Time limit at peak speed without prior warm-up: Effects on test duration, heart rate and rating of perceived exertion

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Summary

Background: Time limit (t_{lim}) at peak speed (V_{peak}), that is maximal time that an individual can keep running at maximal intensity, is used to prescribe interval durations during interval training. The aim of this study was to compare two protocols (without or with 15 minutes of warm-up) for the t_{lim} determination at 100% of V_{peak} in untrained men.
Material and method: Twelve untrained young men performed three running tests on a treadmill: one maximal incremental test to determine V_{peak} and two rectangular tests, performed in randomized order, without a warm-up (t_{lim0}) or with a 15-minute warm-up duration (t_{lim15}) at 60% of V_{peak} to determine the t_{lim} at 100% of V_{peak}, after the warm-up the tests were performed at the speed of the individual V_{peak} until volitional exhaustion. During the tests, heart rate (HR) and rating of perceived exertion (RPE) were monitored and blood lactate sampling was collected prior to session (LA_{pre}); immediately post-exercise ($LA_{0\text{-}min}$); 3 min ($LA_{3\text{-}min}$), 5 min ($LA_{5\text{-}min}$) and 7 min ($LA_{7\text{-}min}$) post-exercise to determine lactate concentrations. The Shapiro-Wilk test was used and confirmed the normality of the data distribution, with maximal and submaximal values compared using Student´s *t* test for dependent samples.
Results: Test duration at t_{lim0} was significant higher than that at t_{lim15} ($P = 0.02$). Additionally, different t_{lim} protocols influenced HR and RPE submaximal responses and did not modify lactate concentrations or maximal variables (HR_{max} and RPE_{max}).
Conclusions: These findings suggest that the determination of t_{lim} at 100% of V_{peak} without a prior warm-up led to a higher test duration in untrained men.

Key words:
Running. Exercise test. Physical endurance.

Tiempo límite en la velocidad máxima sin calentamiento previo: efectos sobre la duración de la prueba, frecuencia cardíaca y grado de esfuerzo percibido

Resumen

Objetivos: Tiempo límite (t_{lim}) en la velocidad máxima (V_{pico}), que es el tiempo máximo que un individuo puede permanecer corriendo en la intensidad máxima, se utiliza para prescribir la duración de los intervalos durante el entrenamiento interválico. El objetivo de este estudio fue comparar dos protocolos (sin o con 15 minutos de calentamiento) para la determinación de t_{lim} al 100% de la V_{pico} en hombres no entrenados.
Material y método: Doce jóvenes no entrenados realizaron tres pruebas de carrera en la cinta rodante: una prueba incremental máxima para determinar V_{pico} y dos pruebas rectangulares, realizadas en orden aleatorio, sin calentamiento (t_{lim0}) o con una duración de calentamiento de 15 minutos (t_{lim15}) al 60% de la V_{pico} para determinar el t_{lim} al 100% de la V_{pico}; después del calentamiento las pruebas fueron realizaradas en la velocidad de la V_{pico} individual hasta el agotamiento voluntario. Durante las pruebas, la frecuencia cardíaca (FC) y el grado de esfuerzo percibido (RPE) fueron monitorizadas y se tomaron muestras de sangre antes de la sesión (LA_{pre}); inmediatamente después del ejercicio ($LA_{0\text{-}min}$); 3 min ($LA_{3\text{-}min}$), 5 min ($LA_{5\text{-}min}$) y 7 min ($L_{A7\text{-}min}$) después del ejercicio para determinar las concentraciones de lactato. Se utilizó la prueba de Shapiro Wilk y se confirmó la normalidad de la distribuición de los datos, con los valores máximos y submáximos comparados utilizando la prueba t de Student para muestras dependientes.
Resultados: La duración de la prueba en el t_{lim0} fue significativamente mayor que aquella en el t_{lim15} ($P = 0.02$). Además, los diferentes protocolos de t_{lim} influenciaron las respuestas submáximas de FC y RPE y no modificaron las concentraciones de lactato o las variables máximas (FC_{max} y RPE_{max}).
Conclusiones: Estos resultados sugieren que la determinación del t_{lim} en la 100% de la V_{pico} sin calentamiento prévio lleva a una mayor duración de la prueba em hombres no entrenados.

Palabras clave:
Carrera. Prueba de ejercicio. Resistencia física.

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Introduction

Endurance racing has been gaining popularity recently; thus, the training prescriptions linked to running performance improvements have received great attention[1,2]. Such prescriptions should be planned for each individual according to the physiological (*e.g.*, heart rate [HR]), psychological (*e.g.*, rating of perceived exertion [RPE]), and performance variables (peak speed [V_{peak}], time limit [t_{lim}]) that control and monitor effort intensity[3].

The t_{lim} is the maximal time that an individual can maintain a given exercise intensity[4], such as V_{peak} occurrence velocity. The original protocol for the t_{lim} determination included a prior 15-minute warm-up at an intensity equivalent to 60% of the reference velocity (*e.g.*, V_{peak} or velocity associated with the occurrence of maximal oxygen uptake [vVO_{2max}]); after the warm-up, without interval, the velocity is automatically increased to 100% intensity, at which the individual should remain as long as possible until volitional exhaustion[4]. However, warm-up duration (5, 10 or 15 minutes) modified the test duration (t_{lim})[5].

Studies demonstrated that various warm-up types, such as stretching (static and dynamic)[6], whole-body vibration[7], and the traditional warm-up consisting of low-intensity cycling[8], could positively or negatively influence aerobic performance. For instance, Tomaras & Macintosh[8] investigated a sample of highly trained male track cyclists and compared the traditional warm-up (WU) for a 200-m sprint in a track cycling competition with an experimental WU that was designed to be shorter and less intense and examined the fatigue and cycling performance after traditional and experimental WU. Results from this study showed that peak active twitch torque was lower after the traditional than experimental WU when expressed as percentage of pre-warm-up amplitude, and Wingate test performance was better after experimental WU than traditional WU; indeed, the traditional track cyclist's WU results in significant fatigue, which corresponds with impaired peak power output, and shorter and lower intensity WU permits a better performance.

However, a recent study showed that warm-up duration (5, 10 or 15 minutes) modified the test duration (t_{lim}) of untrained men in which the warm-up comprising 15 minutes led the participants to exercise for a shorter time compared to other t_{lim} protocols[5]. Since t_{lim} is a variable that is used to determine the optimal stimulus durations in interval training sessions[9-11], this longer or short duration altered by warm-up will directly impact this prescription.

Nevertheless, to the best of our knowledge, there is still a lack of studies that analyzed the best duration of the warm-up[5] and knowing the importance of warm-ups prior to exercise and that the duration modifies the t_{lim}[5], the aim of this study was to compare two protocols (without and with a 15-minute warm-up) for the t_{lim} determination at 100% of V_{peak} in untrained men. Our hypothesis is that the t_{lim} determined without a warm-up will differ from that of the t_{lim} performed with a 15-minute warm-up.

Material and method

Twelve untrained young men, not included in systematic running training programs, with training volume less than 20 km per week, volunteered to participate in this study. The 5-km running times reported by participants were between 25 and 35 minutes, with a pace between 8.6 and 12 km•h^{-1} (≅ 36.1 and 50.4 % of the world record). The main characteristics of the participants were: age 21.4 ± 2.3 years, height 1.8 ± 0.1 m, body mass 76.7 ± 10.9 kg, body mass index (BMI) 24.2 ± 2.8 kg•m^{-2} and body fat 15.3 ± 4.2%. Prior to testing, written informed consent was obtained from all participants. The experimental protocol was approved by the local Human Research Ethics Comittee (#1.262.502/2015) and appropriate standards for human experimentation have been followed.

Experimental overview

Participants performed three tests on a motorized treadmill (Super ATL Inbrasport, Porto Alegre, Brazil), with the gradient set at 1%. In the first visit the evaluation of the anthropometric measurements was performed, and the participants were submitted to a maximal incremental test to determine V_{peak}. After, in a randomized order, two rectangular tests with warm-up durations of 15 minutes and without warm-up were performed to determine the t_{lim} at 100% of V_{peak}. The tests were performed over 2 weeks, with each test separated from the other by 48 hours. For all tests, participants were instructed to stay well-rested, well-nourished, and well-hydrated, wearing lightweight comfortable clothing. Participants were also instructed to avoid eating for 2 hours before the maximal exercise test, to abstain from caffeine and alcohol and to refrain from strenuous exercise for 48 hours before testing. Tests were conducted at the same time of the day, under normal laboratory conditions (temperature 20-22 ºC, relative humidity 50-60%).

Incremental exercise test to determine V_{peak}

After a warm-up, comprised walking at 6 km·h^{-1} for three minutes, the continuous protocol started with a speed of 8 km·h^{-1} and increased by 1 km·h^{-1} between each successive 3-minute stage until participants reached volitional exhaustion[12]. The V_{peak} of the incremental test was calculated as the speed of the last complete stage added to the completed fraction of the incomplete stage[13], calculated according to the equation:

$$V_{peak} = V_{complete} + (t/T \times \text{speed increment})$$

where $V_{complete}$ is the running speed of the last complete stage, t the time in seconds sustained during the incomplete stage, and T the time in seconds required to complete a stage (*i.e.,* 180 seconds), and speed incremental is the speed load increment. The maximal effort was deemed to be achieved if the incremental test met two of the following criteria: 1) $LA_{peak} \geq 8$ mmol•L^{-1} [14] 2) $HR_{max} \geq 100\%$ of endurance-trained age-predicted HR_{max} using the age-based (207 - 0.7 × age) equation[15] and 3) $RPE_{max} \geq 19$ in the 6-20 Borg Scale[16].

Rectangular tests to determine the t_{lim} at V_{peak}

The two rectangular tests differed only by presence or absence of the warm-up of 15 minutes. After the warm-up at 60% of V_{peak}, the treadmill speed was quickly increased (in approximately 6 seconds) to the individual at 100% of V_{peak}[4]. Participants were also encouraged to invest maximal effort and the time of permanency in this intensity was considered the t_{lim} at 100% of V_{peak}.

Psychophysiological and physiological variables

Before testing participants were familiarized with the 6–20 Borg scale[16], which was used to determine the rating of perceived exertion (RPE) during the last 15 seconds the stages of V_{peak} and every minute in t_{lim}. The highest RPE value was adopted as the maximal RPE (RPE_{max}). Heart rate (HR) was monitored throughout the tests (Polar RS800sd, Kempele, Finland) and in the last 10 seconds of each stage da V_{peak} and every minute in t_{lim} HR was registered; the maximal heart rate (HR_{max}) was defined as the highest HR value observed during the tests[15]. Earlobe capillary blood samples (25 µL) were collected in a capillary tube to determine the lactate concentrations. These samples were collected before (LA_{pre}) all exercise tests, after the incremental test at the third ($LA_{3\text{-}min}$) and fifth ($LA_{5\text{-}min}$) minutes, and at the end ($LA_{0\text{-}min}$), at the $LA_{3\text{-}min}$, $LA_{5\text{-}min}$ and seventh ($LA_{7\text{-}min}$) minutes after the rectangular tests. For the LA_{pre}, the participants remained at rest for 15 minutes in a comfortable chair prior to the sampling procedure. For the $LA_{0\text{-}min}$ blood sampled collection the participants remained standing upright on the treadmill, and for the $LA_{3\text{-}min}$, $LA_{5\text{-}min}$, $LA_{7\text{-}min}$ samples the participants remained sitting in a comfortable chair. Peak blood lactate concentration (LA_{peak}) was defined for each participant as the highest post-exercise blood lactate concentration value. The samples were subsequently determined by electroenzymatic methods using the YSI 2300 STAT (Ohio, USA) automated analyzer (accuracy ± 2%).

Statistical analysis

Data are presented as mean ± SD and were analyzed using the Statistical Package for the Social Sciences software v. 20.0 (SPSS Inc., Chicago, IL, USA). The Shapiro-Wilk test was used and confirmed the normality of the data distribution. Maximal and submaximal values were compared using Student´s *t* test for dependent samples. Statistical significance was set at $P < 0.05$.

Results

The variables obtained during the exhaustion incremental test to determine the V_{peak} were: V_{peak} = 12.7 ± 1.2 km•h^{-1}, test duration = 17.1 ± 3.8 min, HR_{max} = 187 ± 8.7 bpm, RPE_{max} = 19.8 ± 0.5 and LA_{peak} = 8.6 ± 3.2 mmol•L^{-1}.

Table 1 compares t_{lim} test duration, maximal variables (HR_{max}, RPE_{max}, and LA_{peak}) and post-test lactate concentrations obtained during the two tests. Test duration at t_{lim0} was significantly higher than that at t_{lim15} (P = 0.02). However, no significant difference was seen in the other variables.

Comparisons between HR and RPE values obtained during the two tests for t_{lim} determination are shown in Table 2. Only the minutes in which the participants remained throughout the two tests were analyzed. Significant differences were noted in the HR and RPE values until the fifth minute ($P \leq 0.01$), in the RPE value at the sixth minute (P = 0.04), and in HR value at seventh minute (P = 0.02).

Table 1. Comparison between the variables: test duration (min), HR_{max} (bpm), RPE_{max} (6-20, AU) and blood lactate concentrations (mmol•L^{-1}) obtained during the t_{lim0} and t_{lim15} (N = 12).

Variables	t_{lim0}	t_{lim15}	*P*
Test duration (min)	9.4 ± 2.2	6.0 ± 2.0*	0.02
HR_{max} (bpm)	184 ± 11.0	184 ± 10.9	0.80
RPE_{max} (6-20, AU)	19.9 ± 0.3	19.9 ± 0.3	1.00
LA_{pre} (mmol•L^{-1})	1.1 ± 0.3	1.0 ± 0.2	0.30
$LA_{0\text{-}min}$ (mmol•L^{-1})	8.5 ± 2.0	7.1 ± 2.4	0.07
$LA_{3\text{-}min}$ (mmol•L^{-1})	8.6 ± 2.7	8.2 ± 3.1	1.00
$LA_{5\text{-}min}$ (mmol•L^{-1})	8.4 ± 2.3	7.7 ± 3.3	0.11
$LA_{7\text{-}min}$ (mmol•L^{-1})	8.1 ± 2.3	7.5 ± 3.3	0.42
LA_{peak} (mmol•L^{-1})	9.5 ± 2.6	8.4 ± 3.3	0.13

Note: AU: arbitrary units; bpm: beat per minute; HR_{max}: maximal heart rate; LA_{pre}: blood lactate concentration at the before of the test; $LA_{0\text{-}min}$: blood lactate concentration at the end of the test; $LA_{3\text{-}min}$: blood lactate concentration at the third minute after the test; $LA_{5\text{-}min}$: blood lactate concentration at the fifth minute after the test; $LA_{7\text{-}min}$: blood lactate concentration at the seventh minute after the test; LA_{peak}: peak blood lactate concentration; RPE_{max}: maximal rating of perceived exertion.
*$P < 0.05$ compared with t_{lim0}.

Table 2. Comparison between the HR (bpm) and RPE (6-20, AU) submaximal values (min) at each minute obtained during the t_{lim0} and t_{lim15}.

Time	HR (bpm)			RPE (AU)		
	t_{lim0}	t_{lim15}	*P*	t_{lim0}	t_{lim15}	*P*
1 min (n=12)	143±12.4	167±10.9*	< 0.01	8.0±2.4	13.8±2.6*	< 0.01
2 min (n=12)	159±11.6	175±10.3*	< 0.01	10.0±2.9	15.5±2.4*	< 0.01
3 min (n=11)	165±10.9	180±9.2*	< 0.01	13.0±3.3	16.9±2.1*	< 0.01
4 min (n=10)	170±10.8	183±9.2*	< 0.01	14.5±3.1	17.9±1.8*	< 0.01
5 min (n=9)	172±10.7	183±8.5*	0.01	16.0±2.7	18.6±1.7*	0.01
6 min (n=6)	174±10.3	184±7.9	0.07	17.0±2.8	18.8±1.2*	0.04
7 min (n=4)	177±9.8	185±10.5*	0.02	19.0±2.3	19.8±0.5	0.06
8 min (n=3)	179±10.5	190±2.0	0.07	19.5±2.2	20.0±0.0	0.42

Note: AU. arbitrary units; HR. heart rate; RPE. rating of perceived exertion.
*$P < 0.05$ compared with t_{lim0}.

Discussion

This study aimed to compare the two protocols (without and with a 15-minute warm-up) in the t_{lim} determination at 100% of V_{peak} in untrained men. The main finding of the present study was that the different protocols for the t_{lim} determination had different test durations;

in particular, the absence of the 15-minute warm-up period led participants to run for a longer duration than the heating test, confirming our hypothesis. Furthermore, the t_{lim} protocol influenced the HR and RPE during the test responses but did not modify lactate concentrations or the maximal variables (HR_{max} and RPE_{max}).

Previous investigations determined t_{lim} using a standard protocol with a 15-minute warm-up duration at 60% of maximal aerobic speed (MAS), vVO_{2max}, or V_{peak}[4,5,17]. Other studies used different warm-up durations (t_{lim10} and t_{lim5})[5,18,19], but none omitted the warm-up (t_{lim0}). This is the first study to investigate performance in a protocol for determining t_{lim} without a previous warm-up and compared it with the standard protocol (t_{lim15})[4]. Our results demonstrated that the runners participated for a longer duration in the protocol without a warm-up than in the protocol with a warm-up. This result was similar to those of Da Cruz *et al.*[5] and Bertuzzi *et al.*[18], who used shorter warm-up protocols (*i.e.*, t_{lim10} and t_{lim5}) when testing untrained young men and recreational long-distance runners, respectively. When investigating the influence of different warm-up durations on determining t_{lim} (*i.e.*, t_{lim15}, t_{lim10}, t_{lim5}), Da Cruz *et al.*[5] reported a longer participation time in the protocol with a shorter warm-up duration for t_{lim} determination. Similarly, Bertuzzi *et al.*[18] observed that the participants remained in the protocol with a 5-minute warm-up longer than they did in the protocol with a 10-minute warm-up. Thus, a longer warm-up time for the t_{lim} determination showed a negative effect on test duration and may be a tiring factor prior to exercise. The longer warm-up duration seems to cause greater physiological wear in the participants at the beginning of the test as demonstrated by the higher values of HR and RPE in the t_{lim15} protocol than in the t_{lim0} protocol observed in the present study.

In addition to warm-up duration, t_{lim} seems to be influenced by participant fitness level since there was an inverse correlation between MAS and t_{lim}[4,20,21]. Renoux *et al.*[20] reported a mean t_{lim15} value of 4.5 ± 1.3 minutes in trained runners, similar to that observed by Billat *et al.*[4] (*i.e.*, 5.01 ± 0.9 minutes) in a study of trained runners that showed a shorter t_{lim} duration than the results of our study for the t_{lim15} protocol (*i.e.*, 6.0 ± 2.0 minutes) as well as the study of Da Cruz *et al.*[5] (*i.e.*, 5.9 ± 1.7 minutes) that evaluated untrained young males. These results show that it is possible to observe a difference in t_{lim} duration despite use of the same protocol (t_{lim15}) due to differences in participant fitness levels.

Since t_{lim} is a variable that is used to determine the optimal stimulus durations in interval training sessions[9-11], this longer duration found by a lack of a warm-up will directly impact this prescription. Previous studies using t_{lim} to prescribe interval training showed that if these sessions do not have the ideal duration, runners may not complete the training and/or show no improvement because of a low stimulus intensity[10,11,22]. Billat *et al.*[10] tested the training effect in that the stimuli had a duration of 50% of t_{lim} in vVO_{2max} in the interval training sessions, and no differences were found in the aerobic variables associated with performance after 4 weeks of training. Similarly, some authors[11,22] tested different combinations of vVO_{2max} and its respective t_{lim} for individualized training with series of 60 and 75%; 60 and 70% of t_{lim} in vVO_{2max}, respectively. As a result, performance improvements were observed only for the groups that trained with the series duration at 60% of t_{lim} in vVO_{2max}. The results of these studies suggest that small changes in t_{lim} duration can have a great impact on the training prescription. Thus, the correct choice of the protocol for determining the t_{lim} is important because the warm-up time (its lack or presence) will directly affect the t_{lim} duration and, therefore, the training prescription.

Regarding HR, RPE, and lactate concentration responses during the test, the protocols with different warm-up durations (*i.e.*, t_{lim0} and t_{lim15}) were not expected to affect the maximal variables (HR_{max}, RPE_{max}, and LA_{peak}). However, when the during the test HR and RPE responses were analyzed during the different warm-up times, we obtained smaller values in the t_{lim0} protocol compared to the t_{lim15} protocol. A similar result was found by Da Cruz *et al.*[5], who observed higher values for these variables in the protocol with a 15-minute warm-up compared to protocols with 5- and 10-minute warm-ups. This change can be explained by the increase in cardiovascular activity after exercises with durations > 10 minutes caused by changes in thermoregulatory mechanisms, energy substrates, and increased blood flow[23,24], which also affected the participants final performances.

Despite the important findings of our study, one limitation was that the determination of the V_{peak} (and warm-up based on V_{peak}) could led to different individual intensities relative to the velocity of anaerobic threshold (vAT). Thus, despite of V_{peak} and vAT are correlated with endurance running performance[12,25] no previous study examined the relationship between V_{peak} and vAT. Future studies should investigate the relationship between V_{peak} and vAT and to better understand how differences in relative intensities of vAT could affect the time limit performance.

Conclusion

Therefore, we conclude that the lack of a 15-minute warm-up, based on the protocol proposed by Billat *et al.*[4], for determining t_{lim} leads to a longer test duration at 100% of V_{peak} and modifies the responses during the test variables (HR, RPE) in untrained men. This result may impact or interfere with the use of t_{lim} for interval training prescriptions. Hence, we suggest that further studies should be performed in training protocols with different warm-up durations to evaluate the impact of the use of time limits.

Conflict of interest

The authors do not declare a conflict of interest.

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