marathon rivalry time ranges from 50 to 70 min for the sprint sessions to a few hours for the Olympic and long distance races. Accordingly, top-level triathletes are characterised by a very high aerobic power (maximal rate of oxygen consumption) (Brownell et al., 2005; Garrett et al., 2000).

Soccer is an exceptionally complex game, and to play soccer at an aggressive level, the competitors require a competitive level of oxygen consumption and anaerobic fitness, strength and flexibility (Alessandro et al., 2015). The high aerobic fitness level (i.e., maximal oxygen uptake VO2MAX) in expert soccer is closely related to the distance covered at high intensity by elite players during an official match (Reilly et al., 1996). High aerobic demand in soccer is necessary to provide power in an endurance event, as well as to provide quick recovery after high-intensity activity (Helgerud

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et al., 2001; McMillan et al., 2006). Moreover, the improvement of soccer players and the development of their aerobic fitness can elevate their technical performance and promote greater contact with the ball during the game (McMillan et al., 2006). In addition, the total distance covered (about 10–12 km) is performed at a relative intensity of 75% of the VO2max, thus, resulting in an aerobic contribution of about 90% of the total energy cost of the game (Helgerud et al., 2001; McMillan et al., 2006).

VO2max is the maximum amount of oxygen that is delivered and utilised during intense exercise. The standard method of assessing VO2max is with the use of specialised metabolic measuring equipment. A widely-used treadmill-based protocol is the Bruce protocol (Bruce et al., 1973), which has been routinely utilised in both athletic and clinical populations (Bruce et al., 1973; Demirhan et al., 2014; Evans and White, 2009; Hamlin et al., 2012). The Bruce protocol may not be a suitable technique for evaluating VO2max for all populations. There are set speeds and inclines for each three-minute stage that are not introduced gradually, but occur abruptly at the beginning of each stage. The test length is roughly 8–12 min with very high levels of exertion that are often reached rapidly and, therefore, it can be unsuitable for untrained individuals. Some stages consist of speed/incline combinations that may be uncomfortable, as they are too fast to walk, but too slow to run (Hamlin et al., 2012).

Numerous protocols have been designed to measure maximal exercise, of which the Bruce protocol is still one that stands out amongst those that are regularly utilised (Eston et al., 2005a,b). However, the most appropriate test design has been debated, and there is interest in designing new protocols using the perceptions experienced by subjects during testing. These tests may overcome the weakness of the Bruce protocol (Myers and Bellin, 2000; Eston et al., 2005a,b).

Table 1
Running protocol specification.

New modifications (modified 30 min Bruce protocol)				
Stage	Speed (km/h)	Grade (%)	Time (min)	% of increased speed between stages
I	2.7	0	3	Warming up
II	4	1		
III	5.6	1		40%
IV	7.5	1	3	34%
V	9.7			29%
VI	12.1	1	3	24.7%
VII	14.7	1	3	21%
VIII	17.3	1	3	18%
IX	19.9	1	3	15.4%
X	2.7	0	3	–

Fig. 1. Quark CPET.

2. Material and methods

2.1. Evaluation procedure and subject preparations

To ensure the validity of the test, the patients were told to keep away from sustenance, coffee, and cigarettes for no less than three hours before the review, and preparation and testing was to be two hours after direct oxygen consuming anaerobic exercise, and 14 hours after an energetic resistance workout.

Weight and height was measured using weight and height scales. Measurements were performed while the subject was standing erect, with back and knees extended and both upper limbs beside the body. Personal data was entered into a body composition analysis (BCA) machine, including the patient's age, sex, weight and height, for each patient. This measured the fat mass, fat free mass, and the body's water composition. Calibration of the COSMED apparatus was conducted daily before the procedure; gas calibration was performed before the procedure for each subject, and flow calibration was performed weekly.

2.2. Procedure

After approval by the institutional review board for human study protocols, Saudi elite athletes were selected from subjects undergoing treadmill stress testing and cardiorespiratory performance assessment. The subjects were assigned into two groups. The first group included elite Saudi triathlon players, and the second group included elite Saudi soccer players. The purpose and the procedures were explained to each subject by the examiner. Each subject's anthropometric data [name, age (years), height (cm), weight (kg)] were entered to allow the COSMED apparatus flow screen to calculate the predicted values. The Quark CPET Cardio Pulmonary Exercise Testing Unit, using a face mask with a gas and flow sensor 'Turbine flow meter', was used during the running test. The specification is illustrated in Table 1, and the procedure, equipment and performance are presented in Figs. 1–3.

The peak heart rate (HR max) was detected through the heart rate detector belt fastened onto the subject's chest and connected to the software of the Quark CPET machine through a wireless connection. Both absolute and relative VO2 max was recorded. The perceived level of exertion was rated by each player, using the revised Borg 10-grade scale (see Fig. 4).

3. Results and discussion

Descriptive statistics using SPSS for Anthropometric characteristics were performed. The mean and standard deviations (SD) were presented to compare between the means. An independent sample *T*-test was conducted to determine the significant difference between both groups, in physical characteristics as well as dependent variables, or responses to the exercise protocol (both absolute and relative VO2 max and HR max), using a Levene's test. A Linear Regression Analysis was conducted to test the association coefficients between the protocol duration and the corresponding, dependent variables, using a 99% confidence interval, (CLs) two tailed values of $p < 0.01$.

4. Characteristics of the subjects included in the study

The mean values and SD of the anthropometric characteristics of both player groups, the Saudi elite triathlon and the Saudi elite soccer players, are shown in Table 2.

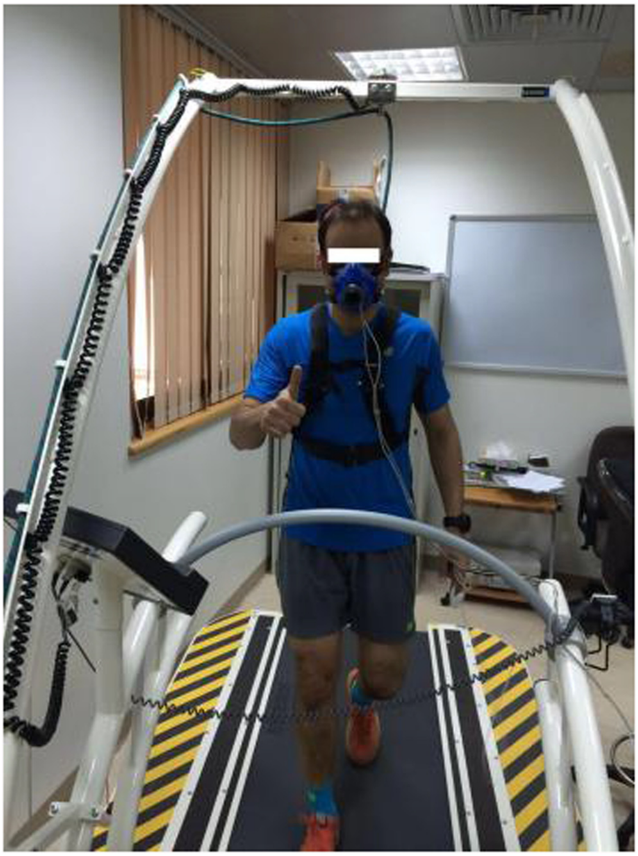

Fig. 2. Test procedure in exercise physiology lab.

Fig. 3. Fastening belts for athlete safety.

A comparison of the mean tests was performed using an independent sample *T*-test, Levene's Test, at 95% confidence interval of the difference, for the following anthropometric characteristics: Age (f = 7.295. p = 0.14); Height (f = 1.368, p = 0.256); Weight (f = 7.020, p = 0.015); Fat mass (f = 1.826. p = 0.192); Fat Free mass (f = 2.249. p = 0.150), and BMI (f = 0.066. p = 0.799), as shown in Table 3.

Protocols for clinical exercise testing generally include an initial warm-up period (at low workload), followed by progressive graded exercise with increasing loads, an adequate time interval in each level, and a post-maximum effort recovery period (again at low workload). One of the disadvantages of the Bruce protocol is the large inter-stage increments in workload between stages. This can make the estimation of the Embedded Image VO2max less accurate. The absence of a recovery phase leads the participant to stop exercising prematurely, because of musculoskeletal discomfort or an inability to tolerate the high workload increments in some subjects, especially those who have co-morbid disorders, medical conditions, gait difficulties or any other sport injury.

As shown in Table 8, the Bruce protocol has seven stages with an abrupt unequal percentage in the increase of the speed between the stages, and with inclination grades ranged between 10% and 22%. The new protocol modifications, with its ten stages equal to 30 min (3 min interval for each grade) include a warm-up phase and a cool-down phase that allow cardiovascular adjustments. It also includes graded increases in the speeds, with an average of 17% of the speed in between the stages. This can reduce the large workload changes between the stages, compared to the standard Bruce protocol. It also uses 1% of GR to mimic the real running situation and reduce musculoskeletal stress, which can be beneficial to subjects experiencing musculoskeletal instability, such as ACL reconstructive surgery.

To the best of our knowledge, this study is the first to develop such modifications to the standard Bruce protocol, and analyses the cardiorespiratory and vascular response using high technology equipment in order to validate the outcome measures during the treadmill running protocols of elite Saudi triathlon and soccer players. It obviously produced relevant physiological data. The high achievements of VO2max level, both absolute and relative, showed positive associations to the protocol duration.

VO2max achievements were reliable, as the portable system's measurement error was about 1%, (using a confidence interval of the difference equal to 99%). The mean and SD, for the absolute, relative VO2max (ml/min), as well as the HR max mean value was (3605.18 ± 515.74) for triathlon players. The football players recorded absolute VO2max (3645.63 ± 897.60) with non-significant difference of the absolute VO2max, between the groups. The overall mean of peak training values was 3625.40 ml/min, which represents 115.3% of the predicted values, as shown in Table 4.

The relative VO2max appeared to be (53.46 ± 7.242) ml/min/kg for the triathlon players, while the football players' relative VO2-max had a mean value and SD of (52.35 ± 6.342) ml/min/kg. With a non-significant difference of the relative VO2 Max between the groups, the overall mean of peak training value was 53 ml/min/kg, which represents 115.008% of the predicted values of relative VO2 Max. The HR max records appeared to be (167.90 ± 19.167) beats/min, for triathlon players, while football players' HR max

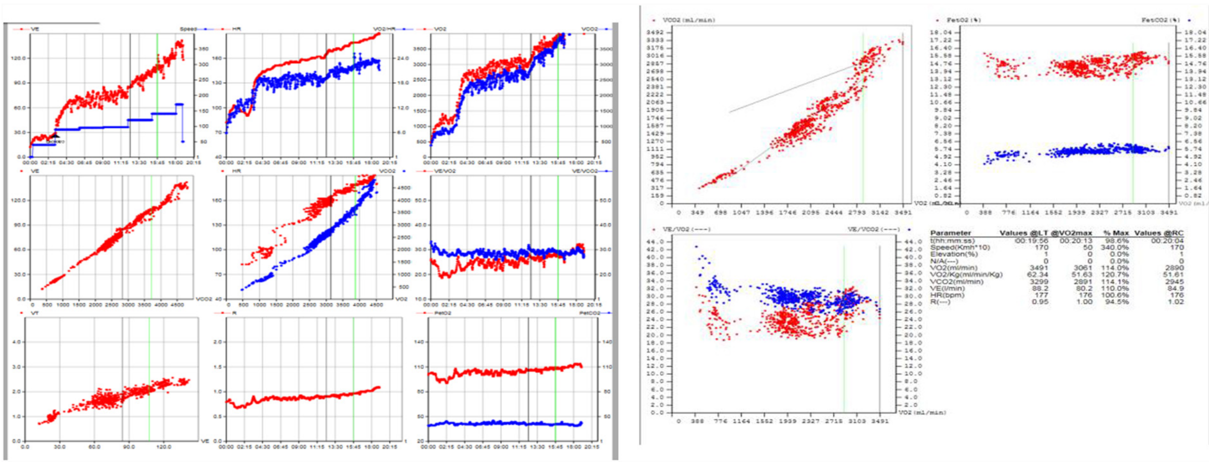

Fig. 4. 9-panel plot chart and graph monitored during running of the test.

Table 2
Descriptive statistics.

Variable	Number	Range	Minimum	Maximum	Mean	Standard deviation
Age (years)	22	15	23	38	29.00	5.173
Height (cm)	22	22	160	182	171.09	6.015
Wight (kg)	22	27.0	56.0	83.0	69.477	9.0402
Fat mass (in Kg)	22	8.2000	4.2000	12.4000	8.940909	5.173
Fat free mass (in Kg)	22	19.7000	53.0000	72.7000	62.495455	6.015
BMI	22	12.0000	20.0000	32.0000	23.950000	9.0402
Valid N (listwise)	22					5.173

Table 3
Comparing means of physical characteristics between triathlon players and football players.

Variable	Game types	Mean values	Standard deviation	Levene's test significance		Significant at P < 0.05
				F	Sig.	
Age (years)	Triathlon Players	33.63	2.730	7.295	0.014	S
	Football Players	24.36	1.206			
Height (cm)	Triathlon Players	169	6.856	1.368	0.256	NS
	Football Players	173	4.400			
Weight (in Kg)	Triathlon Players	67.5	10.627	7.020	0.015	S
	Football Players	71.3	7.131			
Fat Mass (in Kg)	Triathlon Players	9.62	1.8488	2.243	0.150	NS
	Football Players	8.25	2.6485			
Fat Free Mass (in Kg)	Triathlon Players	63.44	5.2443	1.826	0.192	NS
	Football Players	61.54	2.7431			
BMI	Triathlon Players	23.69	3.1274	0.066	0.799	NS
	Football Players	24.20	3.4437			

*Significant at P < 0.05.

Table 4
Comparing means of test protocol durations and response (VO2max, HR Max between triathlon players and football players.

Variable	Game types	Mean values	Standard deviation	Levene's test significance		Significance
				F	Sig.	
Test durations (min.)	Triathlon Players	24.3	3.02	0.192	0.666	NS
	Football Players	27	3.19			
VO2Max (ml/min)	Triathlon Players	3605.18	515.74	0.397	0.535	NS
	Football Players	3645.63	897.60			
VO2Max (ml/min/kg)	Triathlon Players	53.46	7.242	0. 287	0.866	NS
	Football Players	52.35	6.342			
HR Max (beats/min)	Triathlon Players	167.90	19.16	2.909	0.104	NS
	Football Players	139.18	2.64			
Rating of perceived exertion	Triathlon Players	6.10	0.934	0.007	0.934	NS
	Football Players	5.35	0.924			

*Significant at P < 0.05.

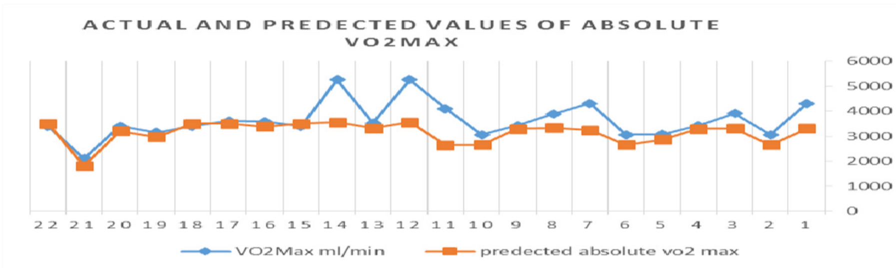

Fig. 5. Actual peak of absolute VO2max and the predicted values. The predicted values were equal to 3143.01 ml/min, while the peak training values were 3625.40 ml/min, which represents 115.3% of the predicted values.

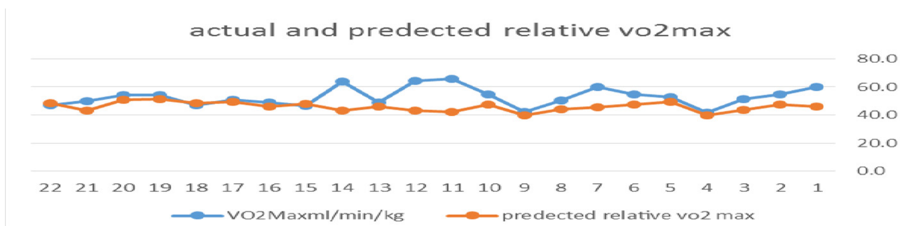

Fig. 6. Actual peak of relative VO2max and the predicted values. The predicted values were equal to 53 ml/min/kg, while the peak actual training values were 46 ml/min/kg, which represents 115.008% of the predicted values.

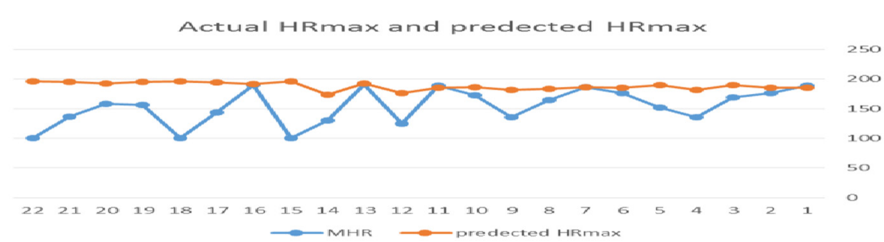

Fig. 7. Actual peak of HR and the predicted values. The predicted values were equal to 188beats/min, while the peak actual training values were 153beats/min, which represents 88.60% of the predicted values.

Table 5
Regression analysis results of the effect of test protocol durations on the dependent variable VO2max ml/min/kg.

Model		Unstandardised coefficients		Standardised coefficients	t	Sig	99.0% Confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	25.217	10.025		2.515	0.021	-3.465-	53.898
	Test Duration	1.064	0.387	0.534	2.751	0.013	-0.042-	2.171

*Significant at $P < 0.01$.
The regression analysis of the relative VO2max indicated that the protocol duration was significantly associated with the relative VO2max, $r = 0.534$ and $B = 1.064$.

had a mean value and SD of (139.18 ± 2.646) beats/min. The overall mean of peak training values was 153beats/min, which represents 88.60% of the maximal predicted HR max values. Comparing the actual peak achieved VO2 Max to the predicted values illustrates the high aerobic performance records obtained using the protocol modifications (Figs. 5–7), as shown below and previously in (Tables 5–7).

The aerobic capacity levels detected were consistent with Al-Hazzaa et al. (2001), who examined the aerobic characteristics of Saudi soccer players. Their results revealed an estimation of the relative VO2max of an overall average equal to 56.8 ml/min/kg, but an absolute VO2max of (2190 ± 160), which was a lower value than the records obtained from the recent protocol. Their study stated that the overall average of elite Saudi soccer players of national teams reached 188 beats/min, which represents 96% of their maximal predicted HR max. In our study protocol, the overall mean of peak training values was 153 beats/min, which represents 88.60% of the maximal predicted HR max values. This could be correlated to the high duration protocol used in this study. The regression analysis in this study revealed that the new protocol duration was significantly positively correlated to both relative and absolute VO2max with ($r = 0.534$, $B = 1.064$) and ($r = 0.563$, $B = 120.848$), respectively. On the other hand, the linear regression analysis of the HR max and test protocol duration, using a 99% confidence interval of difference, revealed a non-significant association. These two regressions may illustrate the increased VO2max with test

Table 6
Regression analysis results of the effect of test protocol durations on the dependent variable VO2max ml/min.

Model		Unstandardised Coefficients		Standardised Coefficients	t	Sig.	99.0% Confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	485.440	1054.669		0.460	0.651	-2531.900-	3502.781
	Test Duration	120.848	40.691	0.563	2.970	0.008	4.435	237.261

*Significant at $P < 0.01$.
The regression analysis of the absolute VO2max indicated that the protocol duration was significantly associated with the absolute VO2max, $r = 0.563$ and $B = 485.440$.

Table 7
Regression analysis results of the effect of the test protocol durations on the dependent variable VO2max ml/min.

Model		Unstandardised coefficients		Standardised coefficients	t	Sig.	99.0% Confidence interval for B	
		B	Std. error	Beta			Lower bound	Upper bound
1	(Constant)	101.172	51.779		1.954	0.066	-46.964-	249.309
	Test Duration	1.971	1.998	0.221	0.987	0.336	-3.744-	7.686

*Significant at $P < 0.01$.
The regression analysis of HR max indicated that the protocol duration was non-significantly associated with $r = 221$ and $B = 101.100$.

Table 8
Comparison between standard Bruce protocol and the new modifications (modified 30 min Bruce protocol): musculoskeletal stress, musculoskeletal instability such as ACL reconstructive surgery.

Standard Bruce protocol						New modifications (modified 30 min Bruce protocol)				
Stage	Speed (MPH)	Speed (km/h)	Grade (%)	Time (min)	% of increased speed between stages	Stage	Speed (km/h)	Grade (%)	Time (min)	% of increased speed between stages
I	1.7	2.7	10	3		I	2.7	0	3	Warming up
II	2.5	4	12	3	48%	II	4	1		
									3	48
III	3.4	5.4	14	3	35%	III	5.6	1		40
									3	
IV	4.2	6.7	16	3	23.5%	IV	7.5	1	3	34
V	5.0	8	18	3	19%	V	9.7			29
								1	3	
VI	5.5	8.8	20	3	10%	VI	12.1	1	3	24.7
VII	6.5	9.6	22	3	9%	VII	14.7	1	3	21
VIII	17.3	1	3	18						
IX	19.9	1	3	15.4						

protocol duration, with a non-significant high HR level that may put the cardiovascular system under stress, and may reduce the cardiovascular risk during both exercise training and testing.

On the other hand, many studies that have investigated the Bruce protocol using the mean rating of perceived exertion from the revised Borg scale (0 to 10), recorded the value of 8 ± 1 (Peter and James, 2005). This can be considered to be higher than the mean rating of perceived exertion recorded by the subjective responses of the subjects in the test, which had an average rating of perceived exertion with a value of 6 ± 1 for triathlon players, and 5 ± 1 for football players.

Many studies that compared the Bruce protocol to other testing protocols, such as the ramp and the slope, stated that duration of exercise was an issue, with many subjects reaching volitional fatigue outside the 8–12 min test length of the Bruce protocol. For example, 8:25 ± 3:00 min was recorded for the Bruce protocol and, in comparison, 10:01 ± 2:32 min for the ramp ($P < 0.0001$). The subjective rating of every test was 2.5 ± 0.9 for the Bruce protocol and 4.1 ± 0.9 for the slope ($P < 0.0001$), demonstrating that the subjects found the ramp more tolerable and, hence, less demanding. Seventeen patients accomplished a target heart rate in both conventions, and in this study, the subjects practised for an extended period of time on the ramp before achieving that rate. Their time was 6:22 ± 2:52 min for the Bruce protocol and 7:19 ± 2:22 min for the ramp ($P < 0.03$) (Storino et al., 2015; Eston et al., 2005a,b).

Total exercise time was reduced in protocols with large increments (e.g. the Bruce protocol) compared with other protocols, such as ramp protocols, and there were higher minute ventilation values. The correlation between estimated oxygen uptake and measured uptake has been shown to be poorer with the Bruce protocol than with a ramp protocol. Having clearly defined the obstacles that may affect patients' perception of their exercise ability, being seen as sequential hurdles that are considered as boundaries that may limit the performance (Eston et al., 2005a,b), patients practised longer with the ramp than with the Bruce protocol, and achieved an optimal duration for the exercise test of approximately 10 min. A mean duration of 10:01 ± 2:32 min was reached on the ramp without individualisation, and individual data showed that each patient exercised longer with the ramp than with the Bruce protocol. METs accomplished with the ramp were essentially higher than with the Bruce protocol. The work of Hogg et al. (2015) demonstrated that this closely reflects the measured peak oxygen consumption than does the Bruce protocol (Demirhan et al., 2014).

In our study protocol, the mean test duration was 24:03 ± 4:02 for triathlon players and 27:03 ± 3:02 for football players. This long duration of the test protocol allowed the achievement of a high aerobic response without subjective high exhaustion limits, nor an abrupt response of the cardiovascular parameter (HR max). Our aim was to demonstrate improved patient performance and comfort. We adhered to the same speed and grade settings at the end of the three-minute intervals as the Bruce protocol. We believed this would better integrate with the clinicians' familiarity with the stages of the Bruce protocol.

6. Conclusion

Improved test duration and comfort are important, and the significant increase in both absolute and relative maximal oxygen consumption VO2max/ml, VO2max/ml/kg respectively, without the association of HR max to exercise protocol duration has a clear clinical advantage in both exercise testing and training. This new modification of the standard Bruce protocol offers a convenient, well-tolerated method that can be introduced to the physical therapy and exercise physiology field, as it emphasises exercise training, rather than performance testing only. We propose a new clinical setting of treadmill protocol modifications to allow the achievement of an optimal test duration with higher degrees of aerobic achievement and greater patient comfort and safety, during both exercise testing and training.

Funding, conflict of interest

No outside funding was received for this work and to the best of our knowledge, no conflict of interest, financial or other, exists.

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