



The Conconi Test – Searching for the Deflection Point

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Abstract

Introduction: The Conconi Test (CT) is an incremental exercise test characterized by stages of equal intensity. For analysis speed (S) and HR (heart rate) are used. The deflection point of the HR/S graph marks the point where the linear relation between S and HR changes to a curvilinear one. As Conconi stated HR at deflection point represents anaerobic threshold (AT) value. Purpose of this study was to extend our previous research dealing with reliability and validity aspects of CT. **Material and Methods:** During 10 years (2007–2017) we tested 2 500 subjects using Conconi protocol. Tested were mainly football players and smaller number of runners (long distance and cross country) different ages and fitness level. Some subjects were tested repeatedly during the years. Initial speed of the running treadmill test was determined in the range of 10 to 12 km·h⁻¹, according subjects age and fitness level. Speed was increased gradually every 150 m of 0.5 km·h⁻¹ to the maximum speed when further increases were impossible. HR was recorded at every 150 meters. From a graphical representation dependence HR on increasing running speed we tried to find apparent diversion from the curve of linearity, labeled by Conconi as "deflection point" (DP). Simultaneously respiration values were recorded. From these respiration data we determined the ventilatory threshold (VT₂) as a metabolic marker of the onset of blood lactate accumulation. **Results:** We found 6 types of response HR to increasing speed. a) regular DP; b) linear regression $r \geq 0.98$ – no DP; c) linear regression $r < 0.98$ – no DP; d) inversion character of deflection point; e) DP not corresponding with value of ANP; f) more than one DP. As an AT predictor compared with VT₂, Conconi test overestimated this value (0.5 km·h⁻¹). **Conclusion:** Using of Conconi test as a predictor of ANP has a limitation. ANP values determined by CT are overestimated (0.5 km·h⁻¹). Test stability of CT is very low and there is evidence that DP is not 100% repeated physiology phenomena.

Keywords: anaerobic threshold, heart deflection point, heart rate

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INTRODUCTION

The Conconi Test (CT) is a non-invasive incremental performance test characterized by stages of equal intensity. For analysis intensity (speed or power) and HR (heart rate) are used [1]. The linear curve of the HR and movement intensity correlation disrupts at a specific point which is called the heart rate deflection point (HRDP) and according to Conconi this value is associated with the value of the anaerobic threshold (AT)

After Conconi defines this physiological phenomenon in his work, he then cites studies conducted by Pendergast et al. [2], who proved that the increased oxygen consumption (VO_2) above the AT level is lower than the proportional increase of activity intensity. Conconi assumes that the speed increase above AT levels is partially dependent on VO_2 and HR and thus the increasing speed above the AT levels is not accompanied by the same increase of HR as we can see in below-submaximal intensities.

This theoretical concept has many opponents. Some studies bring up information of the linear characteristics of HR response based on the increasing performance difficulty during CT, or the occurrence of an inversion deflection point [3–9]. Some researchers expressed doubts about the existence of HRDP regarding it not to be a physiological phenomenon and pointing to it as the result of the test protocol [10]. Generally speaking, we may find a wide range of opinions about the existence of HRDP, and its observable and measurable aspects. Such discrepancies in professional sources may possibly also occur due to modified protocols to a certain extent [11], which are tailored to researchers' needs and take only the core aspects of the original Conconi Test design.

The constant distance of individual segments is frequently mentioned as the explanation for HRDP occurrence. Because the length/distance of the segment is constant and shortens mainly at the few last segments, the time segment needed for going through such a segment shortens as well. The ability of the organism and cardiovascular system to efficiently adapt to the increasing challenge also decreases. This is also one of the HRDP aspects which have to be taken into account [12]. On the other hand, the adaptation of the cardiovascular system to the increasing stress is effectively set between 10 to 20 seconds, unless the speed increase is above $0.5 \text{ km}\cdot\text{h}^{-1}$. Vachon et al. [13] state that the sustainable set occurs between 10 to 20 seconds from the start (± 2 beats per minute) using the Conconi protocol. As can be seen from all of the previously mentioned studies, we may come to the conclusion that the curve deflection after HRDP establishment using the Conconi protocol and the HR curve deflection level is highly dependent on the protocol type used during the experiment [10]. Vachon et al. [13] also state that they were able to come to 100% efficacy level after an HRDP deflection curve establishment using the Conconi protocol in a training environment in contrast to a lab environment, in which case the efficacy level weigh only 50% using the running ergometer. Good reproducibility levels and visual analysis of the HRDP is currently more preferred to computer-based data processing, as Strupler et al. [14] suggest.

The issue is the CT validity to the AT criterion, e.g. Carey [15] excludes the practical use of CT, even though he managed to find significant difference ($p = 0.30$) between AT and CT levels using a Spiroergometer and V-slope method. The main cause of this, according to the author, is the low level of the correlation coefficient ($r = 0.458$), the high standard of error of the estimate ($10.7 \text{ t}\cdot\text{min}^{-1}$) and the high total error ($16.7 \text{ t}\cdot\text{min}^{-1}$) [12]. On the other hand, Petit et al. [16] compare the levels of HRDP with AT detected by a method which analyses the changes in the ventilation threshold with a high correlation coefficient ($r = 0.95$) and without any significant difference detected (deflexion point speed of $16.3 \pm 2.1 \text{ km}\cdot\text{h}^{-1}$ vs. a Ventilation threshold speed of $16.4 \pm 2.3 \text{ km}\cdot\text{h}^{-1}$.) A similar highly significant result has also been detected for HR (178 ± 7.7 for HRDP vs. 180 ± 9.9 beats per minute for the ventilation threshold) [16]. Even though a lot of studies have looked into such issues, none so far has been able to come with an unambiguous result.

Our study would like to provide answers for the following research questions: 1) Is it possible to detect HRDP on a treadmill by using the Conconi protocol? 2) Is this detection point equivalent to the AT level of the established golden standard, also known as the dynamic ventilation parameters?

MATERIAL AND METHODS

Participants

During the last 10 years (2007–2017) more than 2500 subjects participated, in lab conditions, in a modified test conducted according to the Conconi protocol. The subjects were, in the majority, football players who were on a national performance level of participation in Czech senior, youth, and junior leagues ($n=2170$, mean age 24.3 ± 3.6 years, then a smaller number of professional runners of a variety of performance levels (medium and long-distance trail $n = 330$, mean age 29.3 ± 3.2 years). Some subjects participated regularly in the study for over 10 years. All the subjects signed informed consent.

Procedures

All subjects underwent a modified CT test using the motorized runner ergometer HP Cosmos Venus (HP Cosmos Sports and Medical, Germany). Before the testing itself, an individual warm-up exercise took place, each taking two 3-minute exercise segments on a treadmill. The initial CT speed was set to 10, which was $12 \text{ km}\cdot\text{h}^{-1}$ based on the individual performance of each subject. The slope angle was set to 1% as a compensation for the decreased resistance in the environment. After each 150 m reached, the speed was increased by $0.5 \text{ km}\cdot\text{h}^{-1}$. Subjects continued with the increasing speed until exhaustion. To increase the motivation for running, each subject was informed about the current running speed and the distance left after each 150 m segment.

A Cardiometer Polar S810i was used for HR level recording, the gained data were then processed via Polar Precision Performance (Polar Electro, Kempele, Finland) software. All of the 2500 CT attempts were recorded. The following visual inspection helped to identify individual occurrences (or absences) of HRDP.

For the purposes of the second research question, during the modified CT ergometer testing, the values of ventilation and respiratory parameters using the Oxycon Delta (Jaeger, sub. of Viasys Healthcare, Germany) device were recorded simultaneously while the subject was running on the treadmill. The two-way valve with a mouthpiece and a nose clip to prevent nasal breathing, connected to a computer system, was used to record the respiratory parameters. The exhaled gas was analysed via an O_2 and CO_2 analyser connected to a computer system. The same method was used for measuring the levels of the ventilated air after each exhalation.

The mean values were acquired from eight breathing cycles. The Oxycon delta machine was calibrated by an internal calibration method. The integrated software (LAB Manager 4.65e, Viasys Healthcare, Hoechberg Germany) recorded a curve of ventilation air volume (V_E) based on the increasing breathing difficulty. The inflection curve point of the minute ventilation was set by a two-part linear model. The set point was then used to identify the AT level (AT V_E). This value was then associated with the appropriate running speed and HR level.

To analyze the relation of both methods for AT detection (AT V_E a AT HRDP) we selected a random sample of 50 measurements from the overall data sample, which had positive HRDP detection ($N = 1925$).

Statistical Analysis

First part: correlation coefficient (r value for setting the linear correlation of the running speed and HR after HRDP positive detection. Visual HRDP analysis.

Second part: Means and standard deviations for AT HR and velocity assessed by the two methods as well as the correlation coefficient were determined (Table 1). t -value, z -value, p -value, standard error of estimate (SEE), and total error (TE) were identified (Table 2) to accept or reject the null hypothesis of no significant difference between the two methods of AT determination. Shapiro-Wilk test for normal distribution. Paired samples T-test, Wilcoxon test respectively.

Graphical analysis via graph modification based on the residual regression values (Bland-Altman plot). In case a difference trend is detected ($x - y$), correlation between the values of ($x - y$) and $(x + y)/2$ was calculated and then the statistical significance and effect size for rejection of possible proportional error was calculated. Visual inspection of any possible data heteroscedasticity.

RESULTS

Part 1: Out of all 2500 CT detection attempts, 6 heart rate deflection point variants (HRDP) were detected on the curve based on the difficulty intensity of HR. a) regular HRDP – 77% cases; b) linear regression $r \geq 0.98$ – no HRDP – 9%; c) linear regression $r < 0.98$ – no HRDP – 4%; d) inversion character of HRDP – 2%; e) DP probably not corresponding with value of $AT V_E$ – 6%; f) more than one HRDP – 4%. Examples of the individual HR response types are visible in Figure 1. Part 2: The mean difference of the speed level associated with $AT V_E$ and HRDP is $0.53 \text{ km}\cdot\text{h}^{-1}$ in favour of $AT V_E$ and thus equal to the systematic error method, which can be also seen via the Bland-Altman plot for speed (Fig. 2).

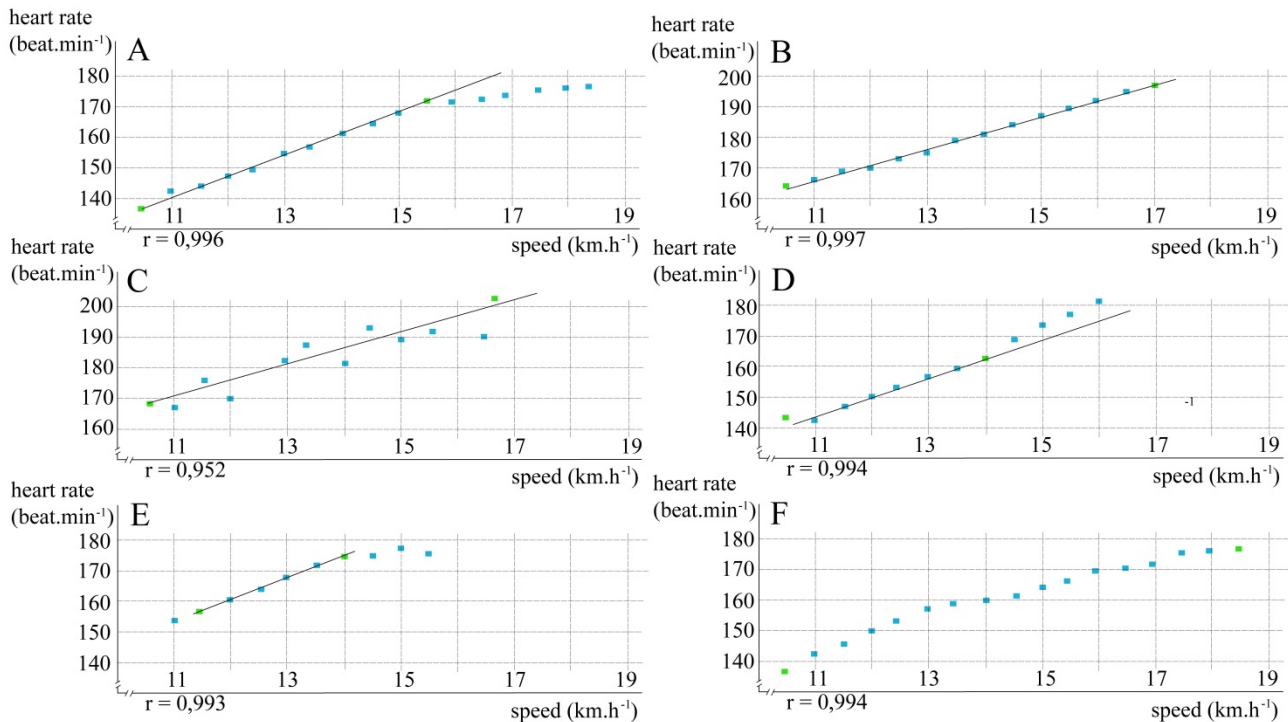


Figure 1. Examples of heart rate deflection point (HRDP) variants. A) regular HRDP; B) linear regression $r \geq 0.98$ – no HRDP; C) linear regression $r < 0.98$ – no HRDP; D) inversion character of HRDP; E) HRDP probably not corresponding with value of $AT V_E$; F) more than one HRDP

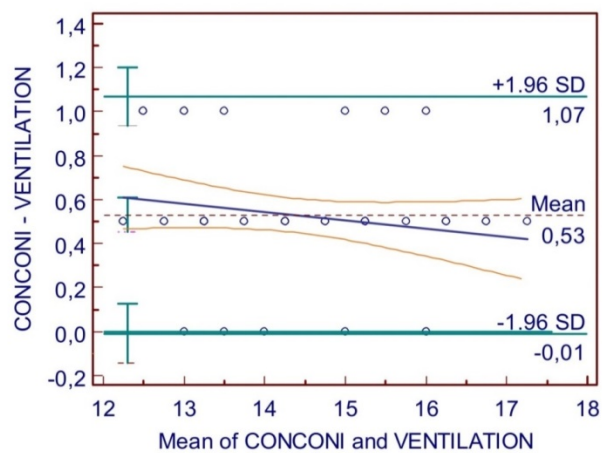


Figure 2. Bland Altman plot of velocity differences between Conconi method and Ventilatory method vs. the mean of the two measurements. The bias of $0.53 \text{ km}\cdot\text{h}^{-1}$ is represented by the gap between the zero axis, corresponding to a zero differences, and the mean line at $0.53 \text{ km}\cdot\text{h}^{-1}$.

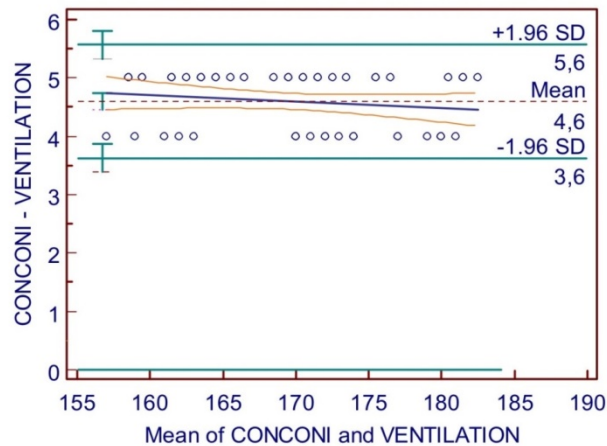


Figure 3. Bland Altman plot of HR differences between Conconi method and Ventilatory method vs. the mean of the two measurements. The bias of 4.6 b.min⁻¹ is represented by the gap between the zero axis, corresponding to a zero differences, and the mean line at 4.6 b.min⁻¹.

Table 1. Means (M) ± standard deviation (SD), and correlation coefficient (r) for anaerobic threshold heart rate (AT HR and anaerobic threshold velocity (AT VEL)

	AT HR		AT VEL	
	M ± SD (b·min ⁻¹)	r	M ± SD (b·min ⁻¹)	r
Conconi method	175.64 ± 8.11	0.937	14.60 ± 1.35	0.967
Ventilatory method	168.52 ± 8.53		14.05 ± 1.39	

Table 2. The t-value, z-value, p-value, standard error of the estimate (SEE), for anaerobic threshold heart rate (AT HR) and velocity (AT VEL) differences.

	t-value (b·min ⁻¹)	z-value (b·min ⁻¹)	p-value (b·min ⁻¹)	SEE (b·min ⁻¹) SEE (km·h ⁻¹)
AT HR	4.278	-	0.001	7.100
AT VEL	-	5.776	0.044	0.550

The mean difference of the HR level associated with AT V_E and HRDP is 4.6 b·min⁻¹ in favour of HRDP AT and thus equal to the systematic error method, which can be also seen via the Bland-Altman plot for HR (Fig. 3).

Table 1 contains means, standard deviations, and correlation coefficients for AT HR and velocity assessed by the two methods. The mean AT heart rate assessed by the Conconi method (175.6 b·min⁻¹) was 7.12 b·min⁻¹ higher than the mean AT heart rate assessed by the ventilatory method (168.52 b·min⁻¹). The correlation coefficient (r = 0.937) showed a significant relationship between the 2 methods (p < 0.0001). The mean AT velocity assessed by the Conconi method (14.60 km·h⁻¹) was 0.55 km·h⁻¹ higher than the mean AT velocity by the ventilatory method (14.05 b·min⁻¹). The correlation coefficient (r = 0.967) showed a significant relationship between the 2 methods (p < 0.0001).

Table 2 contains t values, p values, z values and SEEs, for differences in the AT heart rate assessed by the two methods. The mean difference in heart rate (6.0 b·min⁻¹) was not significant. Therefore, the null hypothesis of no significant difference in methods has been accepted. However, the SEE of 7.1 b·min⁻¹, 0.55 km·h⁻¹ respective, were relatively large and practically statistically significant.

DISCUSSION

As the issue arises from the contemporary studies, the concept and principles of CT are widely and critically discussed. On one hand, the concept is accepted, but on the other, some academics reject the use of it, or individual aspects of it are criticized. An undeniable fact which contributes to this broad discussion of the CT concept is the occurrence of the deflection point in the HR response to the

progressively increasing physical stress. The main reason is that there has been no proven origin of this phenomenon; it has been only previously hypothesized how it may occur. One of the possible physiological mechanisms may be one of the functions of the heart ventricle and atrium. The sources suggest that the deflection point of the HR curve depending on the stress intensity significantly occurs as a biological marker/phenomenon and therefore cannot be regarded as an artefact which has a connection to a specific physical stress protocol [11].

The HR linear curve fitting based on the progressive physical stress level in all its reach (excluding the deflection point occurrence) and the statistical significance of $r \geq 0.98$ has been detected among 9 percent of all cases. Such a finding is in agreement with other published sources which state that a particular amount of CT results always shows a linear fitting in the overall curve range [11]. It is quite difficult to define and establish the causes of such a phenomenon, especially due to the fact that the physiological nature of the deflection point has not yet been specifically and sufficiently defined. One of the discussed possible causes might be the blockage of the parasympathetic nervous system, also other speculated origins are that this might be due to aging, pathological states of the heart muscle tissue, etc. Our findings suggest that a certain percentage of the HR results has occurred even within the repeated testing over several years, during which time the preceding results of a particular (same) subject also included those in which HRDP was detected. We assume then that neither maturation nor processing in the CNS have any significant role during the occurrence of this phenomenon, and more precisely, that they have no significant effect on the decreasing number of shown occurrences of such a phenomenon.

The correlation coefficient has been calculated to be 0.98, which has been set as a threshold value which informs us about the level of linear dependency (relation). The values under this threshold show a high variability of points around the regression line and we do not take into consideration the linear fitting which is necessary to define the deflection point by using the two-part linear model. This trend and the results of CT can also be seen in the high point variability of the HR values which is the indicating sign that the organism has not adapted efficiently to the muscular stress. Sources do not indicate any similar type of CT response. It is possible that this type is automatically assigned to the linear response type (e.g., example a) or assigned only to one of the dichotomy diversion categories of CT (positive \times negative detection of the deflection point). It is important, however, that such cases occurred in our study in a small number of measurements – 4% out of 2500 tests. It is also impossible to objectively exclude the possibility of an error made by the HR measuring devices, due to the fact that a certain percentage of the population has trouble during the HR measurement, which in a majority of cases is very precise. Another factor related to the cause of discrepancies may also be heart arrhythmia, which has not been tested during our study among any of the participants.

Influxive HRDP has been detected in only 2 percent of all cases. Similar findings exist in several other studies which discuss the causes of the influxive deviation from the linear trend. To give an idea, Hoffman [17], for example, in his study detected that 9.7% of all tested participants have the inversion type of deflection (tested on 277 healthy young males).

The causes of the inverse deviation from the linear trend are also related to the higher age of the subjects as a compensation for the probable functional limitations of the heart. With this in mind, age also results in a different sensitivity of the heart tissue to the catecholamine effects (5). On the other hand, Bunc and Heller [18] detected a normal linear trend among a vast majority of older men tested in their study (51.8 ± 5.41 years of age). Another possible explanation for the increased occurrence of the inflection deviation point can be linked to the pathologies of the heart tissue. Pokan [14] in his study states that 89% of patients after a heart attack have been tested positive for having the inverse deviation during the CT response. According to Forstr's hypothesis, the occurrence of the inverse deviation from the linear trend occurs mainly among patients with stabilized stages of heart disease with compensation mechanisms taking place in order to maintain the heart stroke volume in cases of left ventricular systolic/diastolic dysfunction [19]. Another possible aspect which an effect on the inflection point phenomenon can have has been put into question by an experimental study conducted by Pokan [10]. 20 individuals under the influence of an experimental treatment (parasympathetic nervous system blockage) has detected a significantly higher inclination to a linear (inverse) response of the CT during an increased stress situation, in comparison to the control group

of individuals treated with a placebo. A significant correlation has been proven between the inverse character of HRDP and the decreasing performance of the left ventricular function among patients who have suffered heart attacks previous to the testing [17].

HRDP has been detected, however, this does not refer to the anaerobic threshold level. This type of detectable HRDP has occurred among 6 percent of all tested cases, in all of which this included a high SF deflection point level, which has approximated closely to the HR maximum. Out of all examined sources it is possible to conclude that the anaerobic threshold levels range among trained individuals around 87–92% of maximal HR [10]. Our study showed that in the majority of cases the predicted level of anaerobic threshold, derived from the HRDP, 97% reach the maximum HR. It is possible to speculate whether each subject reached his individual maximum. Theoretical calculations of the maximum HR level only have an informative function and they do not reflect the individual differences in each individual's organism. Therefore, the maximum heart frequency cannot be taken into consideration as a valid aspect of the deflection point. One of the possible criteria which we may be able to use to judge the validity in the case of ambiguous output is the contrast stress level test (run for 5km, or 10km) set at the level of the predicted anaerobic threshold and its feedback evaluation. Similarly, we may proceed by setting the DP which would be similar to the anaerobic threshold level in cases in which the DP detection would be ambiguous, more specifically, when more interpretation of HRDP detection would be possible – such a multiplied HRDP result in our study has been detected in 4% of all cases.

CONCLUSION

Even though CT seems to offer a certain simplicity in its use, in terms of material equipment, it is important to keep in mind the limitations which the use of CT also involves. The main reason for this being that a certain percentage of CT results do not offer the unambiguous possibility of detecting HRDP, more precisely, the detection of the anaerobic threshold (if we accept Conconi's two physiologic parameters equivalence hypothesis). The lack of adherence to the standardization requirements, technical issues, and methodology error could have contributed to the undesirable results, as well as the undeniable fact that an unknown aspect could have contributed to the inability to detect HRDP levels in some attempts. It is, however, possible to conclude that HRP is a repeatable physiological phenomenon and as such it is able to be used for endurance diagnostics, training management, and the training feedback evaluation. The Conconi method for AT detection is, however, burdened with a systemic error and overvalues the measurements of $0.55 \text{ km}\cdot\text{h}^{-1}$, specifically the error is set to be around $7.1 \text{ b}\cdot\text{min}^{-1}$. This result has to be taken into account with some caution, specifically for this test data interpretation, only if we set the condition that the primary objective is to identify the AT.

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