Incremental Testing Design on Slide Board for Speed Skaters: Comparison Between Two Different Protocols.

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Abstract

The aim of this study was to investigate the effect of stage duration (Long-stage–LS: 3-min, Short-stage–SS: 1-min) on maximal and submaximal aerobic physiological variables during a simulated skating test performed on a slide board. Ten well-trained male speed skaters performed two maximal incremental tests on slide board until voluntary exhaustion. The second ventilatory threshold (VT2) was determined by the ventilatory equivalent method. All participants reached the criteria for maximal oxygen uptake (VO_2max) attainment in both protocols. Maximal cadence (CADmax), VO_2 at VT2 and cadence at VT2 (CAD_{VT2}) were significantly higher during SS protocol, but maximal heart rate was significantly lower for the SS protocol. VO_2max was significantly correlated with CADmax for the SS (r= 0.62) and LS protocol (r= 0.61). Strong correlation were found between CADmax and CAD_{VT2} during the SS (r=0.83) and LS protocol (r=0.76). The results of the present study suggest that either SS or LS slide board incremental protocols can be used to evaluate skaters, since they elicited maximal physiological responses. Additionally, slide board incremental skating tests may be considered as a more specific and practical alternative than laboratory-based tests, especially when a large number of athletes need to be assessed.

Key words: exercise performance; incremental test; speed skating; maximal oxygen uptake; aerobic evaluation; fitness test design.

INTRODUCTION

Endurance performance in speed skating is related to physiological aspects, such as maximal oxygen uptake (VO_2max), lactate and ventilatory thresholds (VT) (9). Aerobic functional testing is largely used to assess and prescribe training intensities for endurance athletes. It is believed that the results of these tests repeated throughout a season provide useful information about the training status and fitness level of athletes (11). However, the design and mode of an incremental exercise test can confound the measurement of the submaximal and maximal physiological variables (3). This is especially important to consider in speed skaters, who are rarely tested in a sport-specific manner.

Some studies have reported that VO_2max is not statistically different between 1-min and 3-min stage protocols during cycling and running exercises (4,5,24). However, Machado et al. (20), Kuipers et al. (17) and Bishop et al. (5) found that significantly higher maximal work rate is typically attained during an incremental test comprising of shorter stages of 1-min duration, yet higher values for maximal heart rate (HRmax) were found when protocol with 3-min stage duration was used. It is important to note that most of the studies provided no information about the achievement of the criteria used to define maximum effort, i.e. a plateau in VO_2, blood lactate concentration ([Lac]), respiratory exchange ratio (RER), heart rate (HR) or rating of perceived exertion (RPE) values, commonly used to define VO_2max (13).

It is extremely important to appropriately quantify submaximal physiological parameters given its critical role in proper training prescription. However, few studies have compared physiological variables corresponding to the second VT (VT2) between protocols with different durations, and most of them have provided conflicting results. Bentley and McNaughton (4) have shown that the work rate corresponding to the VT2 is quantified differently when using incremental exercise tests comprising either 1-min or 3-min stages, while Amann et al.(1) and Weston et al.(27) reported no difference in the VT2 when obtained from two tests comprising 1-min or 3-min stages.

While the specificity of performance evaluation is a key factor for training prescription, the validations of specific fitness tests with speed skating are scarce, particularly because skating activities are challenging to simulate in the laboratory (11). On track skating tests are more complicated to perform as testing conditions are more difficult to control. Thus, acquisition of physiological data becomes problematic. Similarly, the use of skate specific treadmills is most of time inaccessible and expensive to monitor training and performance during the competitive season. As an alternative to perform a more specific and feasible laboratory test, Piucco et al. (22) proposed a maximal incremental test on a slide board, using a short-stage protocol (i.e. 1 min-stage) as an easy and low cost sport-specific evaluation for speed skaters. The authors found a high reliability (ICC > 0.9 and typical error of measure < 3.5%) of maximal and submaximal physiological variables obtained. However, there are no results in the literature comparing two different incremental protocols of varying stage length to evaluate physiological parameters of speed skaters performing their unique movement pattern. As previously mentioned, the duration of protocols can result in different values, especially for maximum workload and HRmax achieved (5, 20) and also for workload at VT2 (4).

Therefore, the main aim of the present study was to investigate the effect of stage duration (Long-stage–LS: 3-min, Short-stage–SS: 1-min) on maximal and submaximal aerobic physiological variables during a simulated skating test performed on a slide board. In addition, the relationships between mechanical and physiological variables were accessed to describe the influence of stage duration on exercise prescription parameters.

METHODS

Experimental Approach to the Problem

To determine whether physiological responses are influenced by incremental test design (independent variable) performed on a slide board, a sample of speed skaters performed two different maximal incremental tests differing by stage durations. Maximal and submaximal aerobic indices were compared between protocols, as dependent variables. We therefore hypothesized that differences in stage duration would lead to changes in maximal and submaximal physiological values, which are directly related to performance evaluation and training prescription indices, such as HR, VO_2 and intensity. However, the specificity of the skating gesture could reflect on different responses when compared to that reported for cycling and running.

Subjects

Ten well-trained male endurance speed skaters specializing in the 1000, 1500 and 3000 meters event volunteered to participate in this study. The athlete's mean age, body mass, percentage of body fat and height were 18.9±5.3 years (age ranging from 16 to 33 years), 72.1±7.8 kg, 12.8±1.5 %, and 1.78±4.6 m respectively. Informed consent was obtained from the subjects or from parental when under the age of 18 years. All testing fulfilled the institutional Ethics Committee regulations regarding the use of human subjects. Subjects were tested at the end of the off-season, while participating in a structured training program. All participants had experience with the slide board skating movement and with maximal incremental effort tests.

Participants were instructed to refrain from heavy training, maintain a regular diet 24h prior to testing, and to abstain from the ingestion of any stimulant (caffeine, nicotine) or alcohol during the preceding testing day. Each subject performed two incremental skating tests to fatigue using an instrumented slide board. The tests were performed three to six days apart in a temperature-controlled environment.

The slide board protocols were performed on a polyethylene surface (2.10 x 0.6 x 0.2 m) fixed to the ground with double sided tape. Subject wore a pair of nylon socks over their shoes while skating on the slide board. The dynamic friction coefficient (μ_c) between both materials was 0.13 ± 0.05, determined by different loads accelerations, tracked by a high speed kinematic system (240 fps, Eagle System; Motion Analysis Corp.). Optical sensors were placed at either extremity of the slide board to determine the athlete's foot contact time at the lateral stoppers and determine the athletes' instantaneous skating cadence (Figure 1). A software program was developed to help the athlete to keep the pace by providing visual and auditory feedback. The participants performed a five-minute warm-up at a cadence of 30 push-offs per minute (ppm) on the slide board. After a three-minute rest, the protocols started with a cadence of 30 ppm and were increased by three push-offs every minute (short-stage protocol - SS) or every three minutes (long-stage protocol - LS). Therefore, the only difference between the protocols was stage duration time. The distance between the lateral stoppers was kept the same for all subjects (2.10 m). This decision was based on an unpublished pilot study, where 20 subjects performed the SS test on the slide board, and were classified by height, leg length and body mass. The result of a stepwise linear regression showed that only the final cadence was responsible for significant changes in VO_2max during the SS protocol on slide board. Therefore, it is likely that the power output (Po) during the test, which is calculated based on the skating cadence, stride length (stoppers distance), body mass, and on the dynamic coefficient of friction, is the main variable that can influence the physiological responses during the test. The participants were asked to maintain a constant hunched skating posture and were free to move their arms during the test.

FIGURE 1 HERE

The maximal cadence (CADmax) was defined as the maximal number of push-offs.min^{-1} reached during the slide board tests. If the final stage was not completed, the CADmax was calculated according to the following equation adapted from Kuipers et al. (18).

(1)

$$CADmax = CADf \ + \ t/s * 3$$

with CAD_f the cadence of the final stage completed, *t* the uncompleted stage time, *s* the stage duration and 3 the cadence increment per stage.

The mechanical power output (P_o) produced by the speed skaters on the slide board was modeled by the one-dimensional power balance model proposed by van Ingen Schenau (26). The model was driven by skater's body mass (m), gravitational acceleration (g), dynamic friction coefficient (μ_c) and speed (v) measurements in the sideward direction (equation 2).

(2)

$$Po = \mu_c mgv$$

Participants were verbally encouraged to exert a maximal effort during all tests. The tests were completed when the selected cadence could no longer be maintained or at volitional exhaustion. The attainment of VO_2max was defined using the follow criteria proposed by Howley et al. (13): (1) a plateau in VO_2 regardless of increase in cadence; (2) age-predicted maximal HR attained (3) RER $\geq$1.10; and (4) [Lac] $\geq$8 mmol.l^{-1}. Pulmonary ventilation (VE), RER, carbon dioxide production (VCO_2) and VO_2 were measured breath-by-breath during all tests using a gas analyzer (K4b2 Cosmed®, Rome, Italy), calibrated according to manufacturer's instructions prior to each test. VO_2max was considered to be the highest value averaged over a 15-second period. Fingertip blood samples were collected during the final 20 s of every 3 minute-stage, to assess changes in [Lac] during the LS protocol, and at minute one, three, and five following the LS and SS tests conclusion, to assess maximal values of [Lac]. Blood lactate samples were not measured during the SS protocol. A Lactate Pro® (Arkay Inc., New South Wales, Australia) analyser, calibrated according to the manufacturer's recommendations before each analysis, was used to measure [Lac].

The VT2 during SS and LS tests was detected using the ventilatory equivalent method (23). In this way, two independent observers blindly detected intensity associated with the VT2 by examining inflection points in the plots of ventilatory equivalents of oxygen (VE/VO_2) and carbon dioxide (VE/VCO_2). The inter-observers reliability coefficient was assessed with intraclass correlation coefficient (ICC=0.91 for SS and 0.77 for LS). Values of Po, CAD, VO_2, VO_2 as a percentage of VO_2max (%VO_2max), VE, HR and RER corresponding to VT2 for each protocol were determined.

Procedures

Data are presented as mean ± standard deviation (*s*). Normality was assessed using the Shapiro-Wilk test. Student's t test for paired sample was used to compare variables between LS and SS tests. The correlation coefficient of variables between LS and SS protocols and the correlation among VO_2max, CADmax and Pmax during LS and SS protocols were assessed using a Pearson product-moment correlation. The relationship between maximum workload and VO_2max was plotted. Statistical analysis was conducted using GraphPad Prism (v. 5.0 GraphPad Prism Software Inc, San Diego, CA) and Statistical Package for Social Sciences (SPSS Inc. v.17.0, Chicago, USA). The confidence level was set at 5%.

RESULTS

All participants reached at least three of criteria for VO_2max attainment, according to Howley et al. (13), during the LS test (8/10 showed a VO_2 plateau, 7/10 reached maximum HR predicted, 10/10 RER ≥ 1.1, 6/10 [Lac]max ≥ 8 mmol.l^{-1}) and SS test (5/10 showed a VO_2 plateau, 5/10 reached maximum HR predicted, 10/10 RER ≥ 1.1, 8/10 [Lac]max ≥ 8 mmol.l^{-1}).

The main comparisons for maximal and submaximal variables, obtained from LS and SS protocols, are shown on Table 1. The total time duration was 27±2.1 minutes for LS and 10±1.8 minutes for SS protocol. CADmax, Pomax, VO_{2LV2} and CAD_{LV2} were significantly higher during SS protocol, but HRmax was significantly lower for the SS protocol. Significant correlations were obtained for most of the maximal variables, with the exception of RERmax and [Lac]max. Submaximal VO_2, HR and Po values were correlated between LS and SS protocols.

TABLE 1 HERE

VO_2max (l.min^{-1}) was significantly correlated with CADmax for the SS (r= 0.62) and LS protocol (r= 0.61). Strong correlation were found between CADmax and CAD_{VT2} during the SS (r=0.83) and LS protocol (r=0.76).

The relationship between maximum aerobic power (VO_2max) and maximal mechanical workload (Pomax) for the two protocols is presented in Figure 2.

FIGURE 2 HERE

Discussion

The main findings of this study was that incremental slide board skating tests with both short- and long-stage protocols provided similar values of VO_2max, RERmax, VEmax and [Lac]max, while the other maximal variables (HRmax, CADmax, Pomax) presented significant differences. In the same way, certain submaximal values related to VT2 (i.e, HR, RER, VE and Po) were not different between both protocols, while VO_2, CAD and %VO_2max associated to VT2 were found to be significantly different. Another important finding was that the design of the incremental tests analyzed in the present study was adequate to elucidate maximal physiological responses.

No studies were found in the literature comparing different incremental protocols during skating movement pattern. To better discuss the results, the specificity of skating movement should be taking into account, since a large difference on HR and VO_2 responses can be found between skating and cycling or running exercises (15, 16). The difficulty to assess speed skaters using incremental laboratory testing is evident, due to need for a specific ergometer such as wide size treadmills. Slide boards have been frequently used as an off-ice training modality by speed skaters, since it seems to mimic the skating gesture and evokes much more specific physiological and biomechanical responses than cycling (14). In this way, the slide board seems to be an attractive way to evaluate physiological indices with a low cost equipment. Moreover, during inline skating incremental protocol on a track, a low friction coefficient and rolling resistance may reduce the physiological demand at any given speed, and high increase in velocity is necessary to attain maximal effort. However, at maximal levels of exertion it may become biomechanically or technically difficult to skate fast enough at 0% grade to maximally challenge the cardiovascular system (12). The aforementioned problems were not observed during either SL or SS slide board protocols, since most criteria to determine VO_2max were reached. However, some skaters expressed having difficulties maintaining high stroke frequencies during the last stages of the SS incremental protocol. In this sense, it seems that the both incremental test design and characteristics of the board (friction coefficient and size) were adequate to obtain maximal variables without the influence of individual factors as level and specificity of training.

Although there are some suggestions in the literature that longer tests could impair the VO_2max attainment (21), the VO_2max values obtained during the LS and SS slide board protocols were not significantly different (Table 1). This finding is consistent with previous reports using incremental cycling tests (3, 4, 24), suggesting that VO_2max is largely the same during incremental skating exercise on slide board, regardless of the rate of work increments. Despite no differences between VO_2max, the CADmax during the SS protocol was higher than during the LS protocol. The disparity between linear trend lines (Figure 2) indicates that the CADmax may alone have influenced the relationship between maximum workload and VO_2max during both protocols.

The higher CADmax values observed during the short skating protocol compared with longer is in agreement with previous studies which analyzed other modalities (3, 4, 24). In those studies, the higher maximum workload was explained by the fast workload increment. According to Bishop et al. (6), a high cycling peak power might be related to the capacity to delay the accumulation of metabolic products. Therefore, the higher CADmax recorded during the SS test, may be related to decreased accumulation of blood lactate at the same absolute power outputs, allowing the athlete to attain a higher power output before fatigue. This can be evidenced by the strong correlation between peak power and the VT2 in the present study (r=0.83 and r=0.76 for SS and LS protocols). Nonetheless, the relative contribution of anaerobic pathways may contribute to that, regarding the significant difference in [Lac]max between the two protocols. Despite the difference in CADmax attained during the SS and LS incremental skating protocols, the significant correlations observed between VO_2max and CADmax suggest that the maximum cadence reached during both protocols might be a good a predictor of aerobic fitness, as previous demonstrated in different exercise modes (2, 5).

The HRmax achieved during the LS skating protocol was higher when compared to SS. This finding is consistent with previous studies reported by Bishop et al. (5) and Roffey et al. (24) when comparing 1-min stage versus 3-min stages protocols. Many factors could have contributed to the significant elevation in

HR during the LS test, such as an increased thermoregulatory load, increased blood flow, different substrate use, and the lack of time for HR to adapt to the intensity requirement when increasing workload every minute (7, 5, 24). It also is likely that the higher HR observed in the LS protocol compared with the SS protocol can be attributed to cardiovascular drift in HR responses, that is evident in exercise testing that exceeds 10 – 15 min in duration (8). In addition, the high intramuscular forces and long period of isometric contraction on quadriceps, that are typical during skating (10, 25), during could also explain the high HR values found, since it might lead to a disproportionate increase in HR relative to VO_2.

At the intensity corresponding to VT2, significant differences occurred in CAD, VO_2 and $\%VO_2max$ between the two protocols, despite significant correlations between submaximal VO_2 parameters was also found (Table 1). Contradictory results have been reported in the literature when comparing submaximal physiological parameters derived from incremental tests with different design (4, 1, 27). However, it is possible that the long test resulted in a steady state of exercise being achieved and, therefore, induces more valid blood lactate and respiratory responses (3, 4). Nonetheless, the body posture adopted by the skaters during the test could play a role on the physiological response (10). Despite the subjects were asked to keep a skating posture close to real situation, the body posture (knee and trunk angles) was not controlled in this study.

The skating gesture performed on the slide board can be used not only for testing, but for training purposes as well. When prescribing training intensity based on peak exercise testing results, an incremental test comprising shorter stages, could inflate submaximal work rates expressed as a percentage of peak values (4). Therefore, the prescribed work rate may be too severe and result in suboptimal acute training responses. In the other hand, test comprising of longer stages may challenge the athlete to an extended effort and therefore be relate better to field performance (19) and more valid to prescribe endurance training intensities. We believed that these statements could also be valid for prescribing training on slide board, based on SS and SL protocols. Additionally, the relationship found between work intensity and VO_2 during skating on the slide board indicates the importance of including high power skating movement or sprint training for elite speed skaters. Highly fit individuals may require a higher training stimulus to achieve a significant training effect. Since peak values are difficult to reach when training, a slide board skating could be used to perform high intensity interval-training sessions. Intensity can be easily manipulated by changes in cadence or by increasing the friction coefficient on the board surface. Nonetheless, a good physiological and neuromuscular adaptation can be obtained from training loads on the slide board, since the gesture is specifically related to skating activity itself.

In conclusion, the results of the present study suggest that either SS or LS slide board protocols can be used to determine VO_2max in skaters. Additionally, the incremental maximal skating protocol on a slide board elucidated maximal physiological responses and seems adequate to evaluate aerobic indices of performance on skaters. Therefore, the incremental test on slide board may be considered as a more specific and practical alternative to laboratory-based tests, especially when a large number of athletes need to be monitored, given the correlation between CADmax and VO_2max. However, intervention-based studies are necessary in order to better understand the likely benefits applied to slide board training and to compare technical aspects with the real skating movement.

Practical Implications

Based on our results, either short-stage or long-stage skating protocols on slide board can be used to determine VO_2max in skaters. The relationship between CADmax and VO_2max obtained during the both protocols seems to be a good predictor of aerobic fitness. In this sense, the incremental skating tests on the slide board seem to be a more precise, attractive and a practical way to evaluate skaters and to prescribe high intensity interval-training sessions.

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Table 1. Comparison and correlation for maximal and submaximal variables (mean±*s*) derived from long-stage (LS) and short-stage (SS) incremental tests performed on the slide board.

	LS	SS	r
Maximal			
VO_2max (ml.kg^{-1}.min^{-1})	46.3 ± 4.1	46.4 ± 3.6	0.78†
HRmax (bpm)	195 ± 6	190 ± 9*	0.86†
RERmax	1.2 ± 0.07	1.2 ± 0.1	0.50
VEmax (l.min^{-1})	141.0 ± 19.9	146.8 ± 23.5	0.70†
CADmax (ppm)	54.8 ± 2.1	59.5 ± 5.1*	0.78†
Pomax (W)	176.4 ± 23.0	201.2 ± 33.7*	0.94†
[Lac]max (mmol.l^{-1})	8.9 ± 1.8	10.03 ± 1.9	0.05
Submaximal			
VO_{2VT2} (ml.kg^{-1}.min^{-1})	40.8 ± 3.1	42.8 ± 2.6*	0.80†
HR_{VT2} (bpm)	182 ± 7	178 ± 10	0.64†
RER_{VT2}	1.01 ± 0.05	1.04 ± 0.04	-0.27
VE_{VT2} (l.min^{-1})	94.8 ± 12.7	96.9 ± 14.5	0.63
CAD_{VT2} (ppm)	46.2 ± 2.5	49.2 ± 3.7*	0.46
Po_{VT2} (W)	148.2 ± 21.3	158.7 ± 25.2	0.88†
%VO_2max	88.4±4.00	92.5 ±2.9*	0,65†

* Significant difference; †Significant correlation ($p<0.5$). VO_2max = maximal oxygen uptake; HRmax = maximal heart hate; RERmax = maximal respiratory exchange ratio; VEmax = maximal ventilation; CADmax = maximal cadence; Pomax = maximal power output; [Lac]max = maximal lactate concentration; VO_{2VT2} = oxygen uptake at VT2; HR_{VT2} = heart hate at VT2; CAD_{VT2} = cadence at VT2; P_{VT2} = power output at VT2; %VO_2max = % of VO_2max.

Figure 1- Scheme slide-board instrumentation. 1- Photoemitter; 2- Photoreceptor.

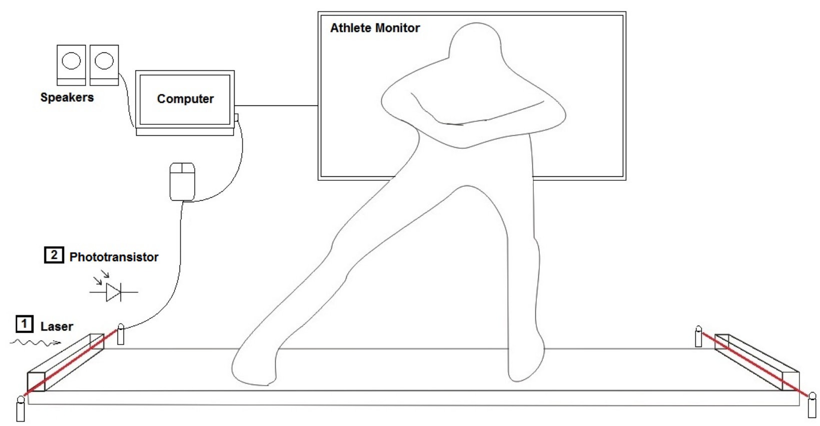
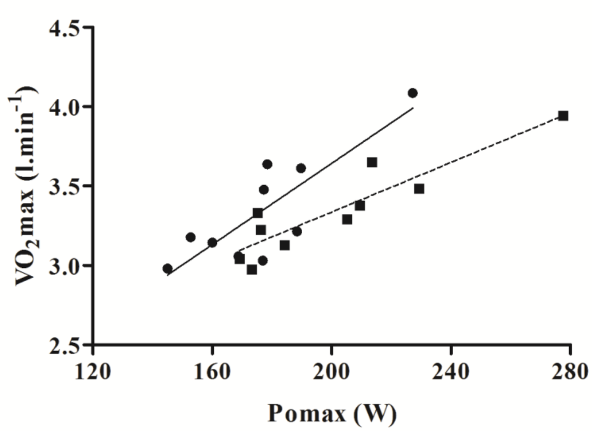
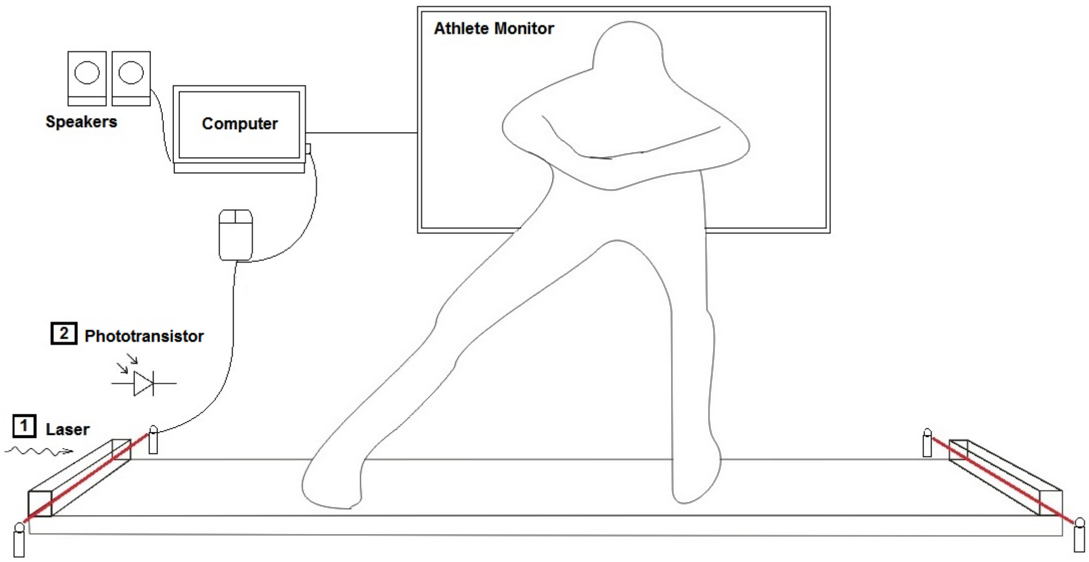
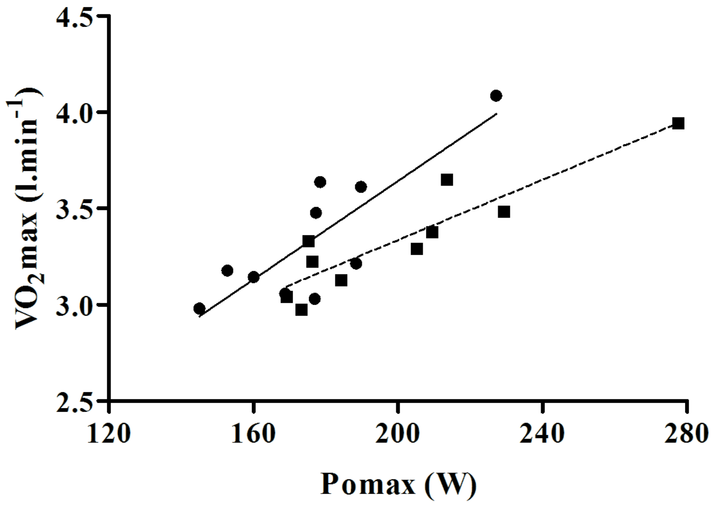


Figure 2- Relationship between VO_2max and Pomax responses during the two protocols. ● LS ■ SS (R^2=0.69 and 0.82, respectively).





Athlete Monitor
Speakers
Computer
2 Phototransistor
1 Laser


VO2max (l.min-1)
4.5
4.0
3.5
3.0
2.5
120
160
200
240
280
Pomax (W)