

(19) World Intellectual Property Organization
International Bureau



(43) International Publication Date
5 November 2009 (05.11.2009)

(10) International Publication Number
WO 2009/133248 A1

(51) International Patent Classification:
A61B 5/22 (2006.01) *G06Q 50/00* (2006.01)
A61B 5/024 (2006.01)

FI-40500 Jyväskylä (FI). **KETTUNEN, Joni** [FI/FI];
Haikantie 3, FI-40900 Säynätsalo (FI).

(21) International Application Number:
PCT/FI2009/050351

(74) Agent: **KESPAT OY**; P.O.Box 601, FI-40101 Jyväskylä (FI).

(22) International Filing Date:
4 May 2009 (04.05.2009)

(81) Designated States (unless otherwise indicated, for every kind of national protection available): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IS, JP, KE, KG, KM, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LT, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RS, RU, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
20085402 2 May 2008 (02.05.2008) FI

(71) Applicant (for all designated States except US): **FIRST-BEAT TECHNOLOGIES OY** [FI/FI]; Yliopistonkatu 28 A, FI-40100 Jyväskylä (FI).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **SEPPÄNEN, Mikko** [FI/FI]; Lampitie 27-29 A3, FI-97900 Posio (FI). **PULKKINEN, Aki** [FI/FI]; Juhontie 8 A 3, FI-41160 Tikkakoski (FI). **KURUNMÄKI, Veli-Pekka** [FI/FI]; Kultalakintie 4 B 4, FI-40640 Jyväskylä (FI). **SAALASTI, Sami** [FI/FI]; Ronsuntaipaleentie 806 A,

(84) Designated States (unless otherwise indicated, for every kind of regional protection available): ARIPO (BW, GH, GM, KE, LS, MW, MZ, NA, SD, SL, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European (AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, SE, SI, SK, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: FITNESS TEST

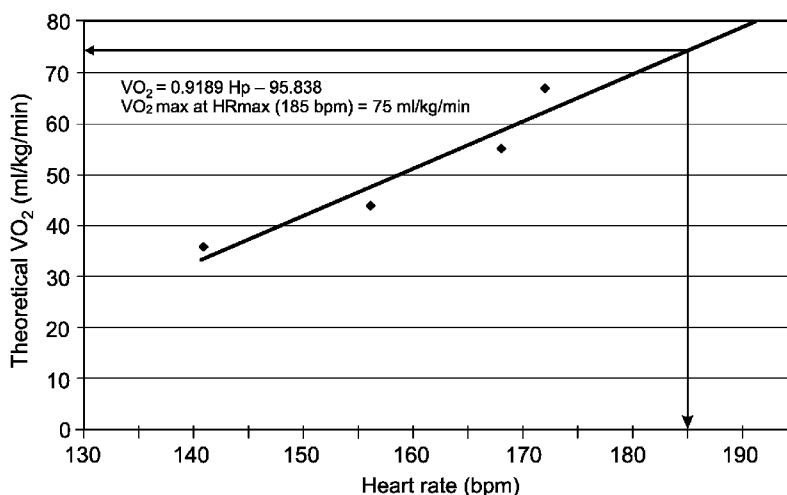


Fig. 3

(57) Abstract: This document describes a fitness test application which allows the user to exercise freely (running and cycling outdoors, bicycle ergometer, rowing ergometer, treadmill) and which provides an estimate of user's fitness during and/or after the exercise. The analysis can be performed either as real-time or as post-analysis.

WO 2009/133248 A1

Published:

— with international search report (Art. 21(3))

— before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))

Fitness Test

Background of the invention

5 Field of the invention

This invention relates to a method and an assembly for assessing of person's cardiorespiratory fitness, which is one of the most significant nominators of human health and longevity.

10

Description of the related art

Prior art comprises many ways to assess fitness. Traditionally fitness tests are performed under the supervision of testing personnel. One option is to utilize direct
15 measurement of respiratory gases during a maximal exercise test during which person's maximal oxygen uptake is determined from the analyzed respiratory gases. There are also a great number of methods to assess fitness indirectly under submaximal exercise but these tests as well as maximal exercise tests require testing personnel to conduct and supervise the test. Some of both maximal and submaximal
20 tests can be performed also in field conditions thus not requiring exercise equipment.

Recently free fitness test modes have also been introduced in EP0709058 (Alessandri), US6882955 (Ohlenbusch & Darley), FR2867055 (Quilliet & Billat) , US2007/0082789 (Nissila, Niva, Jaatinen & Kinnunen), and by Weyand et al. (2001)).
25 These tests combine measurement of heart rate and speed during user performed exercise where the maximal oxygen uptake is determined e.g., using simple mathematical calculations. Speed can be measured by using accelorometry based measures, by using a satellite navigation system (e.g. global positioning system, GPS) or a local positioning system (e.g. using a WiFi network). Current state of art
30 doesn't however know a method which would evaluate and segment measured data to form an accurate measure of cardiorespiratory fitness but rather only give a rough estimate of person's or animals daily performance. Current state-of-art doesn't either know solution where person's fitness information gathered during a freely performed exercise session, is used to guide a user to a physiological target state. Neither does

current state-of-the-art know a method wherein the user's dynamically changing training plan is automatically updated based on his estimated fitness level.

Consequently, this invention introduces a system and method for accurate and sophisticated assessment of person's cardiorespiratory fitness during any user performed exercise session. Accurate assessment is performed by means of data segmentation and evaluation. Estimate of cardiorespiratory fitness can be also utilized in guiding the user during an exercise to reach a preset (set by the user or by an automatic) physiological target state wherein the fitness estimate may have been calculated in the beginning part of the same exercise. Estimate of cardiorespiratory fitness can be also utilized in creating a dynamically changing training plan for the user wherein training plan can be updated if person's fitness level has changed.

Brief description of invention

15

The object of this invention is to achieve an improved method for estimating fitness, wherein a person exercises freely and his/her cardiorespiratory fitness is estimated based on recorded information. This object is achieved with the features described in accompanying claim 1. A system for implementing the method is achieved with the features in accompanying claim 9.

Estimate of person's fitness can be given based on one session only if the data is reliable but combination of several exercise sessions can be also used in estimation.

Selecting or weighting the data segments for determination of person's fitness in addition to data collection and statistical analysis only, is the unique feature of the described invention. Determination of person's cardiorespiratory fitness means determination of aerobic exercise capacity usually measured as VO₂max or METmax (MET = Metabolic Equivalent, 1 MET = the level of person's resting metabolic rate). Determination of cardiorespiratory fitness can be also done by scaling measured VO₂max or METmax based on person's age and gender which produces a fitness class. A preferred method comprises the following steps:

- 1) User selects exercise type and inputs his/her personal parameters (at least age, preferably maximal heart rate). Later on maximal heart rate can be determined during user-performed exercise sessions and updated if necessary.
- 2) Collection of heart beat data and performance data during user-performed exercise session(s). User can exercise freely but it is also possible to give the user broad recommendations on how to get most accurate results.
- 3) Segmenting collected data to different heart rate ranges
- 4) Calculating the reliability of different data segments
- 5) Calculating weighting coefficients for different data segments based on their reliability or excluding low reliability data segments from further analysis wherein low reliability is characterized by following factors:
 - Data segments at the very beginning of every exercise session (e.g. first 3 minutes)
 - Data segments with significant changes in heart beat derivable intensity parameters or in external workload
 - If not measuring directly power output, segments with steep downhills must be excluded
 - Data segments with non-comparable environmental conditions such as running in soft sand or in head-wind or tail-wind can be excluded if correction factors are not used in calculation.
- 6) Selecting most reliable data segments for further analysis; or selecting all data segments for further analysis wherein data segments with high reliability have high weighting coefficients.
- 7) Forming an estimate of person's fitness level by utilizing either linear or nonlinear dependency between one or more heart beat derivable parameters and person's performance data or by utilizing performance data only.
- 8) Giving the person a training plan that is optimal considering his/her fitness level.
- 9) Utilizing information on user's fitness in automatic guidance of a single exercise session wherein the purpose of automatic guidance is to make the user reach a preset physiological target. Preset physiological target can be set by the user or by an automatic training planning system.

Free fitness test application can be integrated in many devices including e.g. heart rate monitors, mobile phones, PDA devices (e.g. Palm PC) and personal computers,

where suitable device has a processor, memory and software stored therein as well as an user interface. The system may have device and a link to external device like heart rate monitor.

5 . The system for implementing the method comprises

- means for inputting personal parameter and exercise type, e.g. user interface having keyboard,
- means for collecting and storing heart beat data during at least one exercise session, e.g heart rate belt and monitor,
- 10 - means for collection and storing performance data of each exercise session, e.g. a bicycle ergometer,
- means for segmenting collected data to different heart rate ranges,
- means for calculating the reliability of each data segment,
- means for calculating weighting coefficients for each data segment based on
15 calculated reliability,
- means for calculating an estimate of user's fitness level based on dependency between the heart beat data segments and said performance data using the calculated weighting coefficients.

20 In certain conditions there is a shortcut to evaluate a minimum fitness level. Said collected performance data is analyzed to find the minimum possible value of user's fitness and an estimate of user's cardiorespiratory fitness level is formed based on the analyzed minimum possible value only instead using data segments and the calculated weighting coefficients.

25

The analyzing, segmenting and calculation are performed by software stored in the device. A blood lactate analyzer may be used to measure blood lactate level. An air flow meter may be used to measure respiration rate or ventilation.

30 After setting personal parameters and selection of exercise type (e.g. walking or pole (nordic) walking or running outdoors / on a treadmill; cycling outdoors / on a bicycle ergometer; ergometer rowing) user starts to exercise. In addition to the exercise types listed above, numerous other exercises can be used since there are equations for calculating theoretical oxygen consumption (theoretical VO₂) for many other

exercises as well. Calculation is based on either positional / altitude data or power output measurement. User can freely change the intensity of exercise. Collection of heart beat data during exercise can be done using equipment of current state of art. Simplest way is to use heart rate transmitter belt and recording of transmitted data to a receiver / recorder unit. Also a heart beat recording belt can be utilized for the purpose. Free fitness test can be applied in many exercise disciplines. Possible exercise disciplines include: (Pole)Walking/running and cycling outdoors, bicycle ergometer, rowing ergometer, Walking/running on a treadmill. In the described invention cardiorespiratory fitness assessment is based on measurement of speed and altitude (or inclination of a treadmill), or power production of the testee which can be derived when performing previously described exercise disciplines. Possible combinations for the assessment of oxygen consumption are: accelerometry + altimetry, GPS or Galileo (or other satellite navigation system) based positioning (+ altimetry), measurement of treadmill speed +inclination and measurement of external power. It is also possible to utilize local (indoor) positioning in the assessment of theoretical oxygen consumption by taking available techniques in use, such as techniques that are based on Wi-Fi / WLAN positioning or other similar technique such as Bluetooth, Radio Frequency Identification (RFID) technology, ultrasound, Ultra Wide Band (UWB) technology, optical positioning or TV radio signals (see e.g. Ekahau RTLS system, CA, USA and <http://www.indoorlbs.com/id115.html>). During outdoor cycling power may be measured using either combination of crank torque and cadence or chain vibration and cadence or other similar method, or by calculating the power by utilizing different equations for mechanical work (see e.g. Martin et al 1998). In stationary bicycles workload (i.e. how much the flywheel is broken) is adjusted usually by magnetic or electromagnetic means or by utilizing friction. In rowing workload / resistance is usually adjusted by magnetic means, or using air or friction resistance. In exercise machines workload information can be either sent or input to a calculation unit (central processing unit, CPU) or calculated in the exercise machine itself. Data can be sent wirelessly by means of e.g. infrared, bluetooth or other similar method; or by using a wired connection. Wireless communication between an exercise machine and a PDA device has been described in patent application publication EP1527801: In the document a universal, exercise machine mounted PDA holder is disclosed. When placed to the universal holder different kinds of PDA devices communicate with an exercise machine through an

infrared signal. Of course, it is possible to attach external measurement devices to fitness machines too. External measurement devices can comprise a separate CPU/display unit to which data can be sent wirelessly or by using wired connection which has been described e.g. in US2002/0160883 (Dugan) and in US7030735
5 (Chen).

As the first step of analysis, external workload is calculated in long sliding windows, say 3 min windows, to calculate the lowest possible value of person's fitness. Generally data segments have each duration of 20 s – 10 min, preferably 30s – 4min.
10 Estimate of minimum level of person's fitness can be made since it is not possible to maintain any external workload harder than the level of maximal oxygen consumption for longer than a few minutes. Minimum level of person's fitness is calculated by calculating the value of oxygen consumption value corresponding to the external workload by using an appropriate equation (equations are presented later in this
15 document).

After the minimum possible value of person's fitness is estimated data is segmented, each segment representing a given heart rate range. Ranges can be e.g. 100-109, 110-119.....190-199, or the ranges can base on %HRmax (51-55%, 56-60%...96-
20 100%). In one embodiment only one data segment with preset criteria is selected to present a given range but there can also be several data segments, or their average presenting each range. Selected data segment is thought to most accurately reflect person's fitness.

25 Data segments with low reliability can be excluded from further analysis. Firstly data segments with significant decreases in heart rate are excluded. Secondly, every time when power output is not directly measured (i.e. when power output is derived from speed and altitude/inclination data), data segments comprising too steep downhill are excluded from further analysis. This is also done in cycling if workload is calculated
30 based on speed, altitude and wind. Thirdly, data segments with measured or reported non-comparable environmental conditions can be excluded in cases when no correction factors are used. As an example, e.g. segments with excessive headwind or tailwind can be excluded from further analysis if wind speed is measured in proportion to speed of motion. Also data segments with too soft surface can be

excluded in the case if running stride is evaluated in more detail and exceptional striding pattern is detected from data. One possible way to recognize different surfaces is to use GPS-positioning and make conclusions based on whether the user is running on a road or in cross-country. It is also possible to include all data
5 segments to further analysis but in this case data segments must be weighted based on their reliability. Data segment with high reliability would have a high weighting coefficient.

Of course, if no correction factors are used, user must be informed before exercise
10 about the factors influencing results. E.g. in the case of running user must be prompted to perform the exercise on a surface which is relatively hard (e.g. running in deep snow or soft sand - or other environment which does not allow normal running technique- does not provide accurate results.). Actually, every time when fitness determination (estimation of person's VO₂max or METmax) is made based on
15 information on speed, user must be informed on the effect of different surfaces to the estimation accuracy. As a second example, also cycling speed is influenced by the surface: (gravel / sand / mud vs. asphalt).

After weighting data segments based on their reliability or alternatively - excluding
20 low reliability data segments and selecting the best data segments for final analysis - final analysis of fitness is made utilizing either linear or non-linear dependencies between heart beat derived parameters and performance parameters; or by selecting the above described minimum possible value of person's fitness if only it gives higher estimate than linear or non-linear equations. If a single exercise session does not
25 include enough reliable data, data from several exercise sessions can be utilized.

Information on person's fitness can be utilized both in automatic guidance of single exercise and in automatic planning of future training.

30 **Description of the drawings**

The invention and its embodiments are described more in detail with reference to following drawings.

Figure 1 presents measured points in recorded heart beat data and selection of points to be used

Figures 2a-2d present for parameters in recorded data of freely performed exercise session by running and showing segments with defined reliability

5 Figure 3 presents a linear equation of the chosen segments to estimate fitness

Figure 4 presents excluding a data point with excessive deviation

Figure 5 presents estimation fitness based on rating of perceived exertion (RPE)

Figures 6 and 7 present determining of VO₂ Max , or HRMAX respectively, using threshold values heart rate variability or respiration

10 Figure 8 presents a similar graph as Fig.6 using respiration rate instead of RMSSD

Detailed description of invention

15 In one embodiment of described invention fitness estimate is provided each time when the user has measured required parameters (HR + speed and altitude/inclination or HR + power production). User is equipped with heart rate monitor (or similar device), and a speed and altitude or a power measuring device. Before beginning the test user sets background parameters: A) If the user is using a
20 software or device equipped with fitness test for the first time, the user is prompted for setting required background parameters automatically (age or preferably HRmax; gender; weight is required e.g. in ergometer cycling and ergometer rowing) . B) Otherwise user may adjust the previously set background parameters from the settings menu and setting parameters is thus not mandatory. User starts exercise:
25 Walking/jogging, (bicycling or rowing). If real-time monitoring is desired, user may observe estimated fitness level throughout the test. Reliability of the fitness estimate is also provided (e.g. scale 0-100%). User observes the final fitness estimate after the test. VO₂max estimate of a single exercise session can be displayed to the user if there are enough reliable and physiologically meaningful data points during the
30 exercise session.

In one embodiment of described invention the progress of the user's cardiorespiratory fitness is evaluated. User has performed a plurality of exercise sessions equipped with appropriate equipment. After the exercise the user may

browse his/her progress in a form of a graph or numbers. A feedback can be provided to the user about his progress. Progress information can be also utilized to provide the user more suitable training plans for the future.

- 5 In one embodiment of described invention user's cardiorespiratory fitness is evaluated during a training session where user's intensity during the training session is automatically guided by an intensity guidance method (patent applications US2006/004265 (FI-U-6796) and WO2008/003830 by Firstbeat Technologies). User selects a route or distance to cover and a physiological target state (e.g. Training
- 10 Effect or EPOC target) for the exercise. Either one or both of route/distance and physiological target state can be also prompted by the system. The location of start and end of route is preferably the same which allows the user to shorten his exercise if needed. User starts to exercise. During the workout pre-predicted fitness level estimate gets more accurate which is used to enhance the intensity guidance. By
- 15 enhancing the intensity guidance preset targets can be reached more precisely. When available training time has run out the user should preferably have covered preselected route and reached his/her target EPOC/TE. It is also possible to change preset route if system estimates the session to become too hard for the user: user will not be able to cover the whole preselected route but will still reach target
- 20 TE/EPOC when arriving to the end point of route.

In one embodiment one or more of the heart rate and performance parameters are input manually by the user during the exercise.

- 25 In one embodiment of described invention it is possible to give to user instructions before and/or during the exercise on how to get as accurate results as possible. During the exercise these prompts may include messages such as "go faster" or "go slower" so that the system gets appropriate amount of data at different intensities.
- 30 In one embodiment of described invention given heart rate ranges are detected from the heart beat time series. Heart rate ranges may be e.g. 120-129, 130-139....190-199. Taking into account the principles of exercise physiology and fitness testing, best possible parts of heart beat time series are selected to represent above mentioned ranges. Generally, the quality of data is the better the longer the series of

successive heart beat intervals is and the smaller is the variation in heart rate level. E.g. If taking data to represent heart beat range 150-160 bpm, there can be several segments of data which could be taken to represent this heart rate range. However the data segment with highest reliability (long duration and low variability) is taken to
 5 represent this range. The reliability can be evaluated e.g. as shown below in table 1:

Table 1.

Standard deviation of successive 10 sec heart rate values (beats per minute)	Duration (min)					
	less than 0.5 min	0.5-1.0 min	1.0-1.5 min	1.5-2.0 min	2.0-2.5 min	2.5-3.0 min
	<i>Reliability coefficient (%)</i>					
more than 3.0 bpm	3 %	6 %	8 %	11%	14%	17%
2.5-3.0 bpm	6 %	11%	17%	22%	28%	33%
2.0-2.5 bpm	8 %	17%	25%	33%	42%	50%
1.5-2.0 bpm	11 %	22%	33%	44%	56%	67%
1.0-1.5 bpm	14 %	28%	42%	56%	69%	83%
less than 1 bpm	17 %	33%	50%	67%	83%	10%

10 Of course, the data could be also segmented to different ranges of theoretical oxygen consumption (theoretical VO₂), e.g. 10-15, 15-20...50-55ml/kg/min, or to ranges of % of maximal heart rate (%HR_{max}), e.g. 51-55%, 56-60%, 61-65%....96-100%.

Naturally, there could be several selection surfaces where the criteria change slightly
 15 depending on heart rate ranges. In higher heart rate ranges the variability of heart rate during a given external work is found to be lower than at lower heart rate levels. Accordingly, variability limits could be stricter at higher heart rate levels.

In one embodiment it is possible to include all data segments to further analysis. In
 20 this embodiment each data segment is weighted based on their reliability. In this case data with high reliability has also a high weighting coefficient when forming the linear/non-linear equations between external power output (theoretical oxygen consumption) and physiological exercise parameters (See figure 1.).

Also the requirements for the length of data segment could be slightly different at different heart rate levels to enhance discriminating power between different data segments.

- 5 There should be a relatively wide range of heart rate levels in use to ensure sufficient accuracy for the fitness (e.g. VO₂max) determination. In one embodiment of described invention, if available heart rate level range is determined to be too narrow, it would be widened by preferring lower end and higher end data segments. In the described embodiment segments with greatest heart rate averages are preferred
- 10 within segments of highest heart rate range (see table 2): reliability percentages from tables 1 and 2 are multiplied together and the segment with highest product is selected. Similarly, smallest values of lowest heart rate range are preferred (see table 3). Then reliability percentages from table 1 and 3 are multiplied together and the segment with highest product is selected. E.g. If highest available heart rate range is
- 15 150-160, then a data segment with average heart rate of 159 could be preferred over a data segment with average heart rate of 152 although the length of latter data segment would be slightly higher and variability slightly lower than in former data segment. Of course, if the quality of the data segment with higher average heart rate would be too low, then the data segment with lower heart rate would be selected to
- 20 VO₂max determination. Similarly, if there was a need to extend intensity range at the lower end, e.g. a data segment with average heart rate of 122 could be preferred over a data segment with average heart rate of 127 if only the length and reliability of the former segment were sufficient.

25 Table 2.

Average heart rate of segment when 150-159 is the highest available heart rate range	Reliability coefficient
150-151	60%
152-153	70%
154-155	80%
156-157	90%
158-159	100%

According to table 2, in a case that heart rate range 150-159 is the highest available heart rate range for a person; if e.g. the reliability of a data segment (based on length and data variation) with average heart rate of 158 beats per minute would be 33%, then the total reliability would be $33\% * 100\% = 33\%$. A more reliable segment (reliability% = 50% based on based on data length and variation) with average heart rate of 151 would produce a total reliability of $50\% * 60\% = 30\%$. This would mean that the former data segment with average heart rate of 158 would be selected to further analysis.

10 Table 3.

Average heart rate of segment when 120-129 is the lowest available heart rate range	Reliability coefficient
120-121	100%
122-123	90%
124-125	80%
126-127	70%
128-129	60%

According to table 3, in a case that heart rate range 120-129 is the lowest available heart rate range for a person; if e.g. the reliability of a data segment (based on length and data variation) with average heart rate of 120 beats per minute would be 33%, then the total reliability would be $33\% * 100\% = 33\%$. A more reliable segment (reliability% = 50% based on based on data length and variation) with average heart rate of 129 would produce a total reliability of $50\% * 60\% = 30\%$. This would mean that the former data segment with average heart rate of 120 would be selected to further analysis.

20

Of course there are numerous other possible heuristics for determining the reliability of data. Another simplified example is below in table 4. Of course it is possible to use e.g. neural network in determining the reliability of data segments.

Table 4.

A) SD of successive 10 sec heart rates is less than 2 bpm	B) Average heart rate of previous segment differs less than 10 bpm	C) Duration at least 1.5 min	Reliability
X			33.3%
	X		33.3%
		X	33.3%
X	X		66.6%
X		X	66.6%
	X	X	66.6%
X	X	X	100%

In one embodiment of described invention, if external workload increases during a data segment, average external work load (theoretical oxygen consumption) and highest 15 sec average of heart rate used to form the equation based on which person's fitness is evaluated. On the contrary, if external workload decreases during a data segment, average external workload and lowest 15 sec average heart rate are used to form the equation based on which person's fitness is evaluated. Almost similar solution would be selecting average external workload and average heart rate of 15 last seconds in all data segment. These solutions should most accurately correspond steady state conditions.

Figure 2 shows a typical freely performed exercise session which has been performed by running. There is data segment in the beginning of exercise (dark grey segments) which has highest 3 min average theoretical VO₂. This segment with average theoretical VO₂ of 55 ml/kg/min is considered as the minimum possible VO₂max of the testee. After determining the minimum value of person's VO₂max data is segmented and appropriate data segments (light grey segments) are selected from the whole exercise session. For clarity only 5 data segments are introduced in this example (see table 5). Data is segmented into segments with similar heart rate level. Data segments with low variance (measured by e.g. variance or standard deviance) and long duration are preferred for further analysis. The reliability of a data segment is assumed to be better if previous data segments have similar external workload. Segments 3, 4 and 5 (see table 5) are determined to best suit for fitness determination.

Table 5.

Segment no.	HR	Theoretical VO2 (ml/kg/min)	Reliability (%)	Notes
1	172	67	22 %	Included to further analysis
2	141	36	30%	Included to further analysis
3	156	44	69 %	Included to further analysis
4	145	47	14 %	Excluded from further analysis
5	168	55	28 %	Included to further analysis

5

Linear equation is made from segments 1, 2, 3 and 5, and the linear equation results in a VO₂max of 75 ml/kg/min (person's maximal heart rate is 185) (see figure 3.).

As a good example, data segment 4 (in table 5) is analyzed in more detail. Data
 10 segment was excluded due to it's low reliability as compared to segment 2 (both segments represent same heart rate range 140-149). The low reliability of segment 4 is due to its short duration and highly increasing intensity.

In one embodiment of described invention the reliability of position/altitude/speed
 15 data is evaluated. It is possible to filter speed signal or to detect and exclude from further analysis the moments when GPS-signal is too weak.

In one embodiment of described invention it is possible to predict the type of activity
 (running or walking) based on person's speed or limb acceleration data, and use
 20 appropriate VO₂ calculation formula which best suits for the activity. When prediction is used, the user must not define the type of exercise before exercise. When distinguishing the type of activity between walking and running, moments with speed lower than 7 km/h could be defined as walking and moments with speed equal to or higher than 7 km/h could be defined as running.

25

In one embodiment of described invention the equations for calculating theoretical oxygen consumption from external workload are the following:

Walking and pole walking:

$$\text{Theoretical VO}_2 \text{ (ml/kg/min)} = 1.78 * \text{speed} * 16.67 * [\tan(\text{inclination}) + 0.073]$$

Running on a level ground:

5 $\text{Theoretical VO}_2 \text{ (ml/kg/min)} = 3.5 * \text{speed}$

Running in a hilly terrain:

$$\text{Theoretical VO}_2 \text{ (ml/kg/min)} = 3.33 * \text{speed} + 15 * \tan(\text{inclination}) * \text{speed} + 3.5$$

10 Cycling:

$$\text{Theoretical VO}_2 \text{ (ml/kg/min)} = (12.35 * \text{Power} + 300) / \text{person's weight}$$

$$\text{(Indoor) rowing VO}_2 \text{ (ml/kg/min)} = (14.72 * \text{Power} + 250.39) / \text{person's weight}$$

15 Unit of speed = kilometers per hour (km/h)

Unit of inclination = degrees (°)

Unit of power = watts (W)

Unit of weight = kilograms (kg)

20 The above presented equations are well-known from the prior art.

In addition: equations has been described by Martin et al. (1998) for the calculation of road cycling power based on measured speed and altitude data etc. based on which VO₂ can be calculated. It is however irrelevant to show these equations in here.

25

In one embodiment of described invention data points with excessive deviation from other data points are also excluded from fitness determination. (See figure 4, where bpm = beats per minute).

30 In one embodiment of described invention changes in exercise intensity are evaluated based on heart beat derivable EPOC (Excess post-exercise oxygen consumption). The derivation of EPOC from heart beat data is described in US pat no. 7192401 (Patent by Firstbeat Technologies).

In one embodiment of described invention the data points for fitness determination are selected from two or more exercise sessions. This is done especially if one exercise session does not provide enough reliable data for fitness determination. The accuracy of fitness estimate is better than when data from several exercise sessions are used as compared to estimation based on one exercise session only.

”Estimation error caused for example by environmental factors (wind, road surface etc) can be minimized or even excluded with data or fitness level estimates from several exercise sessions. This is in especial advantage in PC or in web software application which can utilize easily massive amount of data

10

In one embodiment of described invention one or more parameters other than heart rate and external workload are used in fitness determination. These additional parameters can be heart beat derivable parameters. Possible parameters include respiration rate and ventilation (US patent no. 7460901 by Firstbeat Technologies Oy), blood lactate, subjective feelings (e.g. Rating of perceived exertion, RPE), heart rate variability (HRV) or other similar parameter.

Use of HRV in the determination of maximal heart rate and fitness have been recently described by Lewis et al. (2007), Oshima & Shiga (US7326150), Shiga et al (EP1059102), Heikkilä (US 5810722 and Heikkilä & Pietilä (EP0748185) but not during free exercise sessions which require data segmentation and evaluation. In one embodiment of described invention external workload is monitored against heart rate variability. In the described embodiment data is first segmented as described elsewhere in this document. One or more heart rate variability indices are calculated for reliable data segments. Of course, it is possible to select all data segments in which case segments are weighted based on their reliability. HRV data can be utilized in two different ways: either to increase the accuracy of estimating person's HRmax which information is further utilized in fitness determination; or to directly estimate person's cardiorespiratory fitness (VO₂max) based on heart rate variability information. Person's cardiorespiratory fitness can be evaluated by utilizing either linear or non-linear mathematical equations between any given HRV index and external workload or theoretical VO₂ (For the use of HRV information in estimation of cardiorespiratory fitness, see the figures 6 and 7, where RMSSD [Root Mean Square of Successive Differences in RR Intervals] is used as the HRV index, and theoretical

VO₂ is measured as ml/kg/min and heart rate (HR) as beats per minute). In one embodiment increasing the estimation accuracy of person's HR_{max} can be performed in a way that the equation - $HR_{max} = 210 - 0.65 * age$ - is used but this value is slightly up- or downgraded depending on the HRV response during exercise.

- 5 Of course, it is possible to estimate person's HR_{max} based on person's exercise induced HRV response only. Minimum value of HRV is usually reached at about 75-85 % of HR_{max} (respiratory compensation threshold, RCT), and therefore $HR_{max} \approx HR_{at_RCT} / 0.80$. Similarly when RCT is expressed as %VO_{2max} it is usually reached at about 70-80 %VO_{2max} and therefore $VO_{2max} \approx VO_{2_at_RCT} / 0.75$.

10

- In one embodiment of described invention external workload is monitored against RPE-values reported by the user during the exercise (see figure 8). Data segments with excessive variation in external workload are excluded from further analysis. This is done because the dependency between user's rating of perceived exertion and
- 15 external workload is distorted when external workload fluctuates. RPE scale starts from 6 (perceived exertion equivalent to doing nothing) and ends to 20 (perceived exertion equivalent to exhaustion). The described embodiment can be implemented in e.g. in a mobile phone where the user types his RPE values. In described embodiment the system can ask the user to report current RPE.

20

Borgs RPE-scale:

6	14
7 - Very, very light	15 - Hard
8	16
9 - Very light	17 - Very hard
10	18
11 - Fairly light	19 - Very, very hard
12	20 - Exhaustion
13 - Moderately hard	

In one embodiment of described invention external workload is monitored against respiration rate (see figure 5) or ventilation wherein both respiration rate and ventilation can be derived from HRV as described in US-patent 7,460,901 by

Firstbeat Technologies (Saalasti & Kettunen). In the described embodiment one or more metabolic thresholds are determined based on changes in respiration rate and ventilation, and VO₂max is determined based on information on said metabolic thresholds. E.g. ventilatory threshold is determined as the first and RCT is
5 determined as the second nonlinear increase in respiration rate or ventilation as a function of theoretical VO₂ or power output. In this case VO₂max = VO₂ at RCT / 0.75 or VO₂max = VO₂ at ventilatory threshold / 0.50.

In one embodiment of described invention fitness determination is done based on
10 recovery characteristics of heart rate or heart rate variability after free user performed exercise session. In this embodiment external workload is measured during the exercise. Fitness is evaluated using a databank containing a large amount of exercise and related recovery data. Neural network modeling can be utilized in a way that a neural network is taught with large amount of exercise and recovery data.

15

In one embodiment of described invention fitness determination is done using a neural network.

In one embodiment of described invention reliability percentage of the fitness
20 estimate is shown to the user e.g. as "goodness of fit" (r^2)-value.

In one embodiment of described invention fitness determination is done utilizing one or more methods described in this document. Person's VO₂max can be calculated e.g. as a mean or weighted mean of several calculation methods or by utilizing a
25 neural network model.

Following example of software shows a matlab® m-function, which is used to estimate VO₂max based on ambulatory recordings of heart rate, speed and altitude. This particular function suits for analysis of data that have been recorded with Suunto® T6 wristop computers. As is obvious to a person skilled in art, by slightly
30 modifying the matlab m-function it could be used with other file types as well, e.g. file types wherein only heart rate, position and altitude are provided.

In this example, the data is handled in 4 minute sliding window. Each sliding window is evaluated with parameters heart rate (bpm) and speed (m/s). Accepted variation in heart rate is 2.5 bpm and in speed 1 m/s. Data segment is formed, when 85% of the sliding window

falls into this criteria. In this example, 85% represents the reliability. Then weighting coefficient values are 1 and 0 according to this rule.

Alternatively, instead of fixed 85% reliability threshold, weighing coefficient value can be calculated for each data segment to be continuously between 0-1 according to a function
 5 using percentage value as a variable. The percentage value is the proportion of whole data segment duration and the accepted length with chosen criteria (see c1 and c2 in example 1). Data was segmented in this example by using characteristics of the data itself. This means usually searching coherent (usually steady) periods in each parameter (typically intensity and performance data like speed) in respect to its level and variation.

10 Data segment can be accepted with more complex rules comprising other parameters than those concerning intensity and performance data, for example related to data segment duration.

Additional criteria for reliability can be formed by evaluating the maximum intensity reached during the exercise. For example the whole result can be rejected if the maximum intensity
 15 has not reached a certain threshold, for example 40% maximum intensity.

```
% Matlab® m-function to estimate VO2max based on ambulatory recording with
% Suunto T6®. T6-sdf file containing [POINTS] is stored in a
% matrix-form to a matlab-structure S. Sampling frequency of
% POINTS-matrix is 10 seconds (rows are time series). Also [HEADER] of the
% sdf-file is used.
%
% Algorithm in short: each datapoint is checked if its surrounding, defined
% with a window of length n, meets the variance limits defined by
% coefficients c1 and c2. Only those datapoints accepted are used in the
% linear regression fit VO2teor=b(1)*HR+b(2). VO2max=b(1)*HRmax+b(2).
% VO2theor is estimated using speed and running angle.
%
% Inputs
%   c1      How much heart rate (bpm) may vary
%   c2      How much speed (m/s) may vary
%   n       The size of the window in which the time series are calculated.
%   p       How many percent the window must contain data restricted by
%           c1 and c2 to be accepted.
%
% Outputs
%   VO2max  VO2max estimate in ml/kg/min
%   b       The coefficients of the linear regression
%   ind     Indices of the time series that were accepted for linear
regression
%   HR      Heart rate of the time series
%   VO2theor Theoretical running VO2 ml/kg/min based on speed and running
angle.
%
% Example:
% Inputs
```

```

% c1 heart rate (bpm) may vary 2.5 bpm
% c2 speed (m/s) may vary 1m/s
% n time window 4 minutes periods
% p 85% needs to be within criteria c1 and c2 in the time set
% window n (4 minutes).
% [VO2max, b, stats, ind, HR, VO2theor]=vo2_5(s,2.5,1,6*4,0.85);
% plot(HR,VO2theor, '.');
% hold on;
% plot(HR(ind),VO2theor(ind), 'r*');
% plot(HR,polyval(b,HR))
% title(['Estimated VO2max=' num2str(VO2max)]);
% xlabel('HeartRate (bpm)'); ylabel('VO2theor ml/kg/min');
% hold off;
%
function [VO2max,b,stats,ind, HR, VO2theor]=vo2_5(S,c1,c2,n,p);

v=S.POINTS(:,14);
alti=S.POINTS(:,2);
dist=S.POINTS(:,13);
HR=S.POINTS(:,5);

altiD=zeros(length(alti),1).*0.001; altiD(2:end)=alti(2:end)-alti(1:end-1);
distD=zeros(length(dist),1).*0.001; distD(2:end)=dist(2:end)-dist(1:end-1);

VO2theor=12.*v+54.*tan( (sin(altiD./distD).*pi./180) ).*v+2.5;
HRmax=str2num( S.HEADER( strmatch('PERSONAL_MAXHR',S.HEADER) ,16:18) );

% HR and VO2theor must be nanfree. Heart rate should be at least 80,
% VO2theor>10 and speed at least 1m/s.
accepted_inds=find(~isnan(HR) & ~isnan(VO2theor) & HR>80 & VO2theor>10 & v>1);

ind=[];
n2=round(n/2);
for i=1:length(HR),
    t=intersect(accepted_inds, (i-n2):i+n2);
    if length(t)>=n2 & length(find(HR(t)>=HR(i)-c1 & HR(t)<=HR(i)+c1 &
VO2theor(t)>=VO2theor(i)-c2 & VO2theor(t)<VO2theor(i)+c2))>=p*length(t),
        ind=union(ind,t);
    end;
end;

if length(ind)<10,
    disp('Too few datapoints!');
end;

[b,stats]=polyfit(HR(ind),VO2theor(ind),1);
VO2max=HRmax*b(1)+b(2);

```

Claims

1. A method for evaluating cardiorespiratory fitness of a user during a freely performed exercise comprising the steps of:

- 5 - selecting exercise type and inputting user's physiological background parameters
- collecting heart beat data indicating relative intensity of exercise and performance data during at least one exercise session,
- segmenting said collected heart beat data to data segments with coherent intensity,
- 10 - calculating reliability of data and calculating weighting coefficients for the data segments based on their reliability, and
- forming an estimate of user's cardiorespiratory fitness level based on dependency between the heart beat data segments and performance data by using the calculated weighting coefficients.

15

2. A method as claimed in claim 1, wherein heart beat data describing relative intensity of exercise is a heart beat derivable parameter.

3. A method as claimed in claim 1, wherein heart beat data describing relative
20 intensity of exercise can be inputted by the user.

4. A method as claimed in claim 1, wherein heart beat data describing relative intensity of exercise is rating of perceived exertion.

25 5. A method as claimed in claim 1, wherein heart beat data describing relative intensity of exercise is blood lactate level.

6. A method as claimed in claim 1, wherein heart beat data describing relative intensity of exercise is respiration rate.

30

7. A method as claimed in claim 1, wherein heart beat data describing relative intensity of exercise is ventilation.

8. A method as claimed in claim 1, wherein set data segments have each duration of
35 20 s – 10 min, preferably 30s – 4min.

9. A system for evaluating cardiorespiratory fitness of a user during a freely
5 performed exercise comprising:
- means for inputting personal parameter and exercise type,
 - means for collecting and storing heart beat data during at least one exercise session,
 - means for collection and storing performance data of each exercise session,
 - 10 - means for segmenting collected data to coherent intensity segments forming data segments,
 - means for calculating the reliability of each data segment,
 - means for calculating weighting coefficients for each data segment based on calculated reliability, and
 - 15 - means for calculating an estimate of user's fitness level based on dependency between the heart beat data segments and said performance data using the calculated weighting coefficients.

10. A system as claimed in claim 9, wherein the means for collecting and storing
20 heart beat data are a heart rate belt and a monitor.

11. A system as claimed in claim 9, wherein the system includes a PC and software therein.

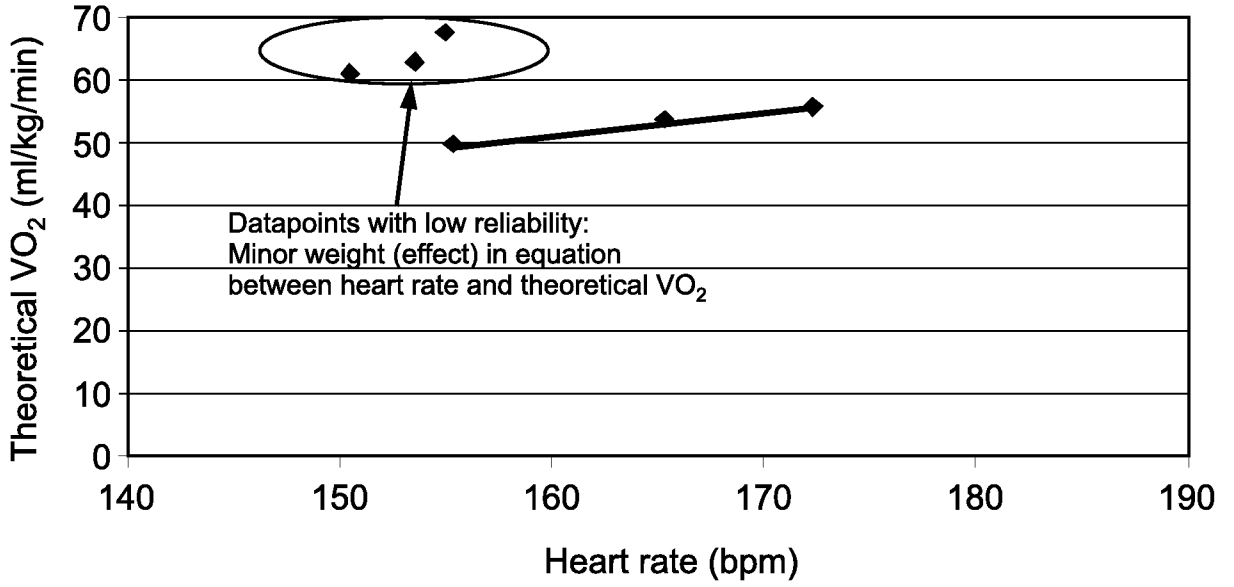


Fig. 1

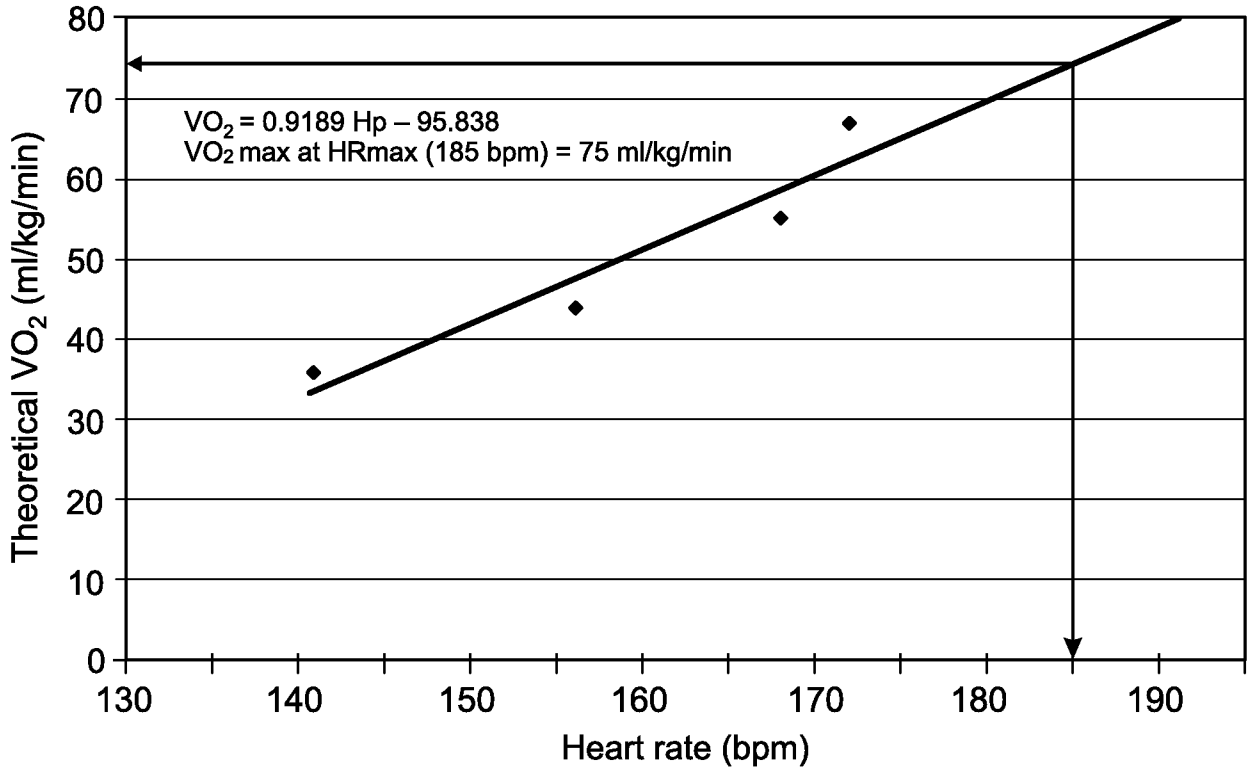


Fig. 3

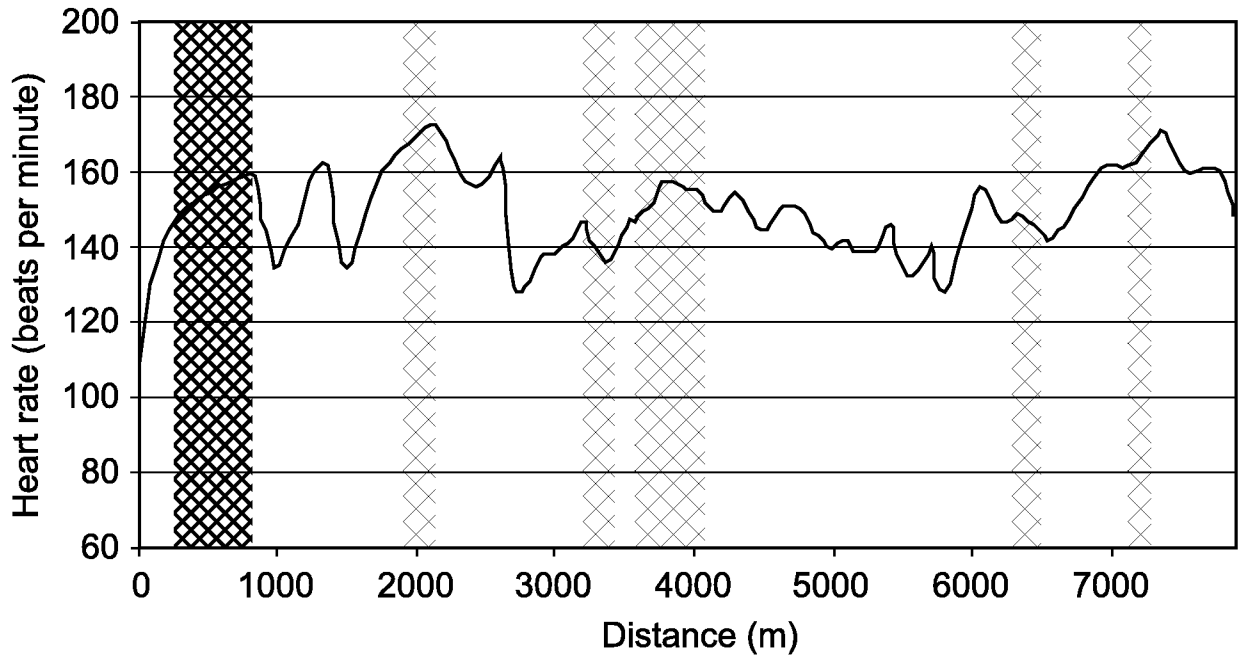


Fig. 2a

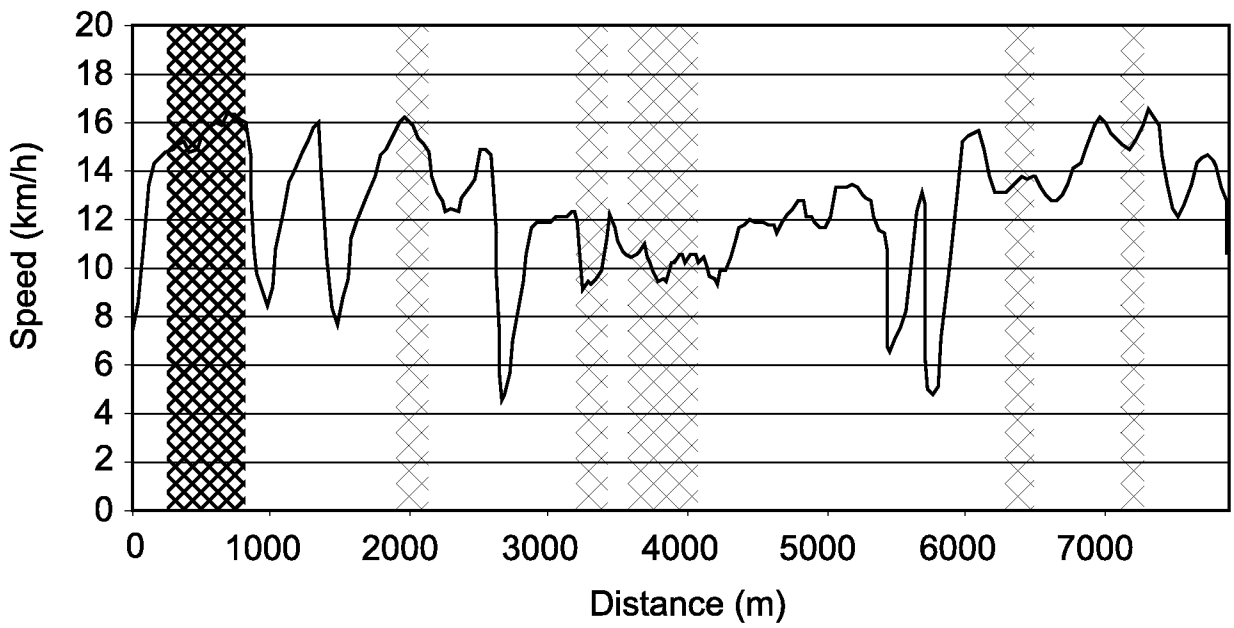


Fig. 2b

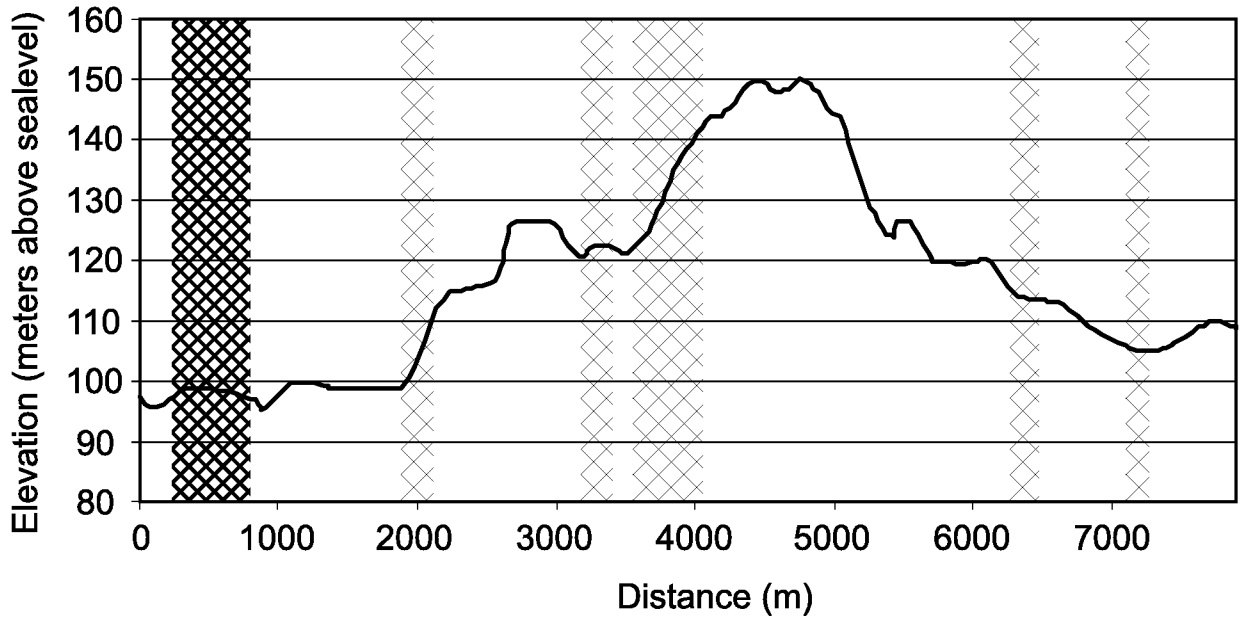


Fig. 2c

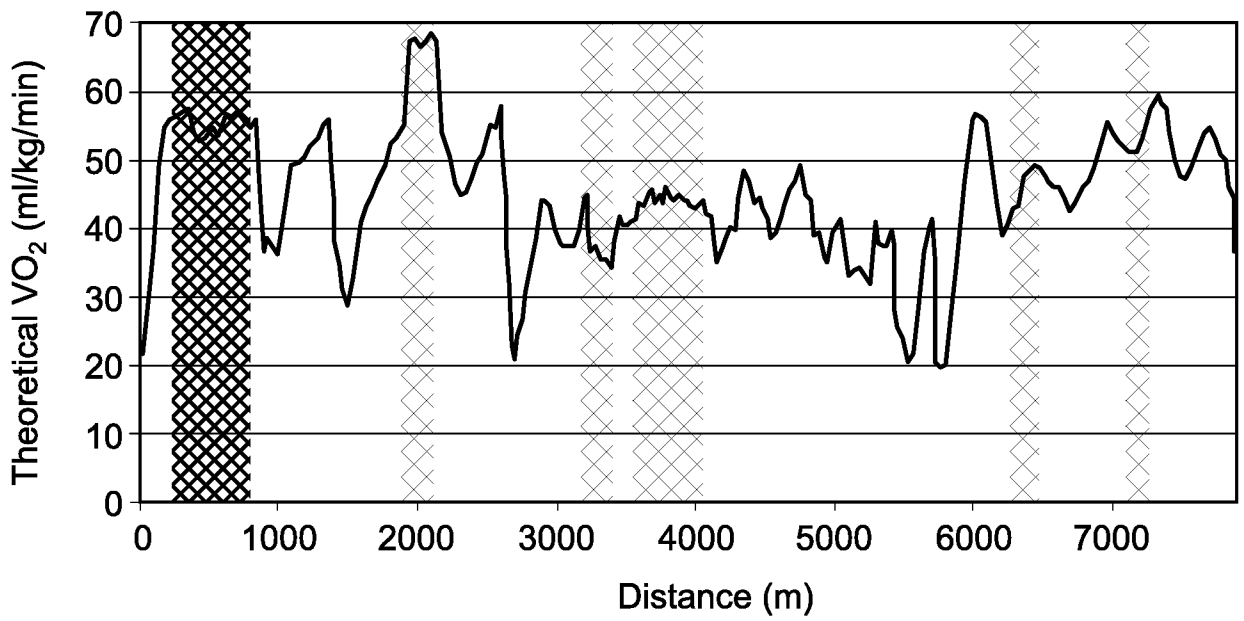


Fig. 2d

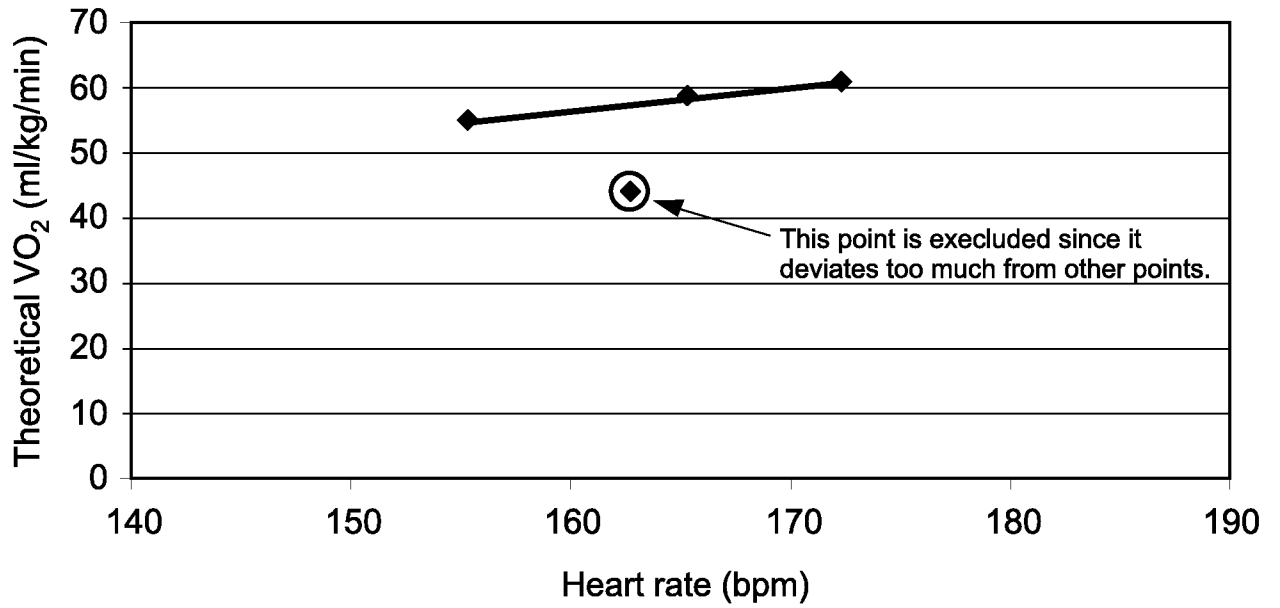


Fig. 4

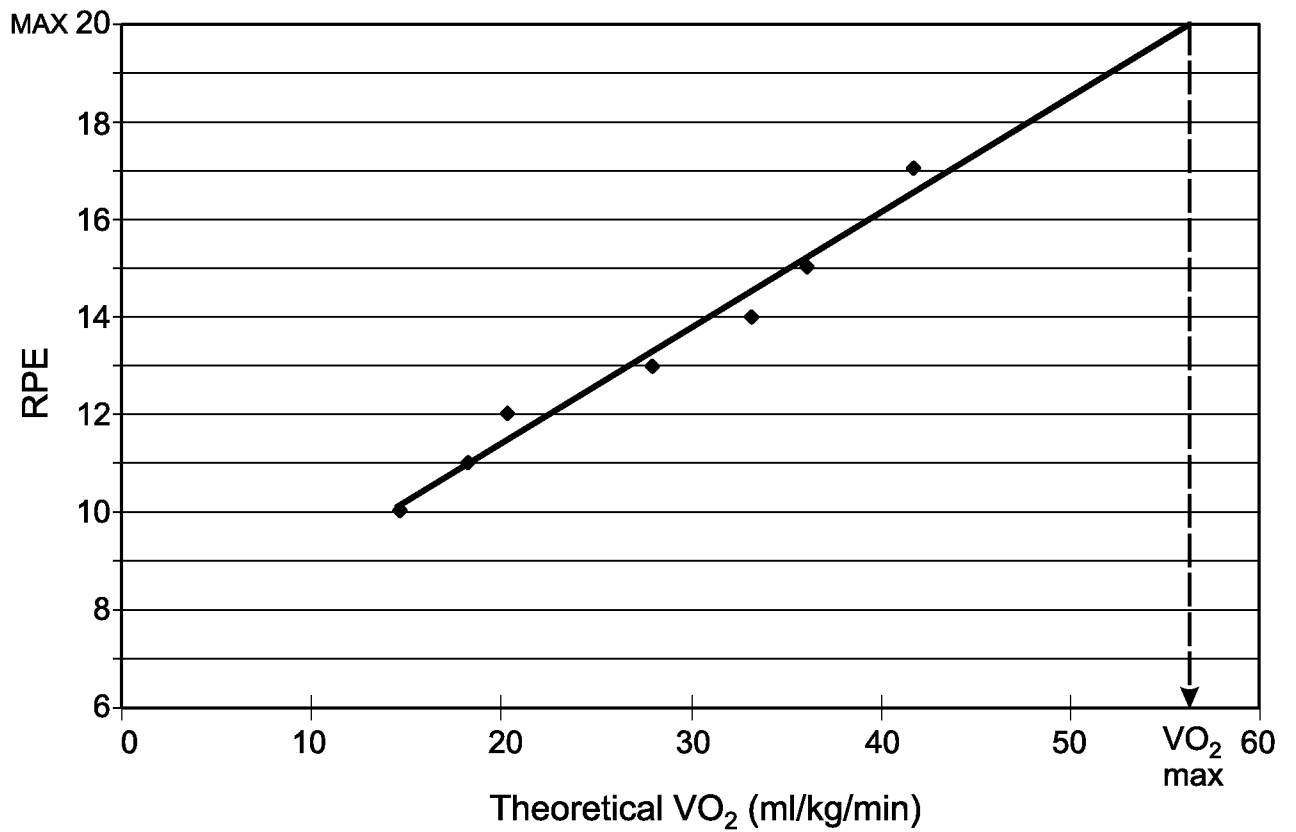


Fig. 5

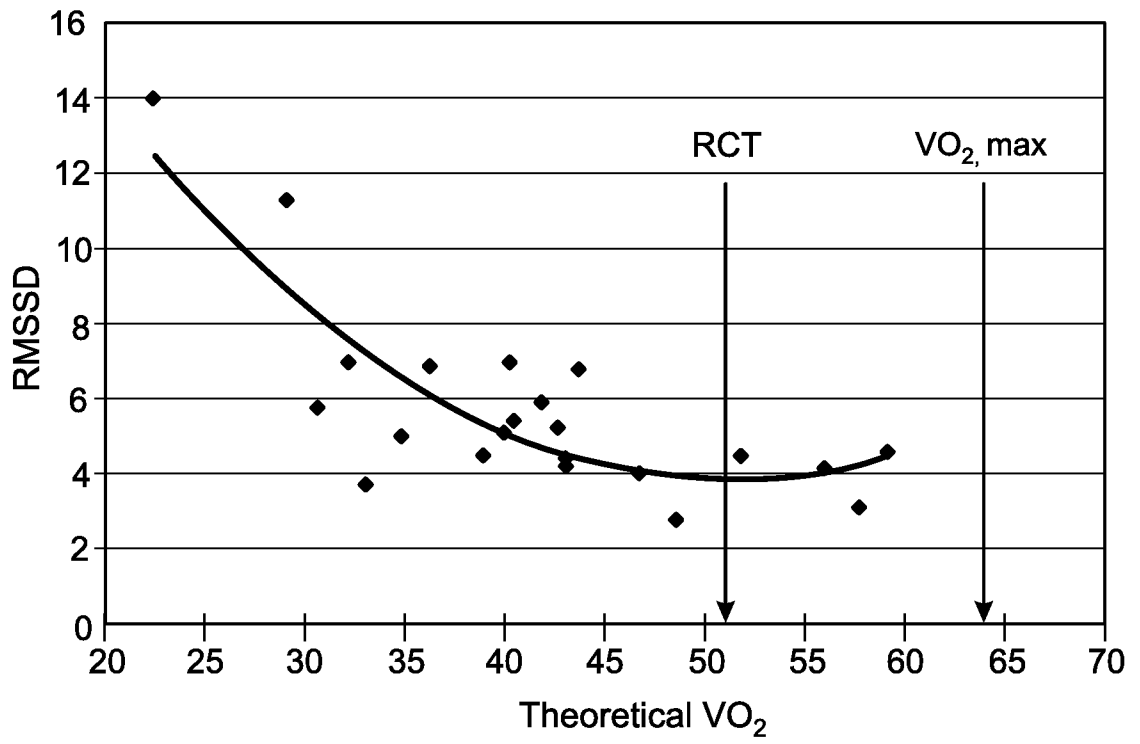


Fig. 6

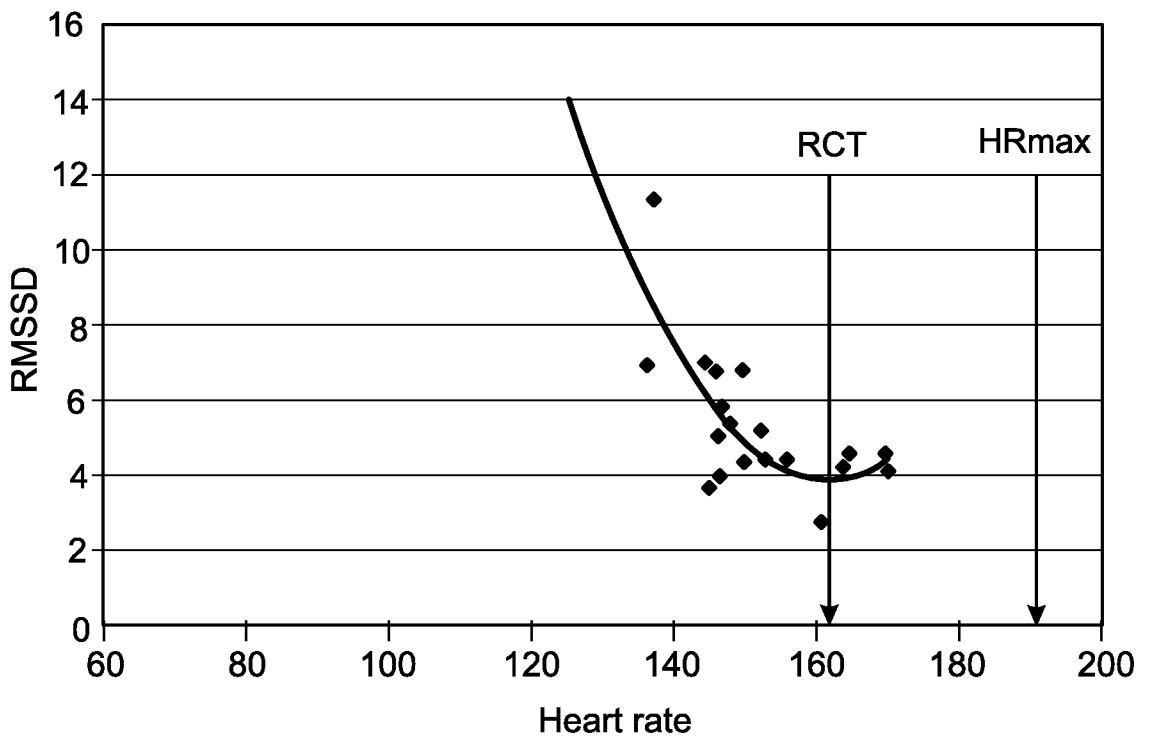


Fig. 7

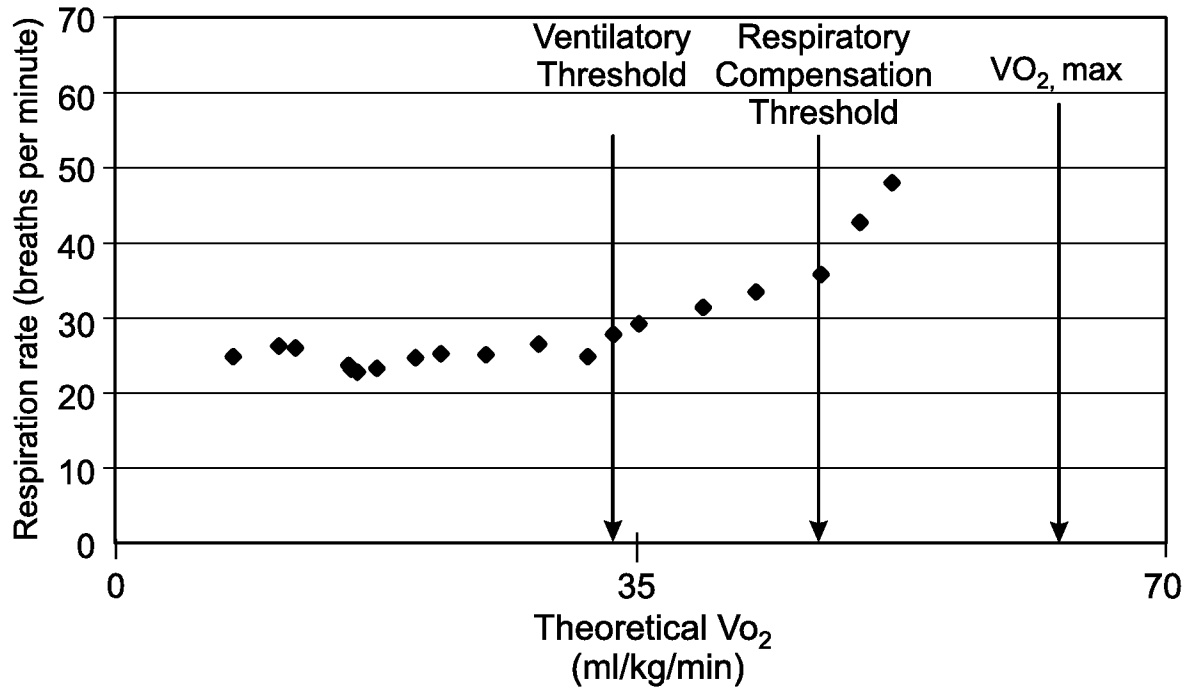


Fig. 8

INTERNATIONAL SEARCH REPORT

International application No.

PCT/FI2009/050351

A. CLASSIFICATION OF SUBJECT MATTER

See extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: A61B, G06Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

FI, SE, NO, DK

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 6176241 B1 (BLAU SAUL et al.) 23 January 2001 (23.01.2001), abstract; column 4, line 20 - column 3, line 35	1-11
A	US 6512948 B1 (SHIGA TOSHIKAZU et al.) 28 January 2003 (28.01.2003), column 2, line 33- column 3, line 63; column 11, lines 49 - 55; figures 7 and 18	1-11
A	WO 2004016173 A1 (FIRSTBEAT TECHNOLOGIES OY) 26 February 2004 (26.02.2004), cited in the application, abstract; pages 5, 6 and 7; page 19	1-11
A, P	US 2008161653 A1 (LIN MING-HUI et al.) 03 July 2008 (03.07.2008), abstract, paragraphs [0009] and [0010], figures 2, 4 and 5	1-11

 Further documents are listed in the continuation of Box C.

 See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search

27 August 2009 (27.08.2009)

Date of mailing of the international search report

03 September 2009 (03.09.2009)

Name and mailing address of the ISA/FI
National Board of Patents and Registration of Finland
P.O. Box 1160, FI-00101 HELSINKI, Finland

Facsimile No. +358 9 6939 5328

Authorized officer

Ann-Charlotte Kahlson-Sjöblom

Telephone No. +358 9 6939 500

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/FI2009/050351

Patent document cited in search report	Publication date	Patent family members(s)	Publication date
US 6176241 B1	23/01/2001	None	
US 6512948 B1	28/01/2003	JP 2004000646 A US 2003149371 A1 TW 474802B B WO 9943392 A1 JP 3551924B2 B2 EP 1059102 A1 CN 1291904 A	08/01/2004 07/08/2003 01/02/2002 02/09/1999 11/08/2004 13/12/2000 18/04/2001
WO 2004016173 A1	26/02/2004	US 2006032315 A1 WO 2004016173 A1 AU 2003251022 A1	16/02/2006 26/02/2004 03/03/2004
US 2008161653 A1	03/07/2008	None	

CLASSIFICATION OF SUBJECT MATTER

Int.Cl.

A61B 5/22 (2006.01)

A61B 5/024 (2006.01)

G06Q 50/00 (2006.01)