

Research article

## Intermittent versus Continuous Incremental Field Tests: Are Maximal Variables Interchangeable?

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### Abstract

The aim of the present study was to compare physiological responses derived from an incremental progressive field test with a constant speed test *i.e.* intermittent versus continuous protocol. Two progressive maximum tests (Carminatti's test (T-CAR) and the Vameval test (T-VAM)), characterized by increasing speed were used. T-CAR is an intermittent incremental test, performed as shuttle runs; while T-VAM is a continuous incremental test performed on an athletic track. Eighteen physically active, healthy young subjects ( $21.9 \pm 2.0$  years;  $76.5 \pm 8.6$  kg,  $1.78 \pm 0.08$  m,  $11.2 \pm 5.4\%$  body fat), volunteered for this study. Subjects performed four different maximum test sessions conducted in the field: two incremental tests and two time to exhaustion tests (TTE) at peak test velocities (PV). No significant differences were found for PV (T-CAR =  $15.6 \pm 1.2$ ; T-VAM =  $15.5 \pm 1.3$  km·h<sup>-1</sup>) and maximal HR (T-CAR =  $195 \pm 11$ ; T-VAM =  $194 \pm 14$  bpm). During TTE, there were no significant differences for HR (TTE<sub>T-CAR</sub> and TTE<sub>T-VAM</sub> =  $192 \pm 12$  bpm). However, there was a significant difference in TTE ( $p = 0.04$ ) (TTE<sub>T-CAR</sub> =  $379 \pm 84$ , TTE<sub>T-VAM</sub> =  $338 \pm 58$  s) with a low correlation ( $r = 0.41$ ). The blood lactate concentration measured at the end of the TTE tests, showed no significant difference (TTE<sub>T-CAR</sub> =  $13.2 \pm 2.4$  vs. TTE<sub>T-VAM</sub> =  $12.9 \pm 2.4$  mmol·l<sup>-1</sup>). Based on the present findings, it is suggested that the maximal variables derived from T-CAR and T-VAM can be interchangeable in the design of training programs.

**Key words:** Peak velocity, field test, aerobic evaluation, continuous versus intermittent exercise testing, exercise prescription.

### Introduction

The specificity of the fitness evaluation of athletes and its consequent ecological validity is an important topic for the analysis and characterization of sports. Traditionally, aerobic assessment has been determined by continuous incremental tests (laboratory or field tests), in order to obtain indices such as maximal aerobic velocity (MAV), maximal oxygen uptake (VO<sub>2</sub>max) and lactate thresholds (Faude et al., 2009).

In order to overcome some of the issues associated with laboratory testing, coaches and researchers have developed field based test procedures, which more closely replicate the nature of a sport. For instance, the University of Montreal track test (UM-TT) (Léger and Boucher, 1980) and the Vameval test (T-VAM) (Cazorla, 1990),

were proposed for aerobic evaluation during running. However, since these tests were characterized as continuous straight-line running (*i.e.* without direction change), alternative modes of incremental tests were developed using a shuttle run system (Bangsbo, 1994; Carminatti et al., 2004; Léger and Lambert, 1982). Bangsbo (1994) developed the Yo-Yo intermittent recovery test (Yo-Yo IR), in order to increase the specificity for the assessment of team-sport athletes. The main objective of this test was to evaluate the athlete's ability to repeatedly perform and their potential to recover from intensive exercise (Krustrup et al., 2003). Similarly, Carminatti et al. (2004) proposed a progressive distance intermittent shuttle-run test (T-CAR) for the purpose of evaluating maximal aerobic power in team-sport athletes.

This test closely replicates the stop-start nature of a typical sports game and includes a range of distances (rather than a single fixed distance) associated with player movement during competitive match play. Thus, the main difference between T-CAR and Yo-Yo tests, is that, during T-CAR, the distance increases as a function of the progressive stages (*i.e.* speed), instead of a fixed distance for all stages.

In addition, the longer distances covered during the latter stages of T-CAR allows the athlete to have a greater distance to accelerate and reach higher peak running velocities compared to shorter fixed distance protocols (Fernandes da Silva et al., 2011). Such a protocol could provide higher ecological validity and hence give better indications regarding the abilities required to perform repeated high-intensity running compared with tests that use set distances and identical recovery periods (Svensson and Drust, 2005).

Due to the importance of the physiological indices obtained in these different field tests for the purpose of training prescription, some studies have been conducted comparing the physiological responses obtained from continuous versus intermittent testing (Castagna, 2006; Castagna et al., 2010). Ahmaidi et al. (1992) showed that the PV obtained from a 20-m shuttle run test (20-m MST, multistage shuttle run test) was underestimated when compared to the UM-TT (Léger and Boucher, 1980). Likewise, Gallotti and Carminatti (2008) compared the PV from T-CAR with the PV from 20-m MST and found higher velocities in T-CAR ( $+ 2.4$  km·h<sup>-1</sup>). The reasons for such differences are likely due to the nature of the shuttle run tests (*i.e.* fixed vs. progressive distance).

Indeed the start, speeding up, slowing down, stopping and change of direction during the shuttle tests, involves broken acceleration and causes marked vertical displacement of the centre of mass and lower stride efficiency (Ahmaidi et al. 1992). The loss of efficiency probably also occurs in T-CAR, however, to a lesser magnitude, since the greater distances covered during the latter stages ( $>15\text{km}\cdot\text{h}^{-1}$ ) allows the athletes to have more distance to accelerate. Furthermore, T-CAR uses short rest periods between shuttles (6 s recovery between 5 repetitions of 12 s of exercise) contributing to the higher PV values in relation to 20-m MST. Thus, the gradual increase in speed, with added distance and the pause during T-CAR allows athletes to reach PV values that correspond to  $\dot{V}\text{O}_2\text{max}$  determined in a treadmill protocol (Dittrich et al., 2011). Therefore, we hypothesized that PV derived from T-CAR would be similar to the PV from T-VAM. Such similarities could contribute to the development of interchangeable models of training sessions, using variables determined in intermittent shuttle test to be used in continuous straight-line training, and of continuous straight-line test data to be used in intermittent shuttle training.

In addition, considering the importance of an appropriate prescribed exercise program, it is also necessary to know the amount of effort that athletes could sustain (i.e., time to exhaustion) in both exercise models, since it can be used as a reference for interval training (Billat et al., 1999; Millet et al., 2003).

Therefore, the aim of the present study was twofold: 1) to analyze and compare the PV and the HR responses between a continuous track test (T-VAM) and an intermittent field test (T-CAR); 2) determine and compare the time to exhaustion (TTE) at 100% of the PV in both tests.

## Methods

### Subjects

Eighteen healthy, physically active male physical education students ( $21.9 \pm 2.0$  years;  $76.5 \pm 8.6$  kg;  $1.78 \pm 0.08$  m;  $11.2 \pm 5.4$  % body fat) volunteered for the present study. Written informed consent documents were received from all the participants after a detailed explanation about the aims, benefits and risks involved with this investigation. Participants were told they were free to withdraw from the study at any time without penalty. All procedures were approved by the ethics committee of the State University of Santa Catarina, Florianópolis, Brazil.

### Procedures

Subjects were tested on four separate occasions (at least

72 hours apart) and in a random order for the field-based tests. Initially, they performed two incremental tests and then two time to exhaustion tests (TTE) at PV. Prior to the first test, all the subjects were assessed for body mass (kg), height (m) and skinfold thickness (mm). The TTE tests were randomly performed on separate days with at least 48 hours between tests. All tests were performed on a 200-m outdoor running track (synthetic surface) at the same hour of the day in order to avoid circadian variation in performance (Carter et al., 2002). All subjects were advised to maintain a regular diet during the day before testing (keeping the same meals) and to refrain from smoking and caffeinated drinks during the two hours prior to testing.

### Incremental running tests

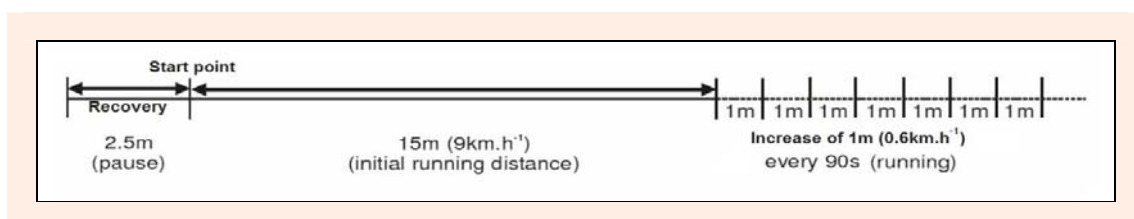
T-CAR consists of incremental intermittent shuttle runs performed between two lines set at progressive distances apart (Fernandes da Silva et al., 2011). The test protocol starts at a speed of  $9\text{ km}\cdot\text{h}^{-1}$  and a corresponding running base of 15-m, which is increased by 1-m at every 90 s stage. Each distance stage (i.e. from 15-m to exhaustion) is composed of 5 repetitions of 12 s shuttle runs interspersed by a 6 s walk to be performed between two lines set 5-m apart from the start/finish line (see Figure 1). During T-CAR, the running pace is controlled by a constant timing (i.e. 6 s) audio cue (beep) which determines the running speed to be performed between the parallel lines established on the track and marked by cones. Failure to achieve the shuttle run in time to the prescribed audio cue on 2 consecutive occasions resulted in termination of the test. Hence, the PV was derived from the last distance covered (i.e. at exhaustion). For instance, an athlete who completed the 30-m stage had a PV corresponding to  $18\text{ km}\cdot\text{h}^{-1}$ .

T-VAM was performed on a 200-m outdoor running track (synthetic surface). Ten cones were placed on the track every 20-m as a reference. The test starts at a running speed of  $8.5\text{ km}\cdot\text{h}^{-1}$  and increases by  $0.5\text{ km}\cdot\text{h}^{-1}$  every minute until exhaustion (Cazorla, 1990). Participants adjusted their running speed to the cones placed at 20-m intervals. The test ended when the subject could no longer maintain the required running speed dictated by the audio beep, for 3 consecutive occasions.

During both test procedures (T-CAR and T-VAM), heart rate (HR) was monitored at 5-second intervals using the Polar S610i system (Polar Electro Oy, Kempele, Finland). The HRmax was the highest 5 s average HR value achieved during the test.

### Time to exhaustion at PV

All subjects were requested to perform a constant speed



**Figure 1.** Visual representation on the T-CAR test.

test to exhaustion at the PV in both protocols previously described. During TTE<sub>T-VAM</sub> cones were set at 40-m intervals along the 200-m track (inside the first lane). The running pace was dictated by audio cue and the participants had to be within 2-m of the cones at each beep. The subjects were controlled by two researchers to ensure that they ran at the required speed and encouraged them when they began to have difficulties with the pace. The tests were stopped when the subjects were unable to maintain the required pace, that is, they were unable to reach the required cones on each audio cue (a 2-m shortfall was used as an objective criteria).

Based on the distances attained in T-CAR (*i.e.* PV), athletes performed the TTE<sub>T-CAR</sub>. Regarding the TTE of T-CAR, the distance to be covered on the fixed intervals of 6 s, corresponded to the PV reached during the T-CAR test. The same pattern of the T-CAR test was applied, that is, the subjects were required to run for 12 s for a set distance (five repetitions), returning to the start point where they completed 6 s rest, this procedure was repeated until exhaustion. The pauses (*i.e.* 6 s) were not included in calculating the TTE.

Prior to each TTE test, the subjects completed a 5 min warm-up, running at 70% of PV, with specific protocols (intermittent, shuttle or continuous straight-line), followed by 5 min rest. After the warm-up phase, 25 $\mu$ l of capillary blood was collected from an ear lobe to measure blood lactate concentration ([La]).

In all the tests, each subject was verbally encouraged to perform their best. No feedback was given to athletes regarding HR or elapsed time. A blood sample was collected from an earlobe 1 min after completion of the TTE, to determine the final blood lactate concentration.

### HR and [La] measurements

For storage and analysis of the HR during the tests, HR monitors were used (S610i system Polar Electro Oy, Kempele, Finland) with Polar Precision Performance SW® software. The analysis of lactate was performed using an electrochemical analyzer (YSI 1500 STAT, Yellow Springs, OH, USA).

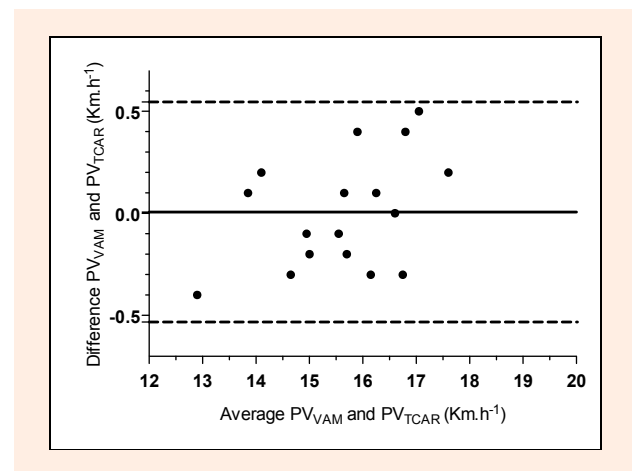
### Statistical analysis

Data are presented as mean  $\pm$  standard deviation. A Shapiro-Wilk test was used to verify the normality of the data. In order to compare the differences between both tests, Student's t-test for paired sample was used. Pearson product-moment correlations were used to examine the relationships between variables. The magnitude of effects was qualitatively assessed according to Hopkins (2001) as follows:  $r < 0.1$ , trivial; 0.1-0.3, small; 0.3-0.5, moderate; 0.5-0.7, large; 0.7-0.9, very large;  $> 0.9$ , nearly perfect; and 1.0, perfect. Heteroscedasticity (*i.e.* systematic error) was verified by plotting the absolute differences of PV against the individual means (*i.e.* Bland-Altman plot) and calculating the correlation coefficient, in order to test if slope was significantly different from zero value. The 95% absolute limits of agreement were calculated according to Atkinson and Nevill, (1998) and Ludbrook (2010).

All analyses were performed using GraphPad Prism software package for Windows (v. 5.0 GraphPad Prism Software Inc, San Diego, CA). Statistical significance was set at  $p < 0.05$  for all analyses.

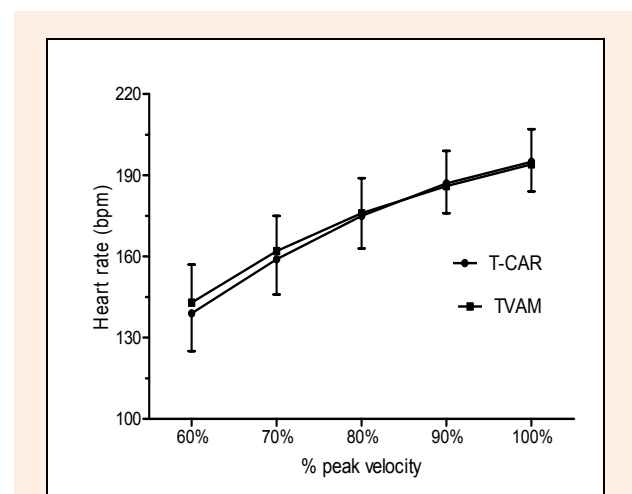
## Results

The PV obtained in both protocols (PV<sub>T-CAR</sub> =  $15.6 \pm 1.2$ ; PV<sub>T-VAM</sub> =  $15.5 \pm 1.3$  km·h<sup>-1</sup>) showed no significant difference and showed a nearly perfect correlation ( $r = 0.98$ ,  $p < 0.01$ ). There was no systematic bias (*i.e.* heteroscedasticity) in the data from both tests for peak velocity. Figure 2 shows the Bland-Altman plot with 95% limits of agreement for peak velocity between tests.



**Figure 2.** Analysis of Bland-Altman plot of PV obtained in T-VAM and T-CAR. The dashed lines indicates 95% limits of agreement.

Regarding the heart rate response, the HR<sub>max</sub> during T-CAR ( $195 \pm 11$  bpm) was not significantly different from T-VAM ( $194 \pm 14$  bpm) and both were highly correlated ( $r = 0.93$ ,  $p < 0.01$ ). The HR response during T-CAR and T-VAM are shown in Figure 3.



**Figure 3.** Relationship between heart rate in T-CAR and T-VAM.

The TTE values, HR at the end (HREnd) and

average-HR (HR<sub>avg</sub>) derived from the constant speed tests are presented in Table 1. Regarding the TTE, a significant difference was found ( $p < 0.001$ ).

**Table 1. Mean ( $\pm$ SD) values and coefficient of correlation among HR<sub>end</sub>, HR<sub>avg</sub> and TTE obtained during the constant speed tests in both protocols.**

n = 18	TTE <sub>T-CAR</sub>	TTE <sub>T-VAM</sub>	R
HR <sub>end</sub> (bpm)	192 (12)	192 (12)	.93 *
HR <sub>avg</sub> (bpm)	178 (12)	180 (13)	.96 *
TTE (sec)	253 (56)	338 (58) #	.41

\* Significant correlation ( $p < 0.001$ ). #  $p < 0.001$  related to TTE<sub>T-CAR</sub>

There was a modest, non-significant correlation between both TTE tests ( $r = 0.41$ ,  $p = 0.09$ ). The final [La] was not significantly different between tests (TTE<sub>T-CAR</sub> =  $13.2 \pm 2.4$  vs. TTE<sub>T-VAM</sub> =  $12.9 \pm 2.4$  mmol·l<sup>-1</sup>).

## Discussion

The major finding of the present study indicates that PV values obtained from two different incremental field tests, that is, one intermittent shuttle run test (T-CAR) and another traditional track test (T-VAM), are interchangeable.

The Bland-Altman's limits of agreement showed that individual variation was about  $\pm 0.5$  km·h<sup>-1</sup> of the actual value (Figure 2). Therefore, it can be observed that T-CAR is a feasible method to estimate maximal aerobic speed, comparable with corresponding values derived from a continuous straight-line protocol (T-VAM).

Similar to our observations, Dupont et al. (2010) showed that the mean PV obtained from Yo-Yo IR level 1 (Yo-Yo IR1) was not significantly different from the University Montreal Track Test (UM-TT) peak velocity. However, this result did not show a constant error (i.e. heteroscedasticity), and therefore the PV was not interchangeable, that is, subjects with PV<sub>UM-TT</sub> higher than 16 km·h<sup>-1</sup> presented an increased error of PV derived from Yo-Yo IR1. The present study showed no systematic bias for either test. The results of the present study are also different from the findings of Gallotti and Carminatti (2008) who reported a study comparing T-CAR and 20-m MST. The authors found that PV<sub>T-CAR</sub> was significantly higher than PV<sub>20m-MST</sub> ( $+ 2.4$  km·h<sup>-1</sup>). The differences were likely to be associated with the pauses in the intermittent model (T-CAR) and by the fact that the distance (shuttle-running bouts) increased during the test. Thus, athletes were able to perform a slower acceleration at the beginning of the shuttle and/or to resume the speed after the direction change especially at the higher speeds of the test ( $>15$  km·h<sup>-1</sup>), when compared to the 20-m MST.

According to Buchheit et al. (2010), running with direction change demands a break followed by an acceleration, thus, the importance of the lower limb muscle strength and endurance are also factors in this exercise model. Thus, compared with continuous straight-line exercise, running with direction changes could present a greater physiological load, as supported by an increased cardiorespiratory response, muscular O<sub>2</sub> uptake, blood lactate concentration and rating of perceived

exertion (Buchheit et al., 2011).

Ahmaidi et al. (1992) compared the maximal aerobic speed of three different protocols (20m-MST, UM-TT and an incremental treadmill test). The authors found no significant difference in VO<sub>2max</sub>, HR<sub>max</sub> and [La]<sub>end</sub> among these tests. However, the PV reached in 20-m MST was significantly lower when compared to the treadmill (16.3 %) and UM-TT (19.3 %), i.e., a difference of approximately 3 km·h<sup>-1</sup> was found, confirming that the PV derived from the 20-m MST is not a reliable index for prescribe training of aerobic power, because it underestimates the maximal aerobic speed during straight-line running. The constant direction changes in a short distance (i.e. 20-m) during some tests (20-m MST and Yo-Yo tests), inhibit subjects reaching their maximum speeds. The act of starting, speeding up, slowing down, stopping and changing direction during the shuttle run tests involves numerous accelerations and decelerations, resulting in marked vertical displacement of the centre of mass and lower stride efficiency (Ahmaidi et al., 1992). In the present study, a possible explanation for the similar PV between T-CAR (intermittent shuttle running) and T-VAM (straight-line running), could be based on the partial recovery provided by the 6 s rests between the 12 s of running in T-CAR, counterbalancing the extra energy expended resulting from acceleration, deceleration and direction changes. To our knowledge, this is the first intermittent shuttle test with direction changes that has a similar PV compared with a continuous track test.

The HR<sub>max</sub> values showed no significant difference (Table 1). This result agrees with Krustup et al. (2003), who found that the HR<sub>max</sub> obtained in the Yo-Yo IR1 ( $187 \pm 2$ ) was the same as derived from the treadmill ( $189 \pm 2$ ), and Dupont et al. (2010) who found similar values comparing Yo-Yo IR1 ( $191 \pm 8$ ) and the UM-TT ( $192 \pm 8$ ) together with a very large correlation score ( $r = 0.88$ ).

According to the present data, it appears that the submaximal HR values are similar to T-VAM for a given speed (%PV) during T-CAR (Figure 2). This similarity in HR values confirms that, despite the shuttle run characteristics required by T-CAR (i.e. acceleration, deceleration, stop, u-turn), the progressive increment in the distance and the frequent pauses among shuttle-runs contributes to similar HR values compared to a continuous straight-line model. This is valuable from a practical point of view, since HR monitors are commonly used as a criterion measure to control and regulate training intensity (Stolen et al., 2005).

Regarding the time to exhaustion, significant differences can be observed between tests (Table 1). Practically, this difference means about 85 s, higher in T-VAM. These TTE values are in agreement with the data reported in the literature, which indicates a TTE at maximal aerobic speed ranging from 2.5 to 10 minutes (Billat et al., 1999). Concerning the difference between TTE, it appears that the cost of accelerating, decelerating and changing direction in shuttle tests determines a decrease in running economy (Buchheit et al. 2011), in turn impairing a sustained time at PV.

Moreover, Bertuzzi et al. (2012) demonstrated that



total energy production,  $\text{VO}_2\text{peak}$ , and lower limb muscle power are the main physiological and neuromuscular determinants of TTE at  $\text{vVO}_2\text{max}$  during treadmill running. To our knowledge, there are no studies that analysed similar associations during shuttle-run exhaustion tests. However, Padulo et al. (2012) found a systematic increase in ground contact time and step frequency during a shuttle run (i.e. Yo-Yo endurance test) at 95% of PV. This result suggests that an increased energy cost occurred due to increased lower limb muscle activity triggered by increased ground contact time.

Thus, based on these observations, it may be concluded that differences in TTE between straight-line and shuttle run protocols can be explained by greater neuromuscular and physiological overload involved in the shuttle run model (Bucheit et al. 2011), impairing the lower limb in generation of muscle power (Padulo et al. 2012).

Furthermore TTE can be used to estimate the bout duration of high intensity intermittent training to elicit a high percentage of  $\text{VO}_2\text{max}$  (Billat et al., 1999; Millet et al., 2003). Previous studies have suggested that bout duration during high intensity intermittent training at PV could lie between 50% and 60% of TTE, with a 1:1 work:recovery ratio (Millet et al., 2003; Esfarjani and Laursen, 2007).

Considering that the present study was conducted with physically active students, the results must be limited to people with similar characteristics. Further studies addressing male and female team-sport players are warranted.

## Conclusion

In summary, the results of the present study showed that the PV obtained in T-VAM versus T-CAR were similar and demonstrate a high level of agreement, thus, the maximal variables derived from T-CAR and T-VAM could be exchanged when designing training programs. However, caution must be taken regarding interchangeability of time to exhaustion at PV.

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### Key points

- T-CAR is an intermittent shuttle run test that predicts the maximal aerobic speed with accuracy, hence, test results could be interchangeable with continuous straight-line tests.
- T-CAR provides valid field data for evaluating aerobic fitness.
- In comparison with T-VAM, T-CAR may be a more favourable way to prescribe intermittent training using a shuttle-running protocol.

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