IMPLEMENTATION AND EVALUATION OF EXISTING ALGORITHMS TO CALCULATE AEROBIC AND ANAEROBIC THRESHOLDS

Burgsteiner H[1], Dorn A[1], Gröschl W[2,3], Hofmann P[2,3], Müller A[2,3], Simi H[4], Tschakert G[2,3], Wallner D[4], Zutz S[1]

Abstract

One important factor in cardiac rehabilitation and training is the correct analysis of aerobic and anaerobic thresholds for individual training plans. Several published algorithms produce exact results within a very homogeneous group of subjects (similar age, weight and level of fitness). We implemented these algorithms and evaluated their accuracy against data of a heterogeneous group of subjects collected during progressive exercise tests. The selected algorithms partially produced accurate results for the prediction of the lactate thresholds on the heterogeneous data sets.

Keywords *–* ***Performance diagnostics, Algorithm, Aerobic Threshold, Anaerobic Threshold, Lactate Turn Points***

1. Introduction and motivation

Generating knowledge from existing data is a challenge in many areas of information technology, particularly in health technology. In performance diagnostics, for instance, the aerobic and anaerobic thresholds are important values that can be used for effective workouts both for professional athletes as well as for patients [7]. One standard method to calculate these values is the application of blood lactate concentration values, because lactate is part of the human metabolism and works as a source of energy [6, p.217]. For this purpose the blood lactate concentration of a single subject has to be measured several times during a progressive exercise test [8, p.119].

Besides this lactate based method for threshold determination, plenty of different algorithms are available, which are mainly based on non-invasively collected data. Most of these published algorithms are evaluated within a very homogenous and diminutive group of subjects (mainly young and healthy subjects) and produced good results within these groups. Because of that reason we implemented and evaluated existing algorithms to verify if they also produce accurate results in an age and performance heterogeneous group of subjects.

[1] Graz University of Applied Sciences, Institute for eHealth, Graz, Austria
[2] Institute of Sport Science, Exercise Physiology and Training Research Group, University of Graz, Austria
[3] Human Performance Research Graz, Medical University and University of Graz, Austria
[4] Graz University of Applied Sciences, Sport Science Laboratory, Bad Gleichenberg, Austria

Performance diagnostics includes examinations and tests to evaluate the physical fitness of a subject for generating an individual, target-oriented workout. These individual workouts are crucial for athletes but are also relevant for patients, particularly for those with cardiac and pulmonary diseases [3, 7, 8 p.119, 9]. The most important values are the aerobic and anaerobic thresholds. These thresholds are typically determined by analysing measured blood lactate concentration values obtained from progressive exercise tests (e.g. treadmill or cycle ergometer) of a subject [7, p.41]. During progressive exercise small blood samples (20µl) have to be taken several times.

The aerobic threshold or LTP1 (first lactate turn point) is the point at which the blood lactate concentration increases above resting value for the first time. Above this certain workload the muscle cannot oxidize the lactate itself but the whole body is able to do so. The anaerobic threshold or LTP_2 (second lactate turn point) is the point at which the blood lactate concentration begins to increase exponentially. At this stage even the whole body systems cannot oxidize the generated lactate anymore and exercise has to be terminated because of exhaustion [7, 8].

2. Methods and related literature

The selection of algorithms for the calculation of the aerobic and the anaerobic thresholds was performed by systematic literature research applying the search terms "anaerobic threshold", "aerobic threshold", "turn point", "respiratory compensation point", "heart rate turn point" and "heart rate threshold". Physiological reasonable methods for the calculation of the aerobic and the anaerobic thresholds were selected, analysed and the algorithms were afterwards implemented with the programming language MATLAB.

In the following section the different algorithms are described briefly. Further and detailed information can be taken from the original papers, which are quoted in the reference section. The target value of Beaver et al. is the anaerobic threshold [2]. Measurements applied were the oxygen uptake and the blood lactate concentration, which were analysed in a coordinate system. The point of interest is the data point at which the lactate curve begins to increase systematically. For this purpose the data was consecutively divided into two data sections at each point. The mean square error of the two regression lines, which were fit to each of the data sections were calculated. Subsequently, the intersection point of the regression lines of both sections were calculated for the partition where the sum of the mean square errors is the smallest .This intersection point is defined as the anaerobic threshold.

A newer algorithm from Beaver et al. [1] is based on the visualization of the slopes of the CO_2 output vs. O_2 uptake in order to detect the beginning of the excess of the CO_2 output generated from the buffering of H^+. The result of this calculation method is the aerobic threshold (but termed "anaerobic threshold" in the US).

Cross et al. [4] attempted to calculate both the aerobic and the anaerobic threshold. For that reason VE/VO_2 (ventilatory equivalent for oxygen), $VE/VC0_2$ (ventilatory equivalent for carbon dioxide), VT (tidal volume) and FR (breathing frequency) were displayed as a function of VO_2 uptake. Subsequently, 6^{th} degree polynomials were fitted to the different curves and the second derivative of the best-fit polynomial was calculated. The calculated extreme values were defined as aerobic or anaerobic threshold towards a formula headed by Cross et al [4].
Wisén and Wohlfart [9] described a method to calculate the aerobic as well as the anaerobic threshold. For the computation the O_2 uptake and the CO_2 output were plotted against time. A 6^{th}

degree polynomial was approximated to the different curves. The first derivatives of these polynomials were calculated. The aerobic threshold was the point at which dCO_2 was just below dO_2. The anaerobic threshold was the point at which RER (Respiratory Exchange Ratio VCO_2/VO_2) equalled 1.

Erdogan et al. [5] tried to calculate the aerobic threshold by means of a multi layer perceptron (MLP). The MLP, which calculates the most accurate results, consists of only one hidden layer with a sigmoid transfer function. The output layer has a linear transfer function. The training of the network was carried out by the Levenberg–Marquardt back propagation algorithm. Due to the limited data size we used a ten-fold cross-validation for the training of the MLP. The input vector consists of the following values: weight, age, BMI, the body height of the subjects and the average value of the heart rate of the last five stages before exhaustion of the progressive exercise test. The target value during the training process was the aerobic threshold, which was derived from our own laboratory tests. The use of these "gold-standards" as the target values enabled us to predict the anaerobic threshold.

2. 1. Subjects

As mentioned before, in the original papers the algorithms were tested against a very homogeneous group of subjects. *Table 1* gives an overview of the included subjects in the original papers. In most cases the subjects come from a very small age sample and also have a very similar fitness level.

Table 1: Range of the age and included subjects in the related literature

Related literature	Range of age (years)	Included subjects
[1] Beaver et al., 1986	19 – 39	10 male subjects
[2] Beaver et al., 1985	19 – 39	10 male subjects
[4] Cross et al., 2011	23 ±1	24 male, 4 female recreational cyclists
[5] Erdogan et al., 2009	21.6 ±4.5	225 male soccer players
[9] Wisén and Wohlfart, 2004	20 – 48	19 male subjects

In real life, patients and athletes do not show such a homogeneity. Hence, were curios how the published algorithms work on a much more diverse set of subjects. Furthermore, we also used two different data sets coming from treadmill and cycle ergometers in comparison to the reference studies (*Table 2*).

Table 2: Range of the age and included subjects in the data sets the algorithms were evaluated on

Data source	Range of age (years)	Included subjects
Treadmill Ergometer	12 – 69	9 male and 9 female subjects from low to high fitness level
Cycle Ergometer	20 – 61	13 male and 11 female subjects from low to high fitness level

3. Results

The algorithms were implemented in MATLAB exactly as described in the papers and tested with treadmill and cycle ergometer data. *Figure 1* shows as an example the results of one subject calculated according to Wisén and Wohlfart [9].

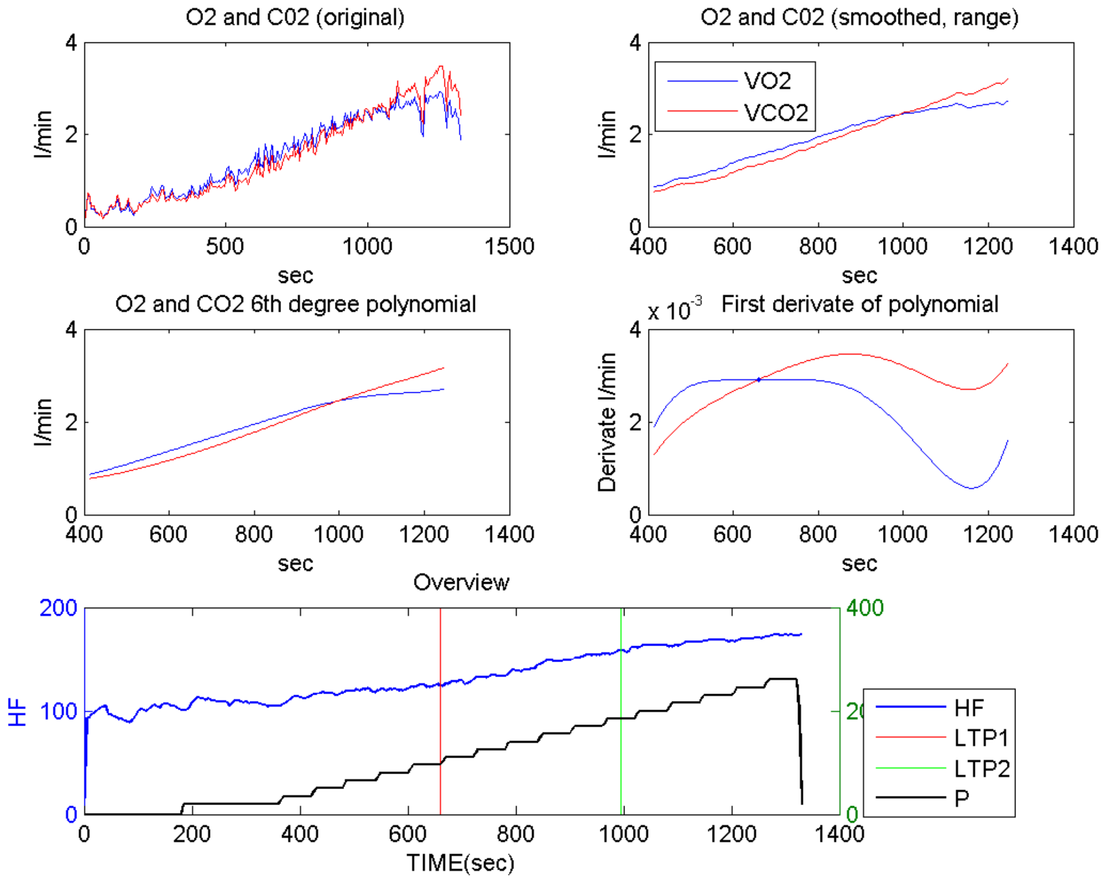

Figure 1: Result of the threshold calculation method according to Wisén and Wohlfart [9].
In the upper left corner the O2 and CO2 uptake over time during an incremental exercise test are illustrated. In the upper right corner the same values are shown, but the range of data was limited and the curves were smoothed. The middle left picture shows two approximated 6th degree polynomials. LTP2 is the intersection point of these two curves. The middle right picture shows the first derivate of the two polynomials. LTP1 is the intersection point of these two curves. The lowermost part of the figure shows the calculated aerobic and anaerobic thresholds (vertical lines) in comparison with the development of the heart rate (upper line) and the exposure (in watt) during incremental exercise test (lower line).

For comparison purposes the calculated heart rates at LTP_1 and LTP_2 were taken and compared to the heart rate at LTP_1 and LTP_2 from the original treadmill and ergometer data sets, which were calculated on basis of the standard lactate method laboratory. Our investigations showed that Wisén and Wohlfart [9] predicted the thresholds for LTP_1 best, Erdogan et al. [5] show best results for LTP_2. As expected, algorithms which were originally developed on more homogenous subject groups data (e.g. [5]) provided worse predictions on heterogeneous data sets than algorithms that were tested with a wider range of subjects.

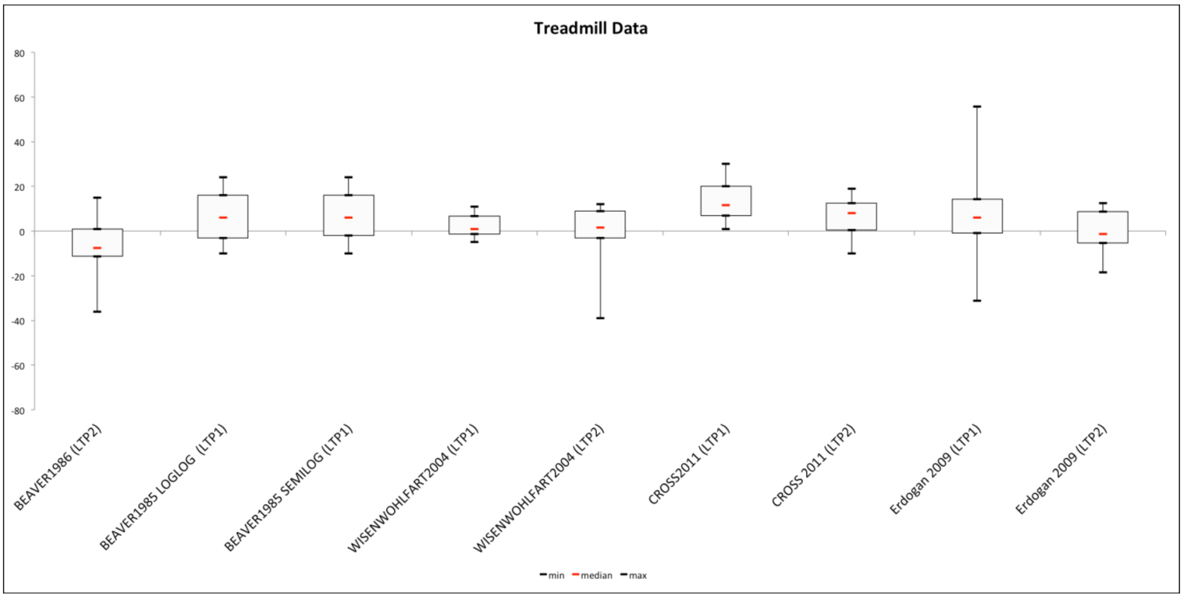

Figure 2: Boxplots of the results of the treadmill data. The boxplots illustrate the heart rate deviation of the aerobic and the anaerobic thresholds calculated with the different algorithms from the thresholds computed with the standard lactate method. The data were collected during a treadmill test.

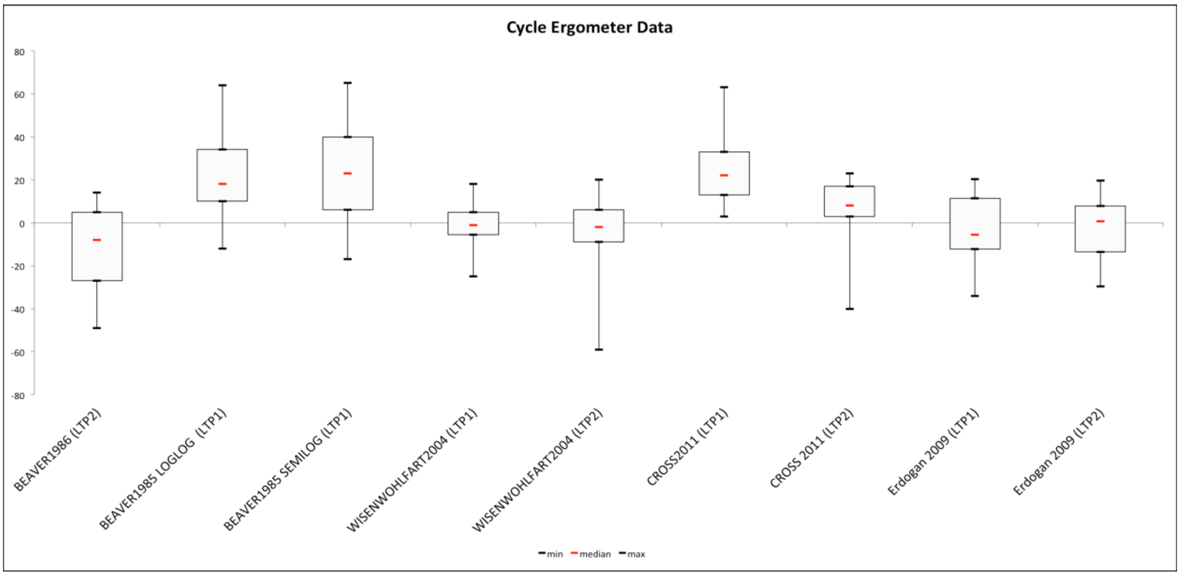

Figure 3: Boxplots of the results of the cycle ergometer data. The boxplots illustrate the heart rate deviation of the aerobic and the anaerobic thresholds calculated with the different algorithms from the thresholds computed with the standard lactate method. The data were collected during a cycle ergometer test.

4. Discussion and Conclusions

We tried to implement the algorithms to the best of our knowledge and beliefs. But especially the preparation of data is not described very well in most of the available papers, e.g. the selected data range or the methods for smoothing the data was not depicted in an appropriate way. We selected the same range of data and smoothing algorithm for all implementations to generate comparable results. Furthermore, some old algorithms [1, 2] were originally not developed for an automated detection of the thresholds; a visual inspection was done in the original papers. We implemented every algorithm to calculate the thresholds automatically. Some algorithms did not produce a result because the quality of the original data was not good enough (e.g. no real increase in the heart rate during exercise).

Most of the applied algorithms gave a fairly good relationship of the means compared to the standard lactate threshold values (*Figure 2 and 3*). However, there are some differences for SD and Min/Max for the different algorithms indicating some difficulties to determine thresholds on an individual level. Additional algorithms besides the applied ones have to be developed and validated in further tests. Our study showed once more, that reliable data classification algorithms require to be developed with and tested against heterogeneous data.

5. References

[1] Beaver WL, Wasserman K, Whipp BJ. A new method for detecting anaerobic threshold by gas exchange. Division of Respiratory Physiology and Medicine. 1986, p. 220-2027.

[2] Beaver WL, Wasserman K, Whipp BJ. Improved detection of lactate threshold during exercise using a log-log transformation. The American Physiological Society. 1985, p. 1936 - 1940.

[3] Binder RK, Wonisch M, Corra U, Cohen-Solal A, Vanhees L, Saner H, Schmid JP. Methodological approach to the first and second lactate threshold in incremental cardiopulmonary exercise testing. Eur J Cardiovasc Prev Rehabil. 2008 Dec;15(6), 726-34.

[4] Cross TJ, Morris SR, Donald SA, Sabapathy S. Evidence of breaking-points in breathing pattern at the gas-exchange threshold during incremental cycling in young, healthy subjects. Eur Journal of Applied Physiology, 2011.

[5] Erdogan A, Cetin C, Goksu H, Guner R, Baydar ML. Non-invasive detection of the anaerobic threshold by a neural network model of the heart rate-work rate relationship. J. of Sports Engineering and Technology, 2009, p. 109-115.

[6] Löllgen H, Erdmann E, Gitt AK. Ergometrie: Belastungsuntersuchungen in Klinik und Praxis: Springer, 2009.

[7] Hofmann, P, Tschakert, G. Special Needs to Prescribe Exercise Intensity for Scientific Studies. Cardiology Research and Practice. Volume 2011, Article ID 209302, doi:10.4061/2011/209302.

[8] Hofmann, P., Wonisch, M., Pokan, R.: Laktatleistungsdiagnostik – Durchführung und Interpretation. In: Pokan R, Förster H, Hofmann P, Hörtnagl H, Ledl-Kurkowski E, Wonisch M. Kompendium der Sportmedizin: Physiologie, Innere Medizin und Pädiatrie DE: Springer; 2004, p. 103-132.

[9] Wisén AG, Wohlfart B. A refined techique for determining the respiratory gas exchange responses to anaerobic metabolism during progressive excercise - repeatability in a group of healthy men. Clinical Physiology and Functional Imaging, 2004, p. 1-9.

Corresponding Author
Harald Burgsteiner
Institute for eHealth, Graz University of Applied Sciences
Eggenberger Allee 11, A-8020 Graz, Österreich
Email: harald.burgsteiner@fh-joanneum.at