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(54) **Health risk indicator determination**

Gesundheitsrisikoindikatorbestimmung

Détermination d'indicateur de risque pour la santé

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(56) References cited:
WO-A1-2013/166341 WO-A2-2009/074985
US-A1- 2014 073 486

- **Nicholas J Wareham ET AL: "A quantitative analysis of the relationship between habitual energy expenditure, fitness and the metabolic cardiovascular syndrome", British Journal of Nutrition, vol. 80, no. 3, 1 September 1998 (1998-09-01), pages 235-241, XP055199341, ISSN: 0007-1145, DOI: 10.1017/S0007114598001287**
- **Kirsten L. Rennie ET AL: "Estimating energy expenditure by heart-rate monitoring without individual calibration", MEDICINE AND SCIENCE IN SPORTS AND EXERCISE., vol. 33, no. 6, 1 June 2001 (2001-06-01), pages 939-945, XP055199470, US ISSN: 0195-9131, DOI: 10.1097/00005768-200106000-00013**

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Description

[0001] The present disclosure relates to the conversion of biometric data to meaningful heath risk indications.

[0002] More specifically, aspects of the disclosure relate to a method and system for determining a health risk indicator for a user from heart rate data.

Background

[0003] According to The World Health Organization (WHO), physical inactivity is the fourth major cause of premature death worldwide (WHO, 2009) and a recent series of publications shows that inactivity kills about 6 million people every year worldwide; a similar number as smoking (I-M Lee, The Lancet 2012). It is also well established that about 80% of all adults do not fulfil the criteria of current recommendations for physical activity (see e.g. Folkehelseinstiuttet 2009) and that major reductions in lifestyle related diseases have to come from population-wide, cost-effective interventions such as systematically increased physical activity level (United Nations General Assembly A/66/83, 2011).

[0004] The public is overwhelmed by exercise advice and frequent disputes as to how, how often and for how long we should exercise. Navigating this information, which covers the whole range from professional athletes to heart patients, can prove confusing and frustrating. This in itself can lead to a lack of motivation.

[0005] Fitness monitoring devices such as pedometers are available. However, many fitness monitoring devices are based on motion sensing alone, which can lead to inaccurate estimation of activity levels. For example a wrist-worn accelerometer could indicate a higher activity level for a period during which a user is eating than a period during which they are climbing stairs.

[0006] While some fitness monitoring devices are based on personal heart rate monitors these tend to be aimed at fitness enthusiasts wishing to track their training. They do not provide meaningful health risk indications suitable for those who only wish to reduce their risk of developing lifestyle-related (e.g. cardiovascular) diseases.

[0007] For example, United States patent application publication number 2014/0073486 describes systems, devices and methods for continuous heart rate monitoring and interpretation. Academic research publications on the relationship between heart-rate and energy expenditure include Nicholas J Wareham et al,: 'A quantitative analysis of the relationship between habitual energy expenditure, fitness and the metabolic cardiovascular syndrome', British Journal of Nutrition, vol. 80, no.3, 1 September 1998 and Kirsten L. Rennie et al.: 'Estimating energy expenditure by heart-rate monitoring with individual calibration', Medicine and Science Sports and Exercise, vol. 33, no.6, 1 June 2001.

[0008] Prevention of disease is a common motivation for exercising. For older people in particular it is often the primary motivation.

[0009] There is a need for an accurate, yet simple and unified, recommendation about activity level, which directly links to an individuals' health.

[0010] Aspects of the invention are set out in the appended claims.

Brief description of the figures

[0011] Aspects of the present disclosure will now be described by way of example with reference to the accompanying figures. In the figures:

Figure 1 sets out a general method;
Figure 2 illustrates an example system;
Figure 3 sets out an example sample rate variation scheme;
Figure 4 sets out an example method;
Figure 5 shows an example user interface; and
Figures 6a to 6d illustrate example data.

Detailed description

[0012] The following description is presented to enable any person skilled in the art to make and use the system, and is provided in the context of a particular application. Various modifications to the disclosed examples will be readily apparent to those skilled in the art.

[0013] Recent (as yet unpublished) research has shown that accumulated number of heartbeats over time is the most important predictor for general cardiovascular health status. Presented below is a method for converting heart rate data to a health risk indicator and possible implementations of systems for collecting and processing heart rate data and informing a user of a health risk indicator derived therefrom.

[0014] Monitoring heart rate provides a more accurate way to track activity level for the purpose of improving health

than, for example, number of steps taken. The former rates walking uphill higher than walking the same number of steps on a flat surface, whereas the latter will rate these activities as the same (or even lower during uphill walking for some gaits) despite the significant difference in physical exertion required. Further, an aggregate heartbeat based system will rate a long hike in the mountains equally with high intensity interval training, if both activities promote the same aggregate heartbeat value, making a system based on aggregate heartbeat measurement suitable for use for health improvement across the population regardless of age or physical capability.

[0015] Figure 1 is a flowchart of a general method 100 for determining a health risk indicator for a user from heart rate data collected from them. At step 110, heart rate data for the user recorded over a monitoring period of at least five days, for example 1 week, is obtained. At step 120, that heart rate data is processed in dependence on a resting heart rate value for the user and a maximum heart rate value for the user to determine an aggregate heartbeat value for the user over the monitoring period. At step 130, a health risk indicator is determined in dependence on the aggregate heartbeat value.

[0016] Figure 2 is a schematic of an example system for providing a user with a health risk indicator.

[0017] Biometric data including at least heart rate data is collected from a user by one or more sensors comprised in a sensor device 210. Sensor device 210 could be a wearable device, for example a sensor wristband or chest strap. Heart rate data could be collected by, for example, a photoplethysmography (PPG) sensor. Other kinds of sensors could also be provided, for example an accelerometer (motion sensor), blood pressure sensor, glucose sensor, blood gas sensor, pressure sensor or any other sensors which could be used to measure user activity, physiological or environmental parameters. Data obtained from such sensors could be taken into account in determining health risk indicators and/or could be part of a wider health/fitness monitoring suite enabling a user or healthcare professional to obtain more detailed health indication information if required.

[0018] The user's resting and maximum heart rates are also obtained. Resting heart rate can be obtained by determining the lowest heart rate value measured by sensor device 210 over the monitoring period. Alternatively, resting heart rate could be measured by the user or a healthcare professional by any known method and manually input to the system via a user interface. Maximum heart rate can be obtained by determining the highest heart rate value measured by sensor device 210 over the monitoring period. Alternatively maximum heart rate could be measured by the user or a healthcare professional by any known method and manually input to the system via a user interface.

[0019] The sensor device 210 could comprise a user interface 211 and/or could comprise means for transferring data to a user device 220 having a user interface 221 such as a mobile phone (e.g. a smartphone), tablet, laptop or personal computer. Such data transfer means could comprise a wired connection such as a Universal Serial Bus (USB) line or a wireless link such as a Wi-Fi or Bluetooth™ connection between a transmitter and associated antenna comprised in the sensor device 210 and a receiver and associated antenna comprised in the user device 220. The sensor device 210 and/or the user device 220 could each run software suitable for implementing part or all of the method described herein by means of memories 212 and 222 and processors 213 and 223 respectively. For example the user device 220 could run a dedicated application or could run a general-purpose web browser through which a web-based application could be accessed. Suitable user interfaces include at least touchscreens, keyboards and/or touchpads or mice or microphones with associated voice recognition capabilities.

[0020] The system could have a calibration mode to collect resting and maximum heart rate from the user without requiring the assistance of a healthcare professional. For example software run on the sensor device 210 or user device 220 could cause a user interface of one of those devices to prompt a user to perform a calibration on first switching on sensor device 210 or opening an associated application with user device 220. The user could also be presented with an option to skip the calibration at that point but, if they select the skip option, they could be prompted to perform the calibration at the end of the monitoring period.

[0021] When the user selects calibration mode, they can be instructed by a user interface to get into a comfortable position for measuring resting heart rate and start a timer when ready. While the timer is running they could be instructed not to perform any physical activity until the timer, which can for example be displayed on a visual user interface of the device, expires. The timer could for example be for one minute. Towards the end of the timer period the sensor device 210 could take a heart rate reading and record this as the user's resting heart rate. Alternatively, sensor device 210 could monitor the user's heart rate over some or all of the timer period, for example at 5 second intervals, and select the lowest measured rate to record as the user's resting heart rate. Once the user's resting heart rate has been obtained, the user could be prompted to get on to some gym equipment (e.g. a treadmill, cross-trainer, rowing machine or exercise bike), or find somewhere to run, cycle or similar and start another timer when ready. While the timer is running they could be instructed to exercise at maximum exertion (e.g. run as fast as possible).The timer could for example be for 5 minutes. Sensor device 210 could monitor the user's heart rate over some or all of the timer period and select the highest measured rate to record as the user's maximum heart rate.

[0022] During the monitoring period itself, sensor device 210 can monitor the user's heart rate continuously or sample at intervals. If sensor device 210 is battery powered, the monitoring could be arranged such that a fully charged battery will outlast the monitoring period. Interval sampling could be periodic. A typical sampling rate could be once per minute.

A minimum sampling rate could be once every 15 minutes. The sensor device 210 could store the heart rate data in local memory 212. Alternatively or additionally the sensor device 210 could be provided with data transfer means such as those described above to convey the heart rate data to a user device 220 for storing in its local memory 222 or upload it directly to a network 240 such as the internet for transmission to a server 230.

[0023] The heart rate data can be processed by an internal processor 213 of the sensor device 210, a processor 223 of the user device 220, at the server 230 or by any combination of these performing any suitable combination of the processing steps.

[0024] Sampling rate could be variable. This can help to achieve a suitable balance between data accuracy and (battery) power consumption. For example if heart rate is determined to have risen above a first predetermined threshold value (indicating that physical activity is being undertaken), for example 60% of the user's maximum heart rate relative to their resting heart rate, the sampling rate could be increased, for example to once every 15 seconds. The sampling rate could be returned to its standard value when the user's heart rate is determined to have fallen below the first threshold, or to have stayed below the first threshold for a predetermined period, for example 5 minutes. Similarly, if the user's heart rate is determined to have fallen below a second predetermined threshold value, for example 5% of the user's maximum heart rate relative to their resting heart rate, or to have stayed below such a threshold for a predetermined period, for example 10 minutes (indicating that the user is sleeping), the sampling rate could be decreased, for example to once every 10 minutes. The sampling rate could be returned to its standard value when the user's heart rate is determined to have exceeded the second threshold again.

[0025] Figure 3 is a flowchart showing an example scheme for varying sampling rate. At 301, a sample counter k is set to zero. At 302, the user's current heart rate is measured and recorded as y_k. At 303, y_k is compared to Δy, the heat rate range of the user where:

$$\Delta y = y_{max} - y_{rest} \quad (1)$$

i.e. the difference between the user's resting and maximum heart rates as previously recorded. If the current heart rate value is less than 5% of Δy, then a sampling interval Δt is set to 10 minutes at 304a. If the current heart rate value is between 5% and 60% of Δy, then Δt is set to 1 minute at 304b. If the current heart rate value is greater than 60% of Δy, then Δt is set to 15 seconds at 304c. At 305, a timer is set to wait for Δt, and when it has expired the value of k is incremented by 1 and the process returns to 302.

[0026] An example processing method 400 is set out in Figure 4.

[0027] At step 410, a series of heart rate values y_k are measured and stored. This series of instantaneous sampled heart rate values is recorded over the monitoring period defined as time, t=-T to t=0. Optionally, a continuous heart rate function $y(t)$ could be extrapolated from the series of heart rate values.

[0028] At step 421, the heart rate values (or heart rate function) are (is) converted to a series of intensity values $\bar{y}_k$ (or an intensity value function $\bar{y}(t)$). This could be done using a linear intensity scaling. In this example method, intensity conversion is a normalisation with respect to the user's heart rate range (from resting heart rate y_{rest} to maximum heart rate y_{max}). This produces a series of normalised heart rate values $\bar{y}_k$ (or a continuous normalised heart rate function $\bar{y}(t)$) according to equations 2. This gives an indication of instantaneous exertion over the monitoring period.

$$\bar{y}_k = \frac{y_k - y_{rest}}{\Delta y} \; ; \quad \bar{y}(t) = \frac{y(t) - y_{rest}}{\Delta y} \quad (2)$$

Alternative intensity scaling could be used, for example by calculating a percentage of individual fitness level based on peak oxygen uptake.

[0029] If a variable sampling rate was used to record the heart rate data then inter-sample data points can optionally be extrapolated between samples for periods when the sampling rate was at less than its maximum value to produce a series of data points at constant intervals. For example linear interpolation between the two (temporally) nearest sampled heart rate values to each desired extrapolated data point could be used. This extrapolation can be performed before or after intensity scaling. Alternatively, if no extrapolation of inter-sample data points is performed, then variable sampling rates as described above, with higher sampling rates used during periods of greater exertion, would result in higher weighting of heartbeats during exercise on calculation of activity score as described below.

[0030] At step 422, the intensity values (or intensity value function) are (is) converted to a series of intensity scores z_k (or an intensity score function $z(t)$). This could be done using a power function. In this example method, intensity score calculation is done using an exponential function according to equations 3:

$$z_k = c_1(e^{c_2 \bar{y}_k} - 1); \quad z(t) = c_1\left(e^{c_2 \bar{y}(t)} - 1\right) \tag{3}$$

where c_1 is a constant scaling factor (which can be unity) and c_2 is a constant weighting factor. Alternative power functions or other scaling functions could be used, for example quadratic or cubic.

[0031] The activity score, *P,* is then computed at step 423. The activity score is a heartbeat aggregate over the monitoring period, *T,* for example the Euler integration sum (or definite integral) of the intensity scores (or intensity function) over the monitoring period as per equations 4.

$$\mathrm{P} = \sum_{\mathrm{i}=-\mathrm{N}}^{\mathrm{k}} \Delta t_i z_i\,; \quad \mathrm{P} = \int_{-\mathrm{T}}^{0} \mathrm{z(t)\ dt} \tag{4}$$

where *N* is the total number of sample points over the monitoring period and Δt is the sampling interval.

[0032] At step 431, a health-predictive activity score, *V*, is determined as an explicit function of activity score *P*, for example according to equation 5:

$$V = c_3 + c_4(1 - e^{-P}) \tag{5}$$

where c_3 and c_4 are constants determined from population study data. For model calibration the health-predictive activity score can be statistically linked to peak oxygen uptake of population study subjects since peak oxygen uptake is a good predictor of cardiovascular health. (Peak oxygen uptake of the user need not necessarily be known, but the health-predictive activity score can be compared with the activity score needed to achieve a certain peak oxygen uptake over time to determine a health risk indicator.)

[0033] Any or all of constants c_1 to c_4 could be chosen from a plurality of options according to one or more user characteristics such as gender, age, weight, height etc. For example, suitable constants for a male user could be c_1=4.51, c_2=7.73, c_3=29.5, c_4=19.8.

[0034] One or more health risk indicators can be derived from the health-predictive activity score at step 432. For example, a health risk indicator could be a linear scaling of the health-predictive activity score, where complete inactivity gives the value 0 and the value 100 indicates minimal risk of developing lifestyle-related diseases. The health risk indicator could be expressed relative to a threshold for reduced/increased risk to health. For example, a health risk indicator of greater than 45 for men, or 35 for women, could indicate reduced risk, while a health risk indicator below that threshold could indicate increased risk.

[0035] A health risk indicator could be expressed as a personal activity index, *PAI,* as defined in equation 6:

$$PAI = \frac{100(V - c_3)}{V_{threshold} - c_3} \tag{6}$$

where $V_{threshold}$ is a constant which could optionally be chosen from a plurality of options according to one or more user characteristics such as gender, age, weight, height etc. It could for example be 45 for a male user or 35 for a female user.

[0036] A health risk indicator could be a binary indication of whether or not the user has been physically active enough over the monitoring period to improve their activity score compared to a previous monitoring period. Alternatively, it could be a binary indication of whether or not the user has been active enough over the monitoring period to reduce their general risk of developing lifestyle-related diseases compared to a previous monitoring period. If a greater level of detail is desired, one or more binary health risk indicators could be provided to indicate whether or not the user has been active enough over the monitoring period to reduce their risk of developing a corresponding one or more specific lifestyle-related diseases/conditions compared to a previous monitoring period. For example, individual health risk indicators could be provided for metabolic syndrome, atherosclerosis, hypertension, high blood glucose, unfavourable blood lipid profile, obesity etc. Alternatively, a percentage general risk factor for developing lifestyle-related diseases could be provided, or one or more percentage risk factors for developing specific lifestyle-related diseases. A binary indication could be provided whether or not the user has been active enough over the monitoring period to increase their life expectancy, or a life expectancy could be provided. The provision of these indicators comprises comparison with population study data, and the provision of some comprise taking into account additional data relating to the user such as age, weight, body mass index, smoking and alcohol drinking habits and diet and/or monitoring of other biometric parameters.

[0037] At step 440, the health risk indicator is provided to the user or a medical professional, for example via a user

interface, at the end of a first monitoring period. For example a report, or an alert that a report can be accessed by, for example, selecting a hyperlink or opening an application, could be text messaged or emailed to an account of the user or medical professional, or an application running in the background of a user device could automatically open or trigger an alert. Alternatively, the user or medical professional could be required to manually request a report when desired. The system's software could provide the user with an opportunity to share each or every report on linked social media accounts.

[0038] A graphical user interface displaying a health risk indicator could for example be as shown in Figure 5. The *PAI* is indicated at the top and graphically represented below by coloured bars indicating risk of developing lifestyle-related diseases. In the example shown, the *PAI* is 125, above the threshold for sufficient activity for minimal risk (100), so the coloured bars fill up to the green zone above the upper divider line.

[0039] A second monitoring period could follow consecutively from the first such that up to date health risk indicators are available at a frequency of one divided by the monitoring period, for example once per week. Alternatively, the monitoring period could be a sliding window so that, for example, up to date health risk indicators are available daily based on data collected over the preceding 7 days.

[0040] Health benefit from activity diminishes as activity level increases, the most benefit being shown from an increase from complete inactivity to only a little activity. Accordingly, the aggregate heartbeat value could be calculated by use of a function that lowers the weighting of higher activity scores.

[0041] If user motion data is obtained for some or all of the monitoring period, for example if sensor device 210 or an additional sensor device comprises a motion sensor such as a tri-axis accelerometer, this can be taken into account in determination of the health risk indicator. For example if a user's heart rate is high (with respect to their resting and maximum heart rate) but they do not appear to be moving, this could be due to emotional stress rather than physical exertion. Therefore the high weighting which would be given to the heartbeats in that high heart rate period according to the method above could provide a false indication of activity level. The weighting applied could therefore be reduced, for example by 15%, for periods during which the measured (or extrapolated) heart rate is higher than would be expected for the activity level suggested by the motion sensor, for example by a predetermined margin such as 30 beats per minute.

[0042] A relatively high measured heart rate (with respect to the user's resting and maximum heart rates) during a period in which a motion sensor suggests the user is not moving could be an indication of heart disease, especially if sustained over hours (Nauman et al, JAMA 2011). If this condition is determined to be sustained over a predetermined period of, for example, two hours the system could inform the user to contact his/her physician for a medical follow-up.

[0043] If such a combined pulse and motion sensor approach is used then greater accuracy could be obtained if, during exercise, the user ensures they wear the motion sensor on an active part of their body. For example, a wrist-worn motion sensor could result in inappropriate decreased weighting of heart rate data collected during cycling, whereas an ankle-worn motion sensor would not. The system could alert the user via a user interface if heart rate data and motion sensor data do not indicate similar activity levels, for example if measured (or extrapolated) heart rate is higher than would be expected for the activity level suggested by the motion sensor by said predetermined margin. Such an indication could, for example encourage the user to switch the motion sensor to a more appropriate part of their body during exercise (e.g. transfer a band-based motion sensor from wrist to ankle for cycling), or could indicate to heart patients that they are under undesirable emotional stress and should rest if possible.

[0044] A further parameter that can be determined from the heart rate data is the user's peak aerobic capacity, or $peakVO_2$. An aggregate heartbeat value, for example the health-predictive activity score, V, can be statistically fitted to data that includes $peakVO_2$. However, since the present invention provides an instantaneous assessment of current activity level (typically over a one-week-period) it cannot explicitly determine $peakVO_2$. $peakVO_2$ evolves over time, increasing slowly with an elevated physical activity profile and decreasing slowly with absence of (or lowered) physical activity. However, persistence of a certain activity score V will converge towards a $peakVO_2$ value determined from the data fitting of V the model. An activity-induced $peakVO_2$ estimate, $AIpeakVO2_k$, could be estimated by a low pass filter on V, for example a first order low pass filter as per equation 7:

$$AIpeakVO2_k = \alpha V_k + (1-\alpha) AIpeakVO2_{k-1} \qquad (7)$$

where α is a constant given by the time constant expressing the individual's response to training. α can be an average value determined from a population study and/or individually fitted by analysing the slowly-varying changes in resting heart rate of the user. The activity-induced $peakVO_2$ estimate could be further corrected to a true $peakVO_2$ estimate by using the user's age, resting heart rate and/or waistline measurement/body mass index (Nes et al 2011 & Nes et al, unpublished data).

[0045] Figures 6a to 6d show how health-predictive activity score, V, as calculated according to equation 5 relates to $peakVO_2$ for test subjects respectively performing various amounts of exercise per week at 50, 70, 80 and 90% of peak oxygen uptake.

[0046] In view of the foregoing description it will be evident to a person skilled in the art that various modifications can be made within the scope of the invention.

Claims

1. A method of processing heart rate data comprising:

a processor (213, 223, 230) processing (421, 422) heart rate data, obtained from a user by a sensor device (210) over a monitoring period of at least one day, in dependence on biometric data for the user, to determine (120, 423) an aggregate heartbeat value for the user over said monitoring period;
a processor (213, 223, 230) determining (431) a health-predictive activity score from said aggregate heartbeat value according to a model calibrated with peak oxygen uptake of population study subjects;
a processor (213, 223, 230) determining (130, 432) a health risk indicator for the user derived from said health-predictive activity score; and
a user device (210, 220) providing (440) said health risk indicator to the user by means of a user interface (211, 221).

2. The method of claim 1, wherein said biometric data comprises a resting heart rate value for the user and a maximum heart rate value for the user.

3. The method of either of claims 1 or 2, wherein the monitoring period is at least five days.

4. The method of any of claims 1 to 3, wherein the heart rate data are a series of pulse measurements.

5. The method of claim 4, further comprising extrapolating said series of pulse measurements to produce an evenly distributed series of data points or a continuous heart rate function over the monitoring period.

6. The method of claim 2, or any of claims 3 to 5 as dependent on claim 2, wherein said processing comprises normalising (421) the heart rate data, an evenly distributed series of data points derived from the heart rate data or a continuous function derived from the heart rate data by subtracting said resting heart rate value and dividing the result by the difference between said maximum heart rate value and the resting heart rate value.

7. The method of claim 6, wherein said processing further comprises determining (422) a series of intensity scores z_k or an intensity score function $z(t)$ from a series of normalised heart rate values $\overline{y}_k$ or a continuous normalised heart rate function $\overline{y}(t)$), a constant scaling factor c_1 and a constant weighting factor c_2 according to: $z_k = c_1(e^{c_2\overline{y}_k} - 1)$; $z(t) = c_1(e^{c_2\overline{y}(t)} - 1)$ wherein c_1 and c_2 are chosen from a plurality of options according to one or more user characteristics.

8. The method of claim 7, wherein said aggregate heartbeat value is determined as the Euler integration sum or definite integral of the intensity scores or intensity function over the monitoring period.

9. The method of claim 8, wherein said determining the health-predictive activity score V is according to: $V = c_3 + c_4(1 - e^{-P})$, wherein P *is* the heartbeat aggregate value and constants c_3 and c_4 are determined from population survey data.

10. The method of claim 9, wherein the health risk indicator PAI is determined according to: $$PAI = \frac{100(V - c_3)}{V_{threshold} - c_3}$$ where $V_{threshold}$ is a constant chosen from a plurality of options according to one or more user characteristics.

11. The method of any preceding claim, repeated periodically, with a repetition period:

equal to the monitoring period such that the method is repeated consecutively; or
less than the monitoring period such that the method is performed in a sliding window.

12. The method of any preceding claim, further comprising estimating the user's peak aerobic capacity using a low pass filter on the aggregate heartbeat value or a value derived therefrom and biometric data for the user.

13. A computer program product comprising computer-executable instructions for performing the method of any pre-

ceding claim.

14. A system for processing heart rate data, said system comprising:

a processor (213, 223, 230) configured to process (421, 422) heart rate data, obtained from a user by a sensor device (210) over a monitoring period of at least one day, in dependence on biometric data for the user, to determine (120, 423) an aggregate heartbeat value for the user over said monitoring period;
a processor (213, 223, 230) configured to determine (431) a health-predictive activity score from said aggregate heartbeat value according to a model calibrated with peak oxygen uptake of population study subjects;
a processor (213, 223, 230) configured to determine (130, 432) a health risk indicator for the user derived from said health-predictive activity score; and
a user device (210, 220), having a user interface (211, 221), the user device being configured to provide (440) said health risk indicator to the user by means of the user interface.

Patentansprüche

1. Verfahren zur Verarbeitung von Herzfrequenzdaten, das Folgendes umfasst:

einen Prozessor (213, 223, 230), der Herzfrequenzdaten, die von einem Anwender durch eine Sensorvorrichtung (210) über einen Überwachungszeitraum von mindestens einem Tag erhalten wurden, in Abhängigkeit von biometrischen Daten für den Anwender verarbeitet (421, 422), um einen gesamten Herzschlagwert für den Anwender über den Überwachungszeitraum zu bestimmen (120, 423);
einen Prozessor (213, 223, 230), der einen Gesundheit-prädiktiven Aktivitäts-Score aus dem gesamten Herzschlagwert gemäß einem Modell, das mit Spitzen-Sauerstoffaufnahme von Populationsstudiensubjekten kalibriert ist, bestimmt (431);
einen Prozessor (213, 223, 230), der einen Gesundheitsrisikoindikator für den Anwender bestimmt (130, 432), der aus dem Gesundheit-prädiktiven Aktivitäts-Score abgeleitet wird; und
eine Anwendervorrichtung (210, 220), die dem Anwender mithilfe einer Benutzeroberfläche (211, 221) den Gesundheitsrisikoindikator bereitstellt (440).

2. Verfahren nach Anspruch 1, wobei die biometrischen Daten einen Ruheherzfrequenzwert für den Anwender und einen maximalen Herzfrequenzwert für den Anwender umfassen.

3. Verfahren nach einem der Ansprüche 1 oder 2, wobei der Überwachungszeitraum mindestens fünf Tage beträgt.

4. Verfahren nach einem der Ansprüche 1 bis 3, wobei die Herzfrequenzdaten eine Reihe von Pulsmessungen sind.

5. Verfahren nach Anspruch 4, das weiter eine Extrapolation der Reihe von Pulsmessungen umfasst, um eine gleichmäßig verteilte Reihe von Datenpunkten oder eine kontinuierliche Herzfrequenzfunktion über den Überwachungszeitraum zu erzeugen.

6. Verfahren nach Anspruch 2 oder einem der Ansprüche 3 bis 5 in Abhängigkeit von Anspruch 2, wobei die Verarbeitung eine Normalisierung (421) der Herzfrequenzdaten, einer gleichmäßig verteilten Reihe von Datenpunkten, die sich von den Herzfrequenzdaten ableiten, oder einer kontinuierlichen Funktion, die sich von den Herzfrequenzdaten ableitet, durch Subtraktion des Herzfrequenzwertes und Division des Ergebnisses durch die Differenz zwischen dem maximalen Herzfrequenzwert und dem Ruheherzfrequenzwert umfasst.

7. Verfahren nach Anspruch 6, wobei die Verarbeitung weiter eine Bestimmung (422) einer Reihe von Intensitäts-Scores z_k oder einer Intensitäts-Score-Funktion $z(t)$ aus einer Reihe von normalisierten Herzfrequenzwerten $\bar{y}_k$ oder einer kontinuierlichen normalisierten Herzfrequenzfunktion $\bar{y}(t)$, einem konstanten Skalierungsfaktor c_1 und einem konstanten Gewichtungsfaktor c_2 gemäß:

$z_k = c_1(e^{c_2\bar{y}_k} - 1)$; $z(t) = c_1(e^{c_2\bar{y}(t)} - 1)$ umfasst, wobei c_1 und c_2 aus einer Vielzahl von Optionen gemäß einem oder mehreren Anwendermerkmalen ausgewählt sind.

8. Verfahren nach Anspruch 7, wobei der gesamte Herzschlagwert als Euler-Integrationssumme oder bestimmtes

Integral der Intensitäts-Scores oder Intensitätsfunktion über den Überwachungszeitraum bestimmt wird.

9. Verfahren nach Anspruch 8, wobei die Bestimmung des Gesundheit-prädiktiven Aktivitäts-Scores V gemäß $V = c_3 + c_4(1 - e^{-P})$ erfolgt, wobei P der Herzschlaggesamtwert ist und die Konstanten c_3 und c_4 aus Populationserhebungsdaten bestimmt werden.

10. Verfahren nach Anspruch 9, wobei der Gesundheitsrisikoindikator *PAI* gemäß $PAI = \frac{100(V-c_3)}{V_{threshold}-c_3}$ bestimmt wird, wo $V_{threshold}$ eine Konstante ist, die aus einer Vielzahl von Optionen gemäß einem oder mehreren Anwendermerkmalen ausgewählt ist.

11. Verfahren nach einem vorstehenden Anspruch, das periodisch mit einem folgenden Wiederholungszeitraum wiederholt wird:

gleich dem Überwachungszeitraum, sodass das Verfahren nacheinander wiederholt wird; oder
kleiner als dem Überwachungszeitraum, sodass das Verfahren in einem Schiebefenster ("Sliding Window") durchgeführt wird.

12. Verfahren nach einem vorstehenden Anspruch, das weiter eine Schätzung der aeroben Spitzen-Kapazität des Anwenders unter Verwendung eines Tiefpassfilters auf den gesamten Herzschlagwert oder einen Wert, der sich davon ableitet, und biometrischen Daten für den Anwender umfasst.

13. Computerprogramm-Produkt, das vom Computer ausführbare Anweisungen für die Durchführung des Verfahrens nach einem vorstehenden Anspruch umfasst.

14. System für die Verarbeitung von Herzfrequenzdaten, wobei das System Folgendes umfasst:

einen Prozessor (213, 223, 230), der zur Verarbeitung (421, 422) von Herzfrequenzdaten, die von einem Anwender durch eine Sensorvorrichtung (210) über einen Überwachungszeitraum von mindestens einem Tag erhalten wurden, in Abhängigkeit von biometrischen Daten für den Anwender konfiguriert ist, um einen gesamten Herzschlagwert für den Anwender über den Überwachungszeitraum zu bestimmen (120, 423);
einen Prozessor (213, 223, 230), der zur Bestimmung (431) eines Gesundheit-prädiktiven Aktivitäts-Scores aus dem gesamten Herzschlagwert gemäß einem Modell, das mit Spitzen-Sauerstoffaufiiahme von Populationsstudiensubjekten kalibriert ist, konfiguriert ist;
einen Prozessor (213, 223, 230), der zur Bestimmung (130, 432) eines Gesundheitsrisikoindikators für den Anwender, der aus dem Gesundheit-prädiktiven Aktivitäts-Score abgeleitet wird, konfiguriert ist; und
eine Anwendervorrichtung (210, 220), die eine Benutzeroberfläche (211, 221) aufweist, wobei die Anwendervorrichtung zur Bereitstellung (440) des Gesundheitsrisikoindikators für den Anwender mithilfe der Benutzeroberfläche konfiguriert ist.

Revendications

1. Procédé de traitement de données de fréquence cardiaque comportant :

un processeur (213, 223, 230) qui traite (421, 422) des données de fréquence cardiaque, obtenues auprès d'un utilisateur par un dispositif capteur (210) sur une période de surveillance d'au moins un jour, en fonction de données biométriques de l'utilisateur, pour déterminer (120, 423) une valeur agrégée de battement cardiaque de l'utilisateur sur ladite période de surveillance ;
un processeur (213, 223, 230) qui détermine (431) un score d'activité prédictif de la santé à partir de ladite valeur agrégée de battement cardiaque selon un modèle étalonné avec une consommation d'oxygène crête de sujets d'étude dans la population ;
un processeur (213, 223, 230) qui détermine (130, 432) un indicateur de risque pour la santé de l'utilisateur obtenu à partir dudit score d'activité prédictif de la santé ; et
un dispositif utilisateur (210, 220) qui fournit (440) à l'utilisateur ledit indicateur de risque pour la santé au moyen d'une interface utilisateur (211, 221).

2. Procédé selon la revendication 1, dans lequel lesdites données biométriques comportent une valeur de fréquence

cardiaque au repos de l'utilisateur et une valeur de fréquence cardiaque maximale de l'utilisateur.

3. Procédé selon l'une ou l'autre des revendications 1 ou 2, dans lequel la période de surveillance est d'au moins cinq jours.

4. Procédé selon l'une quelconque des revendications 1 à 3, dans lequel les données de fréquence cardiaque sont une série de mesures de pulsations.

5. Procédé selon la revendication 4, comportant en outre l'extrapolation de ladite série de mesures de pulsations pour produire une série distribuée uniformément de points de données ou une fonction de fréquence cardiaque continue sur la période de surveillance.

6. Procédé selon la revendication 2, ou l'une quelconque des revendications 3 à 5 en fonction de la revendication 2, dans lequel ledit traitement comporte la normalisation (421) des données de fréquence cardiaque, d'une série distribuée uniformément de points de données obtenus à partir des données de fréquence cardiaque ou d'une fonction continue obtenue à partir des données de fréquence cardiaque en soustrayant ladite valeur de fréquence cardiaque au repos et en divisant le résultat par la différence entre ladite valeur de fréquence cardiaque maximale et la valeur de fréquence cardiaque au repos.

7. Procédé selon la revendication 6, dans lequel ledit traitement comporte en outre la détermination (422) d'une série de scores d'intensité z_k ou d'une fonction de scores d'intensité $z(t)$ à partir d'une série de valeurs normalisées de fréquence cardiaque $\overline{y}_k$ ou d'une fonction normalisée continue de fréquence cardiaque $\overline{y}(t)$), d'un facteur d'échelle constant c_1 et d'un facteur de pondération constant c_2 selon les équations suivantes :

$z_k = c_1(e^{c_2\overline{y}_k} - 1)$; $z(t) = c_1(e^{c_2\overline{y}(t)} - 1)$ dans lequel c_1 et c_2 sont choisis parmi une pluralité d'options selon l'une ou plusieurs caractéristiques d'utilisateur.

8. Procédé selon la revendication 7, dans lequel ladite valeur agrégée de battement cardiaque est déterminée comme étant la somme d'intégration Euler ou l'intégrale définie des scores d'intensité ou la fonction d'intensité sur la période de surveillance.

9. Procédé selon la revendication 8, dans lequel ladite détermination du score d'activité prédictif de la santé V s'effectue comme suit : $V = c_3 + c_4(1 - e^{-P})$, dans lequel P est une valeur agrégée de battement cardiaque et les constantes c_3 et c_4 sont déterminées à partir de données d'étude de la population.

10. Procédé selon la revendication 9, dans lequel l'indicateur de risque pour la santé PAI est déterminé selon : $PAI = \frac{100(V-c_3)}{V_{threshold}-c_3}$ où $V_{threshold}$ est une constante choisie parmi une pluralité d'options selon une ou plusieurs caractéristiques d'utilisateur.

11. Procédé selon l'une quelconque des revendications précédentes, répété périodiquement, avec une période de répétition :

égale à la période de surveillance de sorte que le procédé est répété de manière consécutive ; ou
inférieure à la période de surveillance de sorte que le procédé est réalisé dans un fenêtrage dynamique.

12. Procédé selon l'une quelconque des revendications précédentes, comportant en outre l'estimation de la capacité aérobique crête de l'utilisateur en utilisant un filtre passe-bas sur la valeur agrégée de battement cardiaque ou une valeur obtenue à partir de celle-ci et les données biométriques de l'utilisateur.

13. Produit de programme d'ordinateur comportant des instructions exécutables par ordinateur destinées à réaliser le procédé selon l'une quelconque des revendications précédentes.

14. Système destiné au traitement de données de fréquence cardiaque, ledit système comportant :

un processeur (213, 223, 230) configuré pour traiter (421, 422) des données de fréquence cardiaque, obtenues

auprès d'un utilisateur par un dispositif capteur (210) sur une période de surveillance d'au moins un jour, en fonction de données biométriques de l'utilisateur, pour déterminer (120, 423) une valeur agrégée de battement cardiaque de l'utilisateur sur ladite période de surveillance ;
un processeur (213, 223, 230) configuré pour déterminer (431) un score d'activité prédictif de la santé à partir de ladite valeur agrégée de battement cardiaque selon un modèle étalonné avec une consommation d'oxygène crête de sujets d'étude dans la population ;
un processeur (213, 223, 230) configuré pour déterminer (130, 432) un indicateur de risque pour la santé de l'utilisateur obtenu à partir dudit score d'activité prédictif de la santé ; et
un dispositif utilisateur (210, 220), présentant une interface utilisateur (211, 221), le dispositif utilisateur étant configuré pour fournir (440) à l'utilisateur ledit indicateur de risque pour la santé au moyen de l'interface utilisateur.

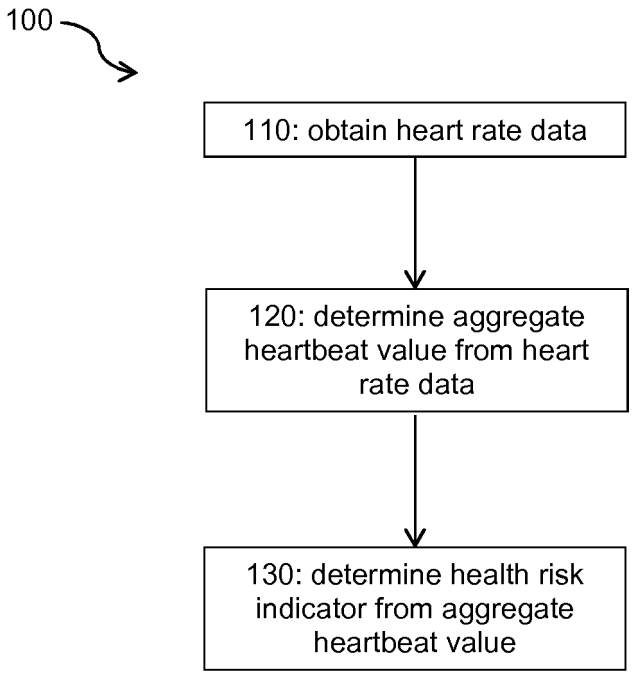
100
110: obtain heart rate data
120: determine aggregate heartbeat value from heart rate data
130: determine health risk indicator from aggregate heartbeat value

Figure 1

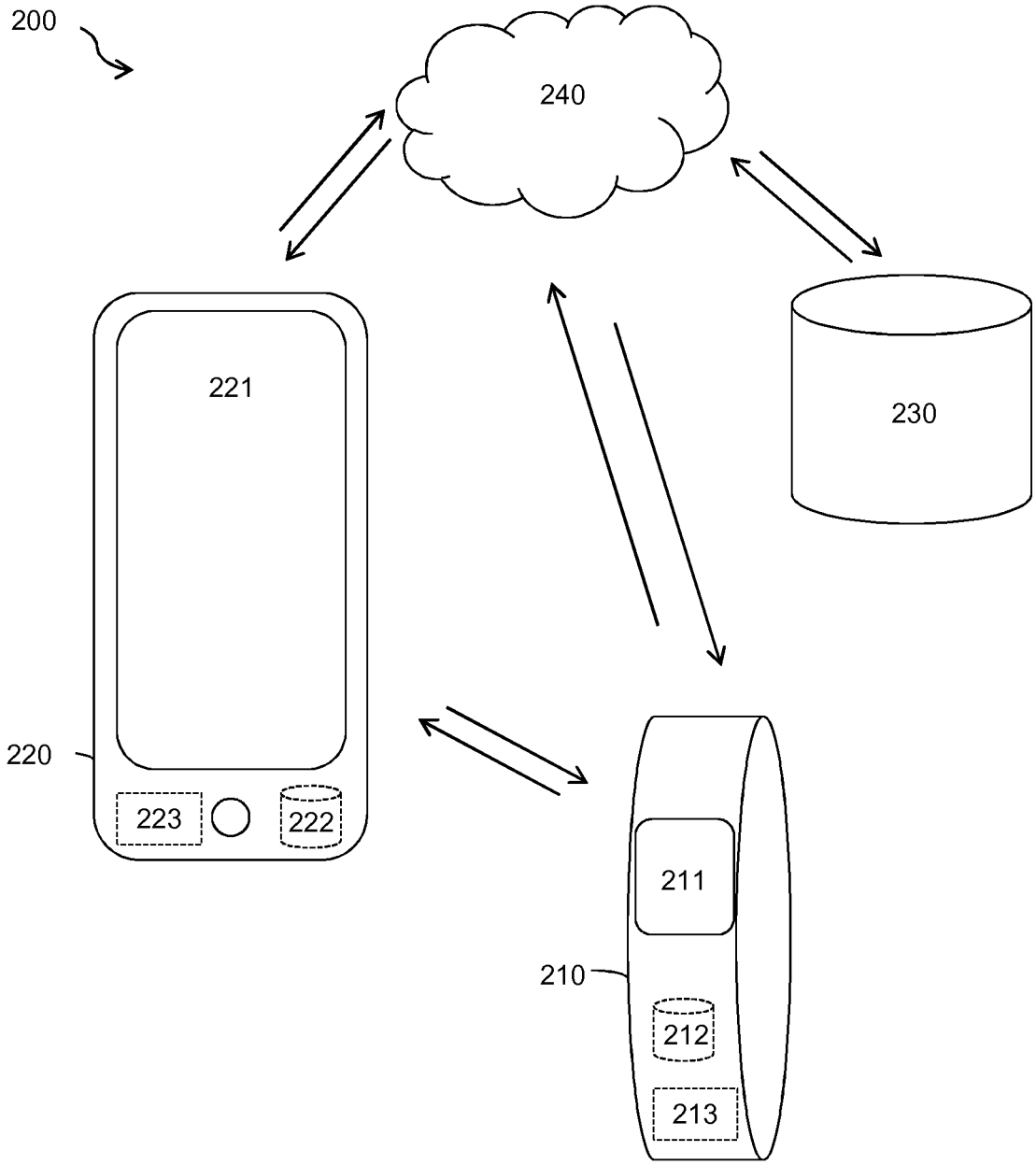

Figure 2

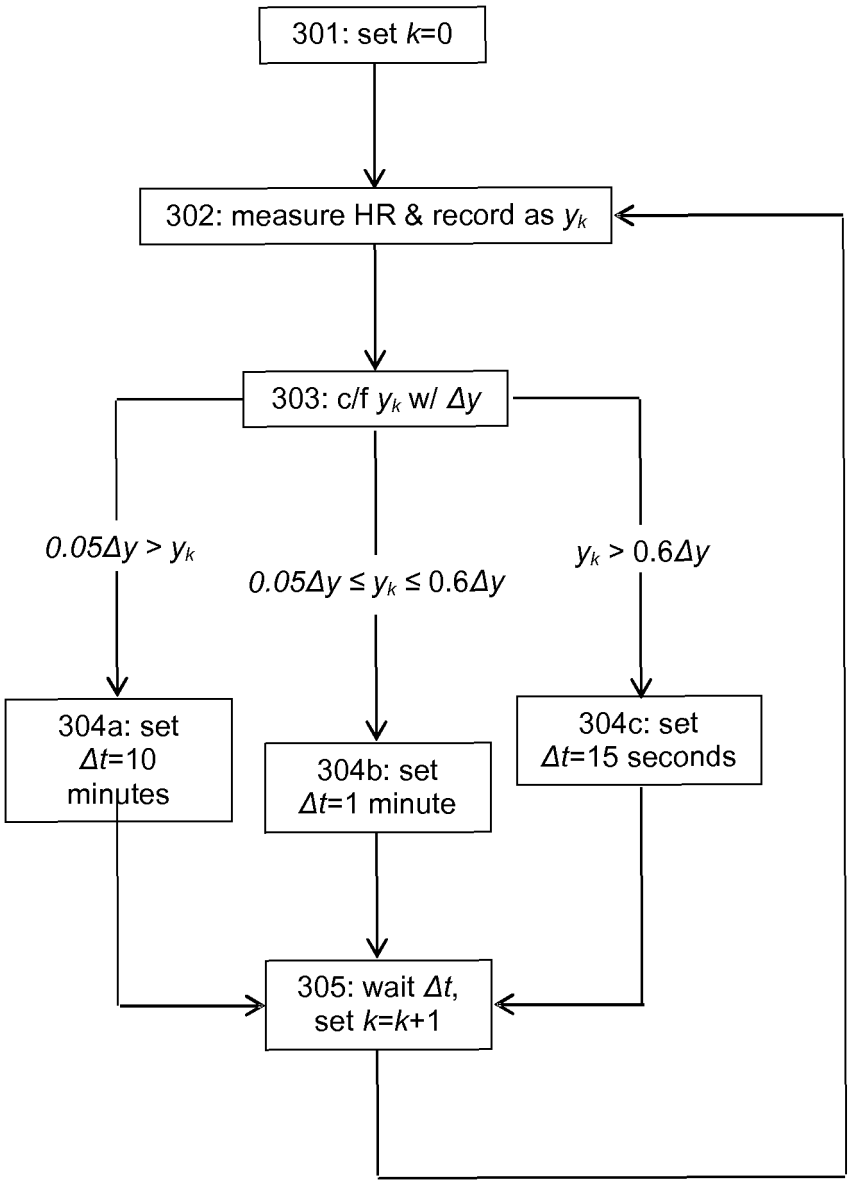
301: set k=0
302: measure HR & record as y_k
303: c/f y_k w/ Δy
$0.05\Delta y > y_k$
$0.05\Delta y \leq y_k \leq 0.6\Delta y$
$y_k > 0.6\Delta y$
304a: set Δt=10 minutes
304b: set Δt=1 minute
304c: set Δt=15 seconds
305: wait Δt, set k=k+1

Figure 3

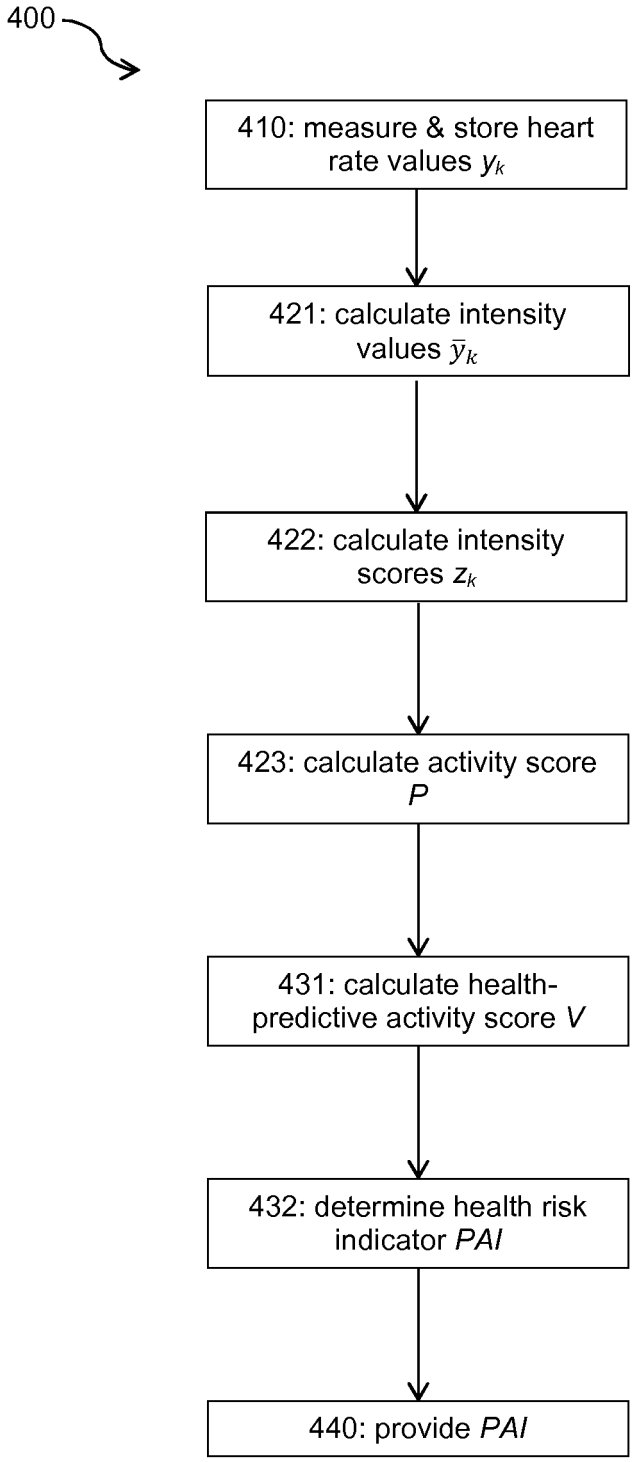
400
410: measure & store heart rate values y_k
421: calculate intensity values $\bar{y}_k$
422: calculate intensity scores z_k
423: calculate activity score P
431: calculate health-predictive activity score V
432: determine health risk indicator PAI
440: provide PAI

Figure 4

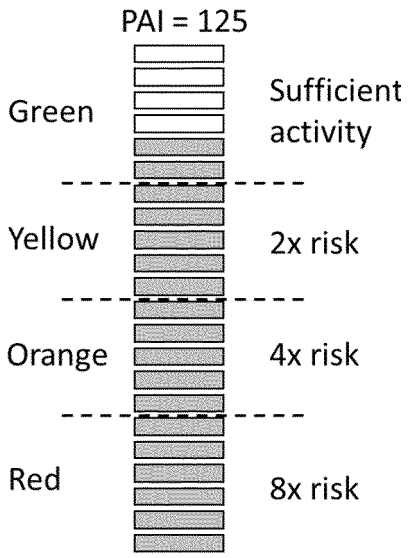
PAI = 125
Green
Sufficient activity
Yellow
2x risk
Orange
4x risk
Red
8x risk

Figure 5

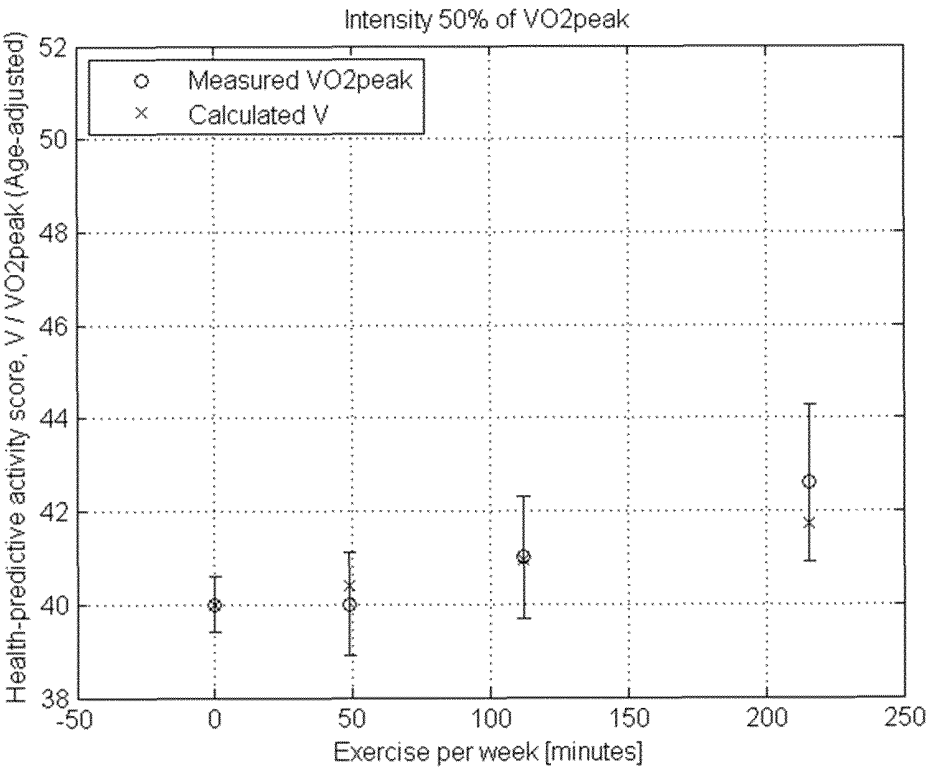

Figure 6a

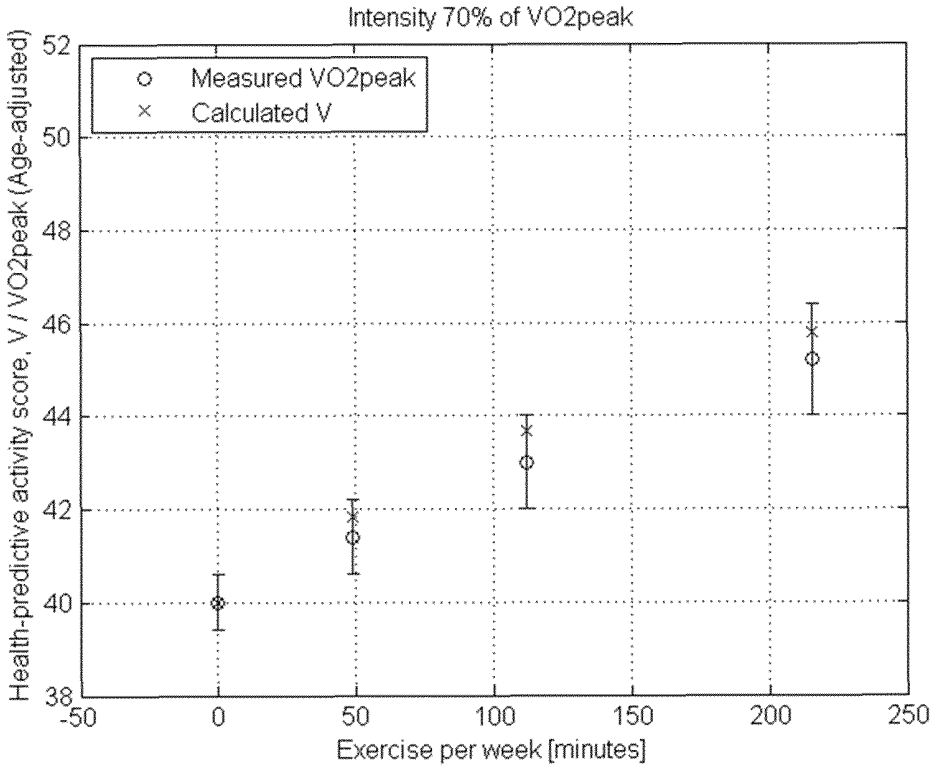

Figure 6b

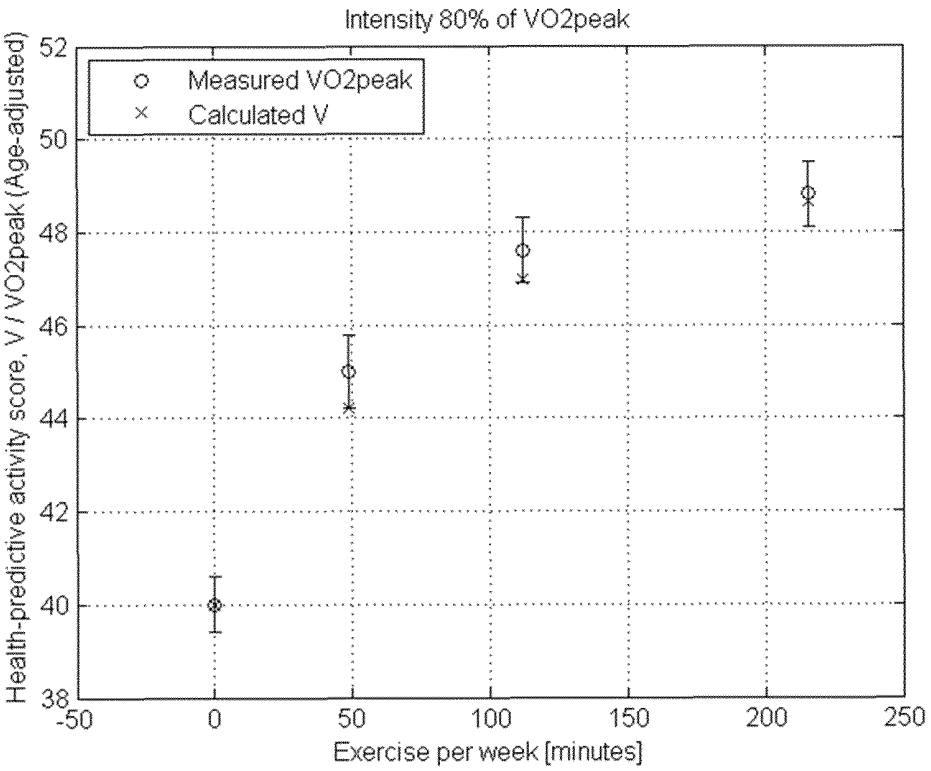

Figure 6c

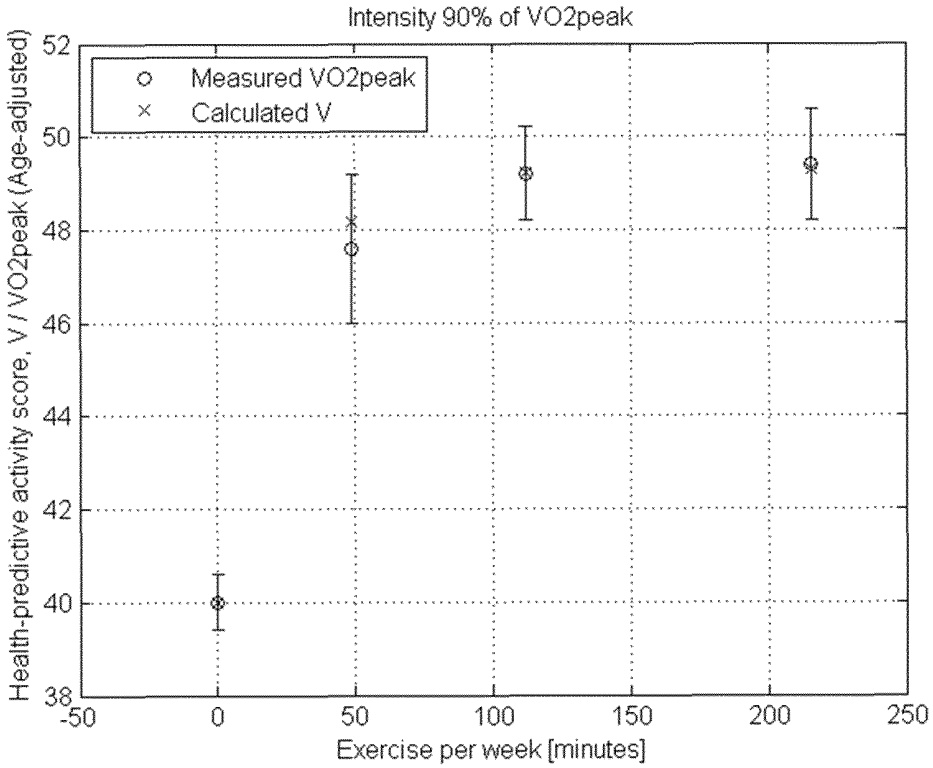

Figure 6d

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- US 20140073486 A **[0007]**

Non-patent literature cited in the description

- **NICHOLAS J WAREHAM et al.** A quantitative analysis of the relationship between habitual energy expenditure, fitness and the metabolic cardiovascular syndrome. *British Journal of Nutrition,* 01 September 1998, vol. 80 (3 **[0007]**
- **KIRSTEN L. RENNIE et al.** Estimating energy expenditure by heart-rate monitoring with individual calibration. *Medicine and Science Sports and Exercise,* 01 June 2001, vol. 33 (6 **[0007]**