Automated Fitness Level (VO_2max) Estimation with Heart Rate and Speed Data

Firstbeat Technologies Ltd.

This white paper has been produced to review the method and empirical results related to the heart rate variability and speed based VO_2max estimation method from any freely performed workout developed by Firstbeat Technologies Ltd. Parts of this paper may have been published elsewhere and are referred to in this document.

TABLE OF CONTENTS

SUMMARY

- A person's maximal oxygen uptake (VO_2max) refers to the maximal amount of oxygen the individual can consume typically over one minute during an intense physical effort
- VO_2max is the golden standard measure for the person's aerobic fitness level
- Aerobic fitness level is strongly and positively related to health, longevity, quality of life, and performance
- Aerobic fitness level is typically measured either directly in a laboratory from breathing gas exchange, not viable for real-life use, or indirectly with controlled exercise protocols
- The present white paper describes a method for assessing a person's aerobic fitness level (VO_2max) automatically from any freely performed, uncontrolled exercise
- The method is based on the well-known heart rate vs. speed relationship and on detecting the most reliable data periods for VO_2max estimate during the exercise

IMPORTANCE OF AEROBIC FITNESS (VO_2MAX)

Introduction

Maximal oxygen uptake or consumption (VO_2max) means the maximal capacity of an individual to perform aerobic work. It is the product of cardiac output (CO) and arteriovenous oxygen (AV-O2) difference at exhaustion, and the golden standard measure for a person's aerobic fitness [1]. It refers to the maximal amount of oxygen the individual can utilize typically over one minute during an intense, maximal effort.

Aerobic fitness is related to a person's ability to perform dynamic, moderate-to-high intensity physical activity with large muscle groups for prolonged periods. Thus, it expresses the abilities of both cardiorespiratory and muscular systems to transport and utilize oxygen for energy. It is one of the most fundamental measures of human physiology with remarkable health, wellbeing, life quality, work ability, and performance - related associations [1-5].

Typically VO_2max is measured directly by analyzing inspired and expired breathing gases in a laboratory setting during maximal exertion, and expressed either as absolute maximal amount of oxygen per minute (L/min) or as relative to the individual's weight as the maximal milliliters of oxygen the person uses in one minute per kilogram of body weight (ml/kg/min).

In addition to oxygen consumption (VO_2), the energy cost of physical activities can be expressed as metabolic equivalents (MET; Metabolic Equivalent of Task). MET is defined as the ratio of metabolic rate (and therefore, the rate of energy consumption) during a specific physical activity to a resting metabolic rate. One MET is defined as 1 kcal/kg/hour or 3.5 ml/kg/min, and it is roughly equivalent to the energy cost of sitting quietly.

Individual VO_2max values can range from about 10 ml/kg/min in cardiac patients to close to 90 ml/kg/min among world-class endurance athletes. Average values for men and women in different age groups have been used to establish reference fitness categories, as aerobic fitness generally declines with age [1, 6].

It would be extremely beneficial to measure VO_2max accurately in real-life because laboratory tests are typically directed towards special subject groups, such as persons with known or suspected cardiovascular diseases or high-level athletes. In addition, laboratory tests require expensive equipment and trained personnel, and are thus difficult and expensive to perform. Therefore, they are not feasible for large-scale use and do not allow for frequent follow-up of aerobic fitness.

Consequently, there would be several valuable application areas for accurate real-life fitness level information. The information could be used for example for assessing the current fitness level in different populations, motivating towards physical activity, giving feedback on specific exercise sessions or long-term progress, helping to choose suitable exercise modes, and even in planning entire training programs.

The present white paper describes a method for estimating VO_2max from any freely performed, uncontrolled real-life exercise developed by Firstbeat Technologies Ltd. The method is based on utilizing the most representative and reliable data on the individual's heart rate and speed during exercise. The method provides an accurate, yet easy way to monitor the progress in aerobic fitness level on a daily basis in real-life settings.

Aerobic fitness, health, and quality of life

Low level of aerobic fitness is an inevitable consequence of physical inactivity and sedentary lifestyle that some experts state to be the most important public health problem of the 21st century [7]. Physical inactivity and poor physical fitness are associated with several health problems, such as cardiovascular diseases, metabolic disorders (e.g. overweight, obesity, diabetes), musculoskeletal disorders, pulmonary diseases, cancer, psychological problems and so on [e.g. 2-3].

Consequently, low levels of aerobic fitness have also been associated with a markedly increased risk of premature death [8-9]. Positively, improvements in aerobic fitness have been shown to reduce all-cause mortality [9-10]. Furthermore, although aerobic fitness generally declines with age, by belonging to a higher fitness category, one can better maintain functional ability with aging or during retirement [11]. In practical terms, for a person with poor fitness level, a 10% increase in VO_2max can reduce mortality risk by 15% and give 10 more years of good-quality life.

Aerobic fitness and physical work capacity

Aerobic fitness i.e. the cardiorespiratory capacity is also related to an individual's ability to cope with the demands of work. This is especially important when considering the changing demographics and as the retirement age is getting higher, along with longer life expectancy. Based on international recommendations, work should not demand more than 50% of a person's VO_2max [28]. However, the level of physical abilities required to sufficiently perform job tasks may vary from minimal to extreme between different jobs. Therefore, especially in physical work, aerobic fitness level is a crucial factor regarding the individual's ability to perform the needed tasks. This leads to a conclusion that the demands of work should be reduced along with a decreased physical fitness level (typically occurring with increasing age) and/or the aerobic fitness level needs to be maintained or improved through physical activity if the person aims to meet the work requirements.

Aerobic fitness and sports performance

In addition to its effect on health and work ability, maximal oxygen uptake is a crucial determinant of endurance performance [e.g. 5, 12]. VO_2max sets the upper limit for metabolism during physical activity because it is impossible to exercise above 100% of VO_{2max} for extended periods. Oxygen delivery to exercising muscles is viewed as the primary limiting factor for VO_2max [5]. In addition, the ability to exercise at a high intensity level for prolonged periods (e.g. distance running) is determined by fat oxidation, ability to buffer lactic acid, economy of performance, and fractional utilization of VO_2max for the given speed [5, 12]. Table 1 expresses examples of oxygen consumption requirements of different tasks.

Table 1. Examples of oxygen consumption requirements during different tasks and activities. The higher the requirement, the better the individual's aerobic fitness level needs to be to be able to perform the task. Thus, VO_2max is used to describe the individual's functional capacity [29]. 1 MET ≈ 3.5ml/kg/min.

Tasks, activities, and occupations	METs required	VO_2 (ml/kg/min) required
Sleeping	0.92	3
Inactivity (sitting quietly, watching TV etc.)	1.0	4
Office work (computer)	1.6	6
Car driving	2	7
Light housework (dishes)	2.1	7
Healthcare support (nursing)	2.8	10
Walking 5km/h	3.2	11
Heavy housework (washing floors)	3.3	12
Gardening (digging)	4.4	15
Fishing	4.5	16
Walking upstairs	4.7	16
Walking 7km/h	5.3	19
Cycling 20km/h	7.1	25
Backpacking 6.4km/h, 5% slope, 20kg	8	28
Running 9km/h	8.8	31
Cycling 30km/h	9.8	34
Ice hockey (competitive)	10	36
Firefighting (standard fire suppression tasks while wearing personal protective equipment)	11.9	42
Running 15km/h	14.6	51
Running 19.3km/h	19	67
Running 22.5km/h	23	81

Methods used to estimate aerobic fitness

The only direct way to actually measure maximal oxygen consumption is to use open-circuit spirometry in a laboratory. In this procedure, pulmonary ventilation and expired fractions of oxygen and carbon dioxide are measured during a controlled exercise protocol. When the direct measurement of VO_2max is not feasible or desirable, a variety of submaximal or maximal indirect tests with a controlled exercise protocol can be used to estimate VO_2max [1]. Also non-exercise methods have been developed to estimate a person's VO_2max from individual characteristics such as age, sex, anthropometrics, history of physical activity, or resting-level physiological measurements [13]. However, these non-exercise based assessment methods are often very inaccurate.

DESCRIPTION OF THE FIRSTBEAT METHOD

The Firstbeat method for accurate assessment of a person's aerobic fitness level (VO_2max) during uncontrolled exercise is described next in detail.

Physiological basis of the method

It is well known that there is a linear relationship between oxygen consumption and running speed. The oxygen cost of running increases when running speed increases. At identical submaximal speeds, an endurance athlete runs at a lower percentage of his or her VO_2max than an untrained person, although both maintain similar VO_2 [6].

Technology (such as GPS sensors and foot pods in wrist devices or mobile phones) enables reliable measurement of running speed along with heart rate (HR). Therefore, these parameters can be monitored continuously and automatically during each workout. Because VO_2max is a key variable to fitness training that needs to be easily measurable without additional protocols, an automatic VO_2max estimation method applicable for any uncontrolled workout has been developed by Firstbeat. The method is based on the well-known connection between heart rate and the speed of the activity (e.g. running, walking).

Calculation steps

The following calculation steps are used for VO_2max estimation:

1) The personal background info (at least age) is logged
2) The person starts to exercise with a device that measures heart rate and speed
3) The collected data is segmented to different heart rate ranges and the reliability of different data segments is calculated
4) The most reliable data segments are used for estimating the person's aerobic fitness level (VO_2max) by utilizing either linear or nonlinear dependency between the person's heart rate and speed data.

Only reliable data used for VO_2max estimation

One of the key features of this method is the detection of reliable periods for VO_2max detection. Figure 1 shows an example of how fitness level can be reliably detected during an uncontrolled running session. The reliability detection includes both exercise mode detection and data reliability detection. There are some situations in which the exclusion of data segments is necessary for reliable fitness level estimation. These automatically detected situations are, for example, running on soft ground, on a steep downhill, stopping at a traffic light (where the speed is zero but the heart rate is elevated), or the effect of cardiovascular drift (heart rate elevation) in long-duration workouts.

Figure 2 (next page) further illustrates the difference between traditional fitness tests in a laboratory that need fixed exercise protocols and the Firstbeat VO_2max method based on the data from uncontrolled real-life exercise.

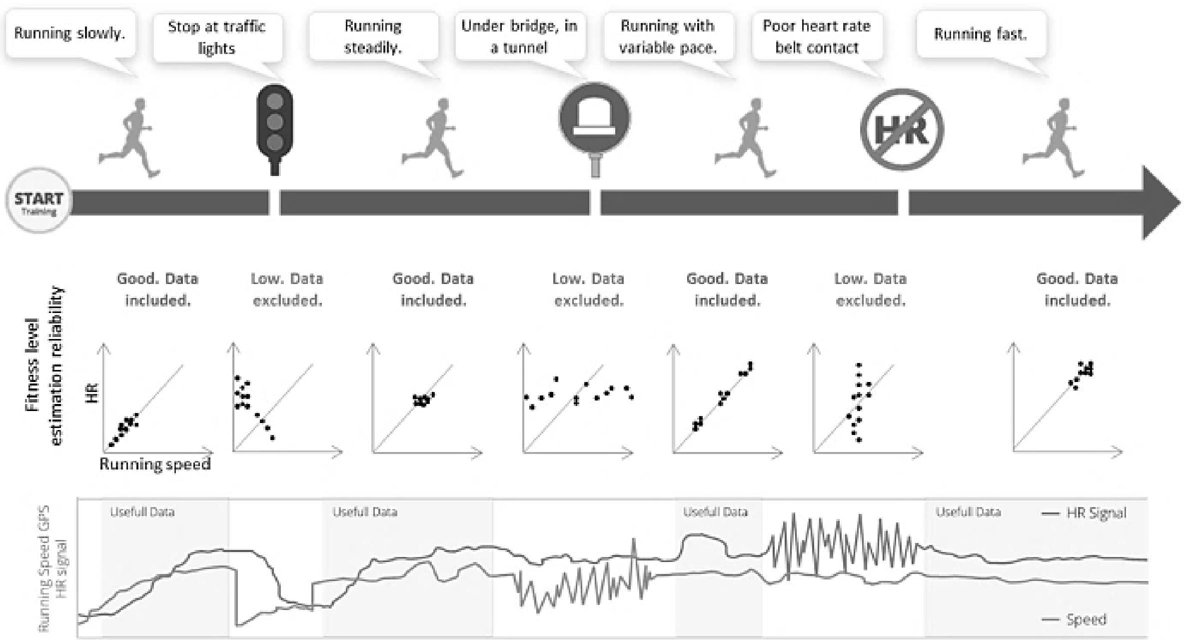

Figure 1. Reliable detection of fitness level during uncontrolled running exercise (Firstbeat patented technology).

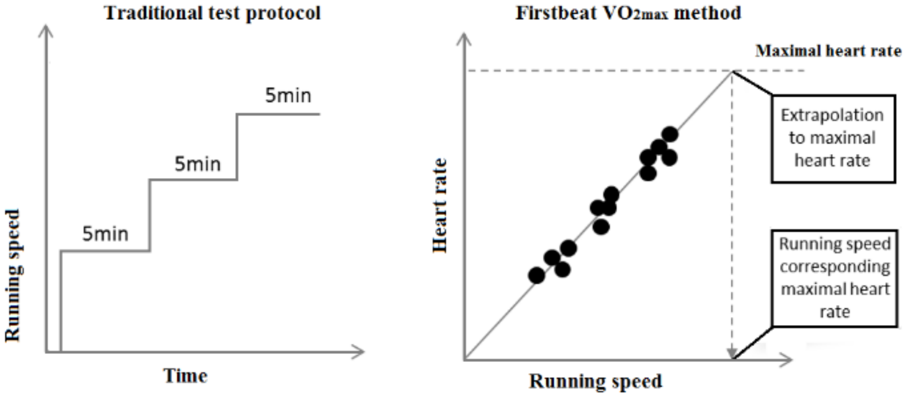

Figure 2. Comparison of the VO_2max testing concept between traditional laboratory assessments (on the left) and Firstbeat real-life VO_2max assessment (on the right).

VALIDATION OF THE FIRSTBEAT MODEL

The Firstbeat VO_2max method has been developed against laboratory measured VO_2max values (Figure 3) and validated with different exercise modes. The accuracy of the method when applied for running is 95% (Mean absolute percentage error, MAPE ~5%), based on a database of 2690 freely performed runs from 79 runners whose VO_2max was tested four times during their 6-9 -month preparation period for a marathon. In a vast majority of the measurements, the error was below 3.5 ml/kg/min and the error was evenly distributed around the mean value. For perspective, the error in a typical indirect submaximal test is 10-15% and in a direct laboratory test about 5%.

Figure 3. The Firstbeat method has been developed against measured VO_2max values in laboratory tests.

As shown in Figure 4, the estimation error falls close to 5% in running already with a very short period of data, and in 75% of the workouts, VO_2max has been assessed successfully after running 2 kilometers. The method has been validated also with freely performed cycling by 29 cyclists whose pedaling power and heart rate were collected. The accuracy of the method when applied for cycling was 92% (MAPE ~5%).

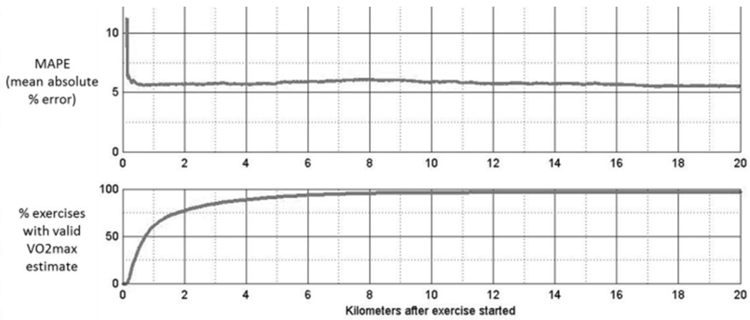

Figure 4. Mean absolute percentage error (MAPE) for VO_2max estimate of the Firstbeat method (upper), and the percentage of how many (%) of the 2690 workouts were successfully given a VO_2max estimate relative to running distance (lower).

Because the Firstbeat method is sub-maximal by nature, it uses an age-based estimated maximum heart rate (HRmax) in the calculation. Therefore, the error in the HRmax estimation affects the accuracy of the VO_2max estimate. Figure 5 shows how much the difference between a person's actual and age-based HRmax affects the VO_2max estimation error in the mentioned database of 2690 freely performed workouts. If the HRmax is estimated 15 beats/min too low, the error in the VO_2max result is about 9%. Respectively, if the HRmax is estimated 15 beats/min too high, the error in VO_2max result is 7%. If the person's real HRmax is known, the VO_2max assessment error falls to the 5% level.

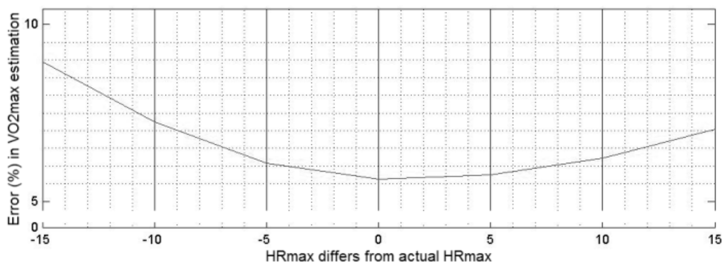

Figure 5. Error (%) in VO_2max estimation relative to the error in age-based maximal HR estimation.

A study examining the accuracy and replicability of results by the Firstbeat method (used foot pod to measure running speed and laboratory tests for reference) found that the method slightly underestimates the true VO_2max but the %-error fell into 4.3% when real HRmax was used [32]. The repeatability of the test was good, and the method was suitable for different running conditions.

COMPARISON OF DIFFERENT FITNESS TESTS

A variety of methods have been developed to assess VO_{2max} from submaximal or maximal exercise. These methods are based mostly on the linear relationship between oxygen uptake (VO_2) and power output, as well as between VO_2 and heart rate during exercise. VO_2 tests have most often been conducted on a cycle ergometer, a treadmill or a rowing ergometer.

Non-exercise estimates of VO_{2max} have also been used, and those have been based for example on the ratio between HR_{max} and HR_{rest}, or on self-reported predictor variables, such as subject's perceived functional ability to exercise, habitual physical activity, age, gender, body mass, body mass index, and body composition (% of fat). All of the methods have some advantages as well as limitations, which are summarized in Table 2.

PRACTICAL USE OF THE FIRSTBEAT METHOD

Next, more details about the key practical use cases of the Firstbeat VO_2max method are presented.

Assessing fitness level for health and work ability

VO_2max can be used to indicate general cardiorespiratory health but also to monitor the progress of fitness with different training protocols. As aerobic fitness level is strongly associated with health and ability to perform daily tasks, it can be used to monitor physical and functional capacity and the changes in them. In addition, VO_2max information can be used, for example, to guide nutritional interventions or exercise training programs to achieve the individual's goals and targets, such as improved endurance, changed body composition, or better quality of life.

As described, VO_2max can be expressed as ml/kg/min, but that value can be confusing for persons unfamiliar with the topic. Therefore, VO_2max is typically expressed as individual fitness level relative to the reference group of the same age and gender. Tables 3a and 3b (next page) show fitness level categories based on VO_2max values in different age groups for both genders.

In general, the highest VO_2max values are reached around the age of 20, after which the aerobic fitness starts to decline. Moreover, men have about 20% higher values than women due to differences in body size, body composition, and blood volume [14]. The current scientific evidence supports the view of 10% decline per decade in VO_2max among both men and women, regardless of activity level [11, 15-16], although some studies have found that the VO_2max of active individuals declines at a slower rate than that of inactive persons [17]. A possible explanation is that changes in VO_2max over the entire age range may be curvilinear, with active individuals declining slowly as long as they keep exercising, and inactive individuals declining at a rapid rate during their 20's and 30's, followed by a slower rate of decline of their VO_2max as they age further [15,17]. Still, to be able to perform daily tasks and maintain functional ability also at an older age, it would be extremely important for everyone to aim for a sufficient aerobic fitness level.

Table 2. Methods used to measure or estimate fitness level.

Fitness test	Accuracy	Advantages	Limitations
Exercise-based tests			
Direct VO_2max laboratory test (gas analysis)	The golden standard method as the only test that truely measures maximal oxygen consumption	The most accurate test for aerobic fitness and can also be used to estimate anaerobic threshold.	Expensive. Maximal effort required so suitable for healthy persons only (difficult for specific populations). Interpretation of results requires a specialist. Motivation to "reach the individual limits" can have significant impact on the results.
Firstbeat VO_2max real-life estimation	Correlation between estimated and measured $V0_2$max 0.95. MAPE 5%.	Works on freely performed everyday exercise without a need for separate test. Cheap and very easy to perform. Does not require maximal effort.	Exercising conditions should be standardized to get reliable results. For example running surface and wind may have effect on the result.
Indirect submaximal (treadmill, cycle ergometer, step test)	Not as accurate as direct test but can be more accurate than Cooper's-test and walking tests	Cheaper and safer than direct test allowing usage for larger populations. Duration usually shorter and no maximal effort required.	Requires fixed and controlled protocol. Accuracy of the test is dependent on accuracy of maximal heart rate estimation
Cooper's 12-min test / 1.5-mile test and others	Quite accurate	Can be used in field conditions. Easy to administer to large numbers of individuals at the same time.	Requires maximal effort. For fit and healthy persons only. HR usually not monitored. Motivation and pacing can have an impact on results.
Walking tests (e.g. UKK 2 km test / Rockport 1 mile test)	Able to estimate changes in fitness level. The least accurate from exercise tests presented	Can be used in field conditions. Easy to administer to large numbers of individuals at the same time. Safe.	Fitness level of very fit persons may be underestimated. Motivation and pacing can have an impact on results. Distance has to be measured accurately.
Non-exercise tests			
Non-exercise equations (e.g. Jackson et al 1990 etc.)	Not as accurate as an exercise based tests.	Simple and safe. No exercise required. Easy to administer to large numbers of individuals at the same time.	Heavily based on self-chosen activity level.
Resting heart rate test	Very inaccurate if only resting heart rate used	Does not require exercise.	Does not have solid physiological basis

Table 3a. Fitness level (VO_2max) classification for men.

Age (year)		Very poor	Poor		Fair		Average		Good		Very good		Excellent
from	to	under	from	to	from	to	from	to	from	to	from	to	over
20	24	32	32	37	38	43	44	50	51	56	57	62	62
25	29	31	31	35	36	42	43	48	49	53	54	59	59
30	34	29	29	34	35	40	41	45	46	51	52	56	56
35	39	28	28	32	33	38	39	43	44	48	49	54	54
40	44	26	26	31	32	35	36	41	42	46	47	51	51
45	49	25	25	29	30	34	35	39	40	43	44	48	48
50	54	24	24	27	28	32	33	36	37	41	42	46	46
55	59	22	22	26	27	30	31	34	35	39	40	43	43
60	65	21	21	24	25	28	29	32	33	36	37	40	40

Table 3b. Fitness level (VO_{2max}) classification for women.

Age (year)		Very poor	Poor		Fair		Average		Good		Very good		Excellent
from	to	under	from	to	from	to	from	to	from	to	from	to	over
20	24	27	27	31	32	36	37	41	42	46	47	51	51
25	29	26	26	30	31	35	36	40	41	44	45	49	49
30	34	25	25	29	30	33	34	37	38	42	43	46	46
35	39	24	24	27	28	31	32	35	36	40	41	44	44
40	44	22	22	25	26	29	30	33	34	37	38	41	41
45	49	21	21	23	24	27	28	31	32	35	36	38	38
50	54	19	19	22	23	25	26	29	30	32	33	36	36
55	59	18	18	20	21	23	24	27	28	30	31	33	33
60	65	16	16	18	19	21	22	24	25	27	28	30	30

Regarding the health effects of VO_2max, an interesting meta-analysis of 23 studies, examining the effect of leisure-time physical activity and fitness level on the risk for coronary heart disease (CHD) and/or cardiovascular disease (CVD) was conducted [27]. The study found that the disease risk was reduced significantly better by being more physically fit than by being more physically active (Figure 6). Although it is clear that physical fitness can be improved by training, the study highlights the importance of aerobic fitness level *per se* as a significant health factor. The reductions in relative risk were nearly twice as great for cardiorespiratory fitness than for physical activity.

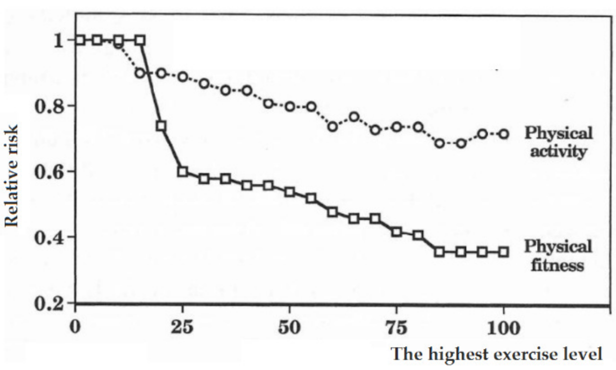

Figure 6. The relative risk for CHD or CVD by being physically active versus having better physical fitness (risk=1 for the least active or fit) [modified from 27].

Moreover, studies have found that better aerobic fitness seems to be cardioprotective also in overweight or obese persons, compared to less fit counterparts. Indeed, a longitudinal study with 14,345 men found that maintaining or improving aerobic fitness over a period of 6.3 years was associated with significantly lower mortality from CVD regardless of the body mass index change [30]. A recent meta-analysis concluded that there is more and more evidence to suggest that aerobic fitness modifies the association between adiposity and mortality [31]. In the general population, better aerobic fitness is associated with improvements in obesity-related cardiometabolic risk factors, resulting in improved survival comparable to fit and normal-weight individuals and further highlighting the importance of fitness level for health.

In addition to its importance for health, relatively high VO_2max is needed in many occupations, especially in physical work, such as in some tasks related to firefighting, construction, forestry, manufacturing, farming, transporting, and nursing (see examples of the oxygen demands of different tasks in Table 1). An 8-hour work shift should preferably not demand more than 30-50% of individual VO_2max to avoid overloading [28]. Fitness level measurements can be used to indicate individual abilities and tolerable levels.

Improving VO_2max by training

Everyone can improve aerobic fitness by training. The magnitude of the improvement depends substantially on the starting point and the intensity of training. The less fit an individual is when he/she starts exercising, the easier it is to increase the VO_2max [18-19]. Vigorous exercising seems to be more effective than moderate exercising for improving VO_2max, and highly fit individuals improve less than less fit at any given training intensity.

Indeed, a beginner may increase his/her fitness level during 4-10 weeks of successive training by up to 10-20% [18-19], although even 44% increase in VO_2max in ten weeks has been reported for persons with average aerobic fitness, by using very high-intensity interval training [20]. Still, for highly trained athletes who already have a very high VO_2max, it is extremely hard to significantly improve aerobic fitness within a short time period. In any case, it is important to monitor VO_2max regularly to see whether the training is effective in improving aerobic fitness or if some changes in the training program are required. A concrete, regular result also motivates to continue training.

Assessing competitive sports performance and training

Race time prediction

One of the most interesting application areas for VO_2max information is the prediction of race time. In sedentary runners, improvements in VO_2max most probably result in improvement in race time, and therefore, the prediction of race time based on VO_2max is quite straightforward.

In elite endurance athletes, VO_2max is not the only determinant of a good race performance, since they all have high VO_2max and the margins between the athletes are small. Thus, other physiological, biomechanical, and psychological factors affect the competition results significantly.

For example, if a sedentary runner improves his/her VO_2max by 2ml/kg/min, the marathon race time could improve an astonishing 15min, while the same absolute improvement in VO_2max in an elite athlete could improve the marathon race time by only one and a half minutes! In any case, race time prediction provides interesting and concrete feedback about the current fitness level and a rough estimate of the expected ability to perform in a race. See an example of Jack Daniels' race time prediction in Table 4 [21].

Table 4. Race time prediction based on VO_2max.

VO_{2max}	Marathon	1/2 Marathon	10K	5K	1Mile
30	4:49:17	2:21:04	1:03:46	30:40	9:11
36	4:10:19	2:01:19	54:44	26:22	7:49
42	3:40:43	1:46:27	48:01	23:09	6:49
48	3:17:29	1:34:53	42:50	20:39	6:03
54	2:58:47	1:25:40	38:42	18:40	5:27
60	2:43:25	1:18:09	35:22	17:03	4:57
66	2:30:36	1:11:56	32:35	15:42	4:33
72	2:19:44	1:06:42	30:16	14:33	4:13
78	2:10:27	1:02:15	28:17	13:35	3:56
84	2:02:24	58:25	26:34	12:45	3:41

Personalized training

Optimal exercise intensity is a key factor in successful training. For example, by conducting basic endurance workouts at right intensity increments in training volume and a greater frequency and quality of more intense workouts are enabled. The training intensity that elicits the improvement in VO_2max is highly dependent on the initial aerobic fitness level. Therefore, it is safer for initially sedentary persons to begin with moderate intensity exercise, which is effective enough to improve their VO_2max, and move up to higher intensities only after a period of adaptation [19].

Figure 7 shows how important it is to adjust the training based on the aerobic fitness level. In the example, a trained person (high VO_2max) and untrained person (low VO_2max) are performing exactly the same exercise sessions (black bars). As a result, the fitness level of the untrained person develops with training, while the fitness level of the trained person begins to decrease, as the training level is too low for him/her. Thus, knowing the VO_2max helps to start training at optimal intensity, and can be used to personalize and plan the training [19, 22].

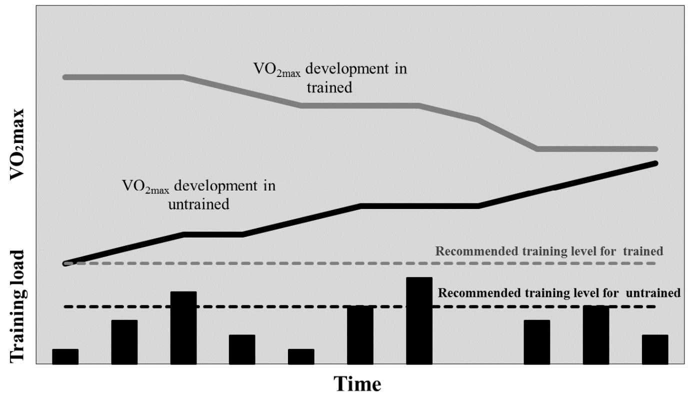

Figure 7. An untrained and trained person's VO_2max development when both have done the same training sessions.

If the training load (volume and/or intensity) is too low compared to a person's current fitness level, the VO_2max will not increase and can start to decrease, and if the training load is too high, the fitness level can decrease due to overloading. With an optimal training load, the fitness level development is the greatest. For this reason, fitness level monitoring is an essential part of training and coaching. Figure 8 shows an example of how periods of different training load (black bars) affect the fitness level development in an untrained person.

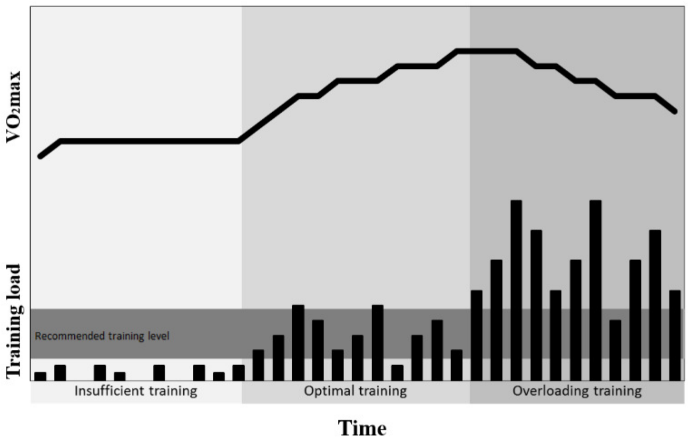

Figure 8. Effect of different training load on fitness level development. An optimal training load results in the best progress in aerobic fitness.

Athlete recovery and supercompensation

Periodization of hard and easy training is the key for successful fitness improvement [e.g. 23-26]. Athletic performance improves as the athlete adapts to progressively increasing training loads and this adaptation occurs during periods of recovery and reduced training [23]. High-intensity training for longer periods results in a decrease in performance. If there is a reasonable recovery phase after that, the performance will return to the baseline and further above it. This is called supercompensation.

If a new exercise session is applied at the peak of supercompensation, this will result in further enhancement in performance [23-26]. The time needed for supercompensation and recovery is individual and greatly affected by several internal and external factors, such as training, stress, eating, sleeping, and health status. The real recovery is unknown until the recovery has taken place. The only unquestionable measure of recovery is the change in performance, i.e. whether VO_2max is improving or declining in the short and long term. Because the recovery can vary significantly, it is beneficial to determine the body's readiness to exercise by measuring performance. Thus, the Firstbeat VO_2max method can be used to indicate supercompensation and recovery from previous training, in addition to the other described application areas.

CONCLUSIONS

Aerobic fitness or aerobic capacity (VO_2max) means the individual's highest level of aerobic metabolism, i.e. the ability to utilize oxygen for energy during maximal physical effort. Aerobic fitness level has been strongly and positively associated with reduced disease and mortality risk, good quality of life, performance level, and functional ability [3-4, 8-10, 19, 27, 30-31]. Based on scientific studies, having a high aerobic capacity reduces one's risk of cardiovascular disease and the reduction is greater than that obtained merely by being physically active [19, 27]. Obviously individuals who perform regular physical activity are expected to have better aerobic fitness, but engaging only in physical activity at a low intensity level might not increase aerobic capacity. Therefore, it has been suggested that "given the importance of aerobic capacity, recommendations for increasing physical activity should consider how best to increase VO_2max" [19].

As VO_2max is one of the most fundamental measures of human physiology, there should be an easily applied and practical way to measure it. This far, VO_2max has been measured during maximal effort in a laboratory, during fixed and controlled protocols using submaximal tests, or have been grounded on often very inaccurate estimations from non-exercise variables. The present white paper describes an innovative method for VO_2max estimation based on the heart rate and speed relationship from any uncontrolled real-life exercise.

The method utilizes only reliable data periods and has been found to be very accurate. In order to obtain consistent results, the exercise conditions should, however, be standardized because for example running surface, wind, and high altitude may affect the moving speed. When applied in unstandardized conditions (such as high altitude), the method expresses the changes in performance in those conditions.

The method makes it possible to evaluate the effectiveness of training on a day-to-day basis rather than checking the aerobic fitness level seldom, with separate tests (e.g. once a year). Thus, the Firstbeat VO_2max method allows continuous follow-up of the aerobic fitness, and helps to plan and personalize training. The method can also be used to estimate recovery or supercompensation from the preceding training load, and even to predict race times.

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For more information:
Firstbeat Technologies Ltd.
Yliopistonkatu 28 A, 2nd floor
FI-40100 Jyväskylä
FINLAND
info@firstbeat.com
www.firstbeat.com
www.firstbeat.com/physiology/research-and-publications