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(54) **FATIGUE MEASUREMENT IN A SENSOR EQUIPPED GARMENT**

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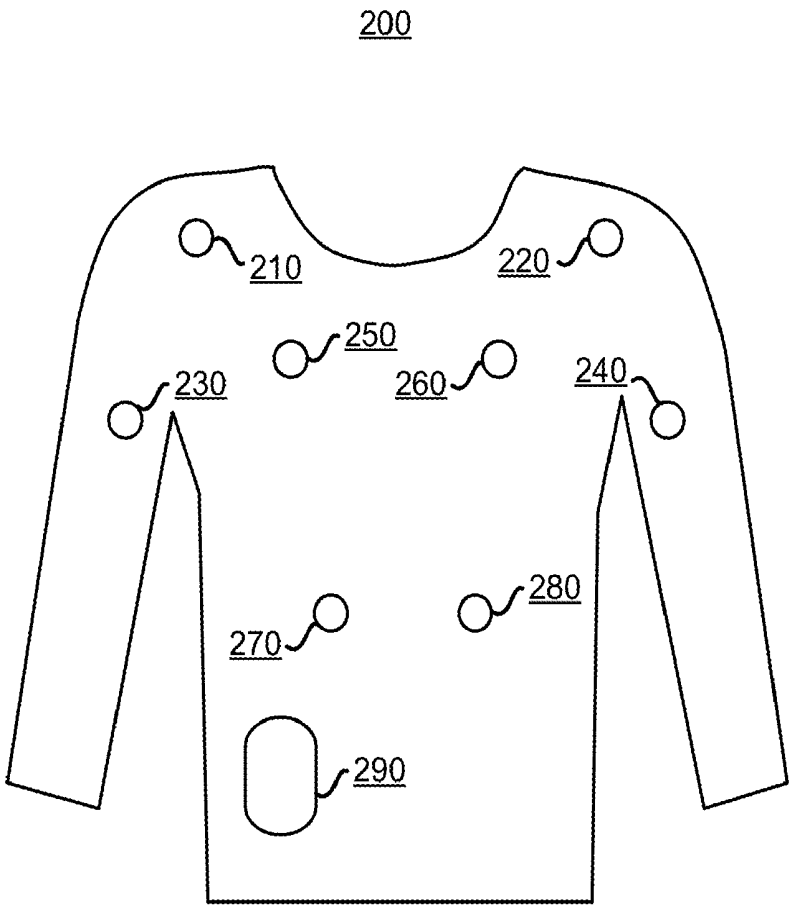
(57) **ABSTRACT**

An exercise feedback system determines muscle fatigue measurements using physiological data generated by a sensor-equipped athletic garment. The muscle fatigue measurement is determined by analyzing the frequency spread of the physiological data. The exercise feedback system may customize exercise programs, determine risks of injury, or generate biofeedback for presentation on graphical user interfaces using the muscle fatigue measurements. The exercise feedback system accesses pre-determined muscle fatigue measurement models that define criteria for the aforementioned features. For instance, if an athlete is becoming fatigued and exercising with improper form based on a muscle fatigue measurement, the exercise feedback system modifies the athlete's exercise program to help target and improve the athlete's weaknesses as well as to prevent injury.



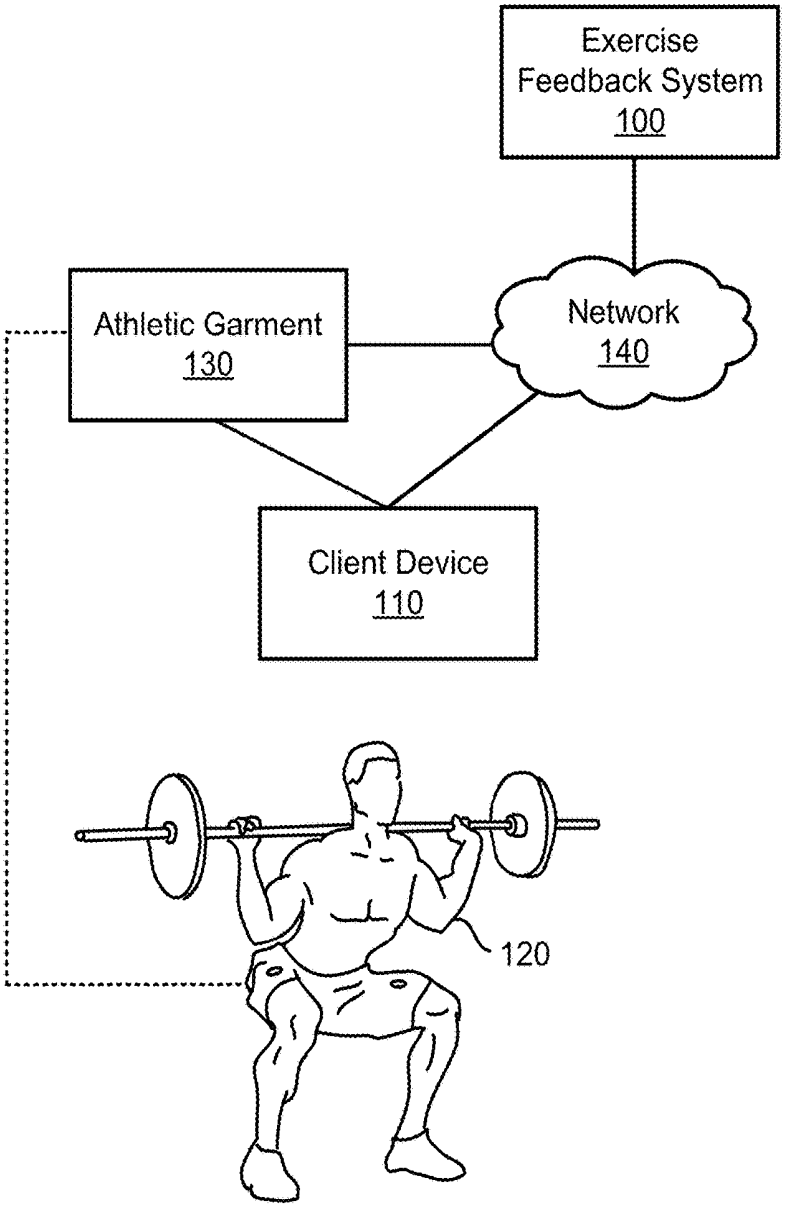

Exercise
Feedback System
100
Network
140
Athletic Garment
130
Client Device
110
120

FIG. 1

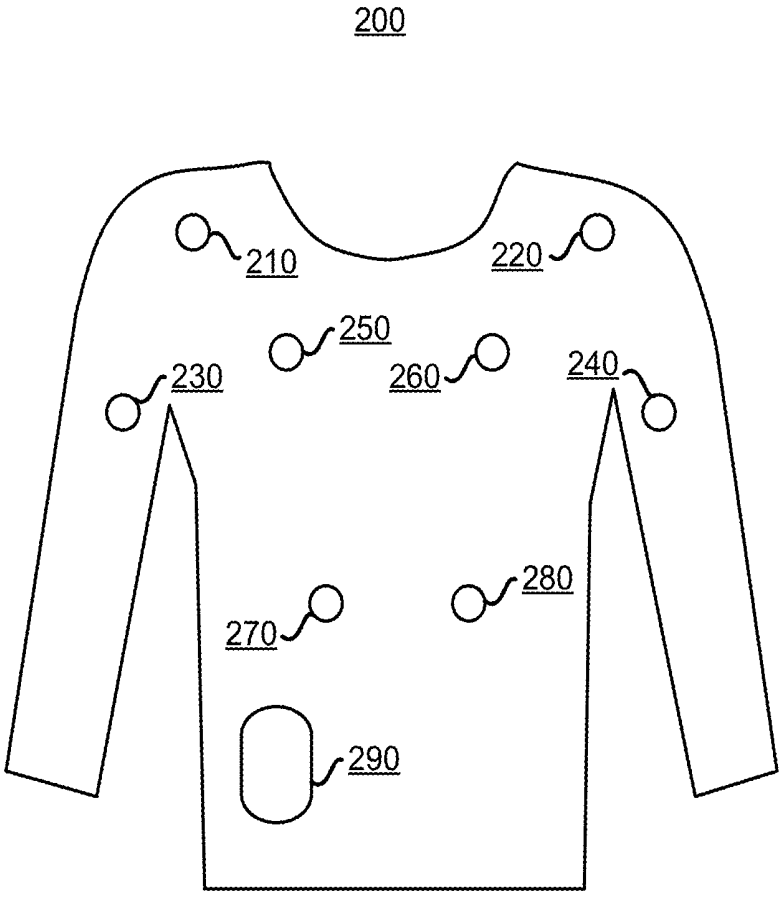


FIG. 2

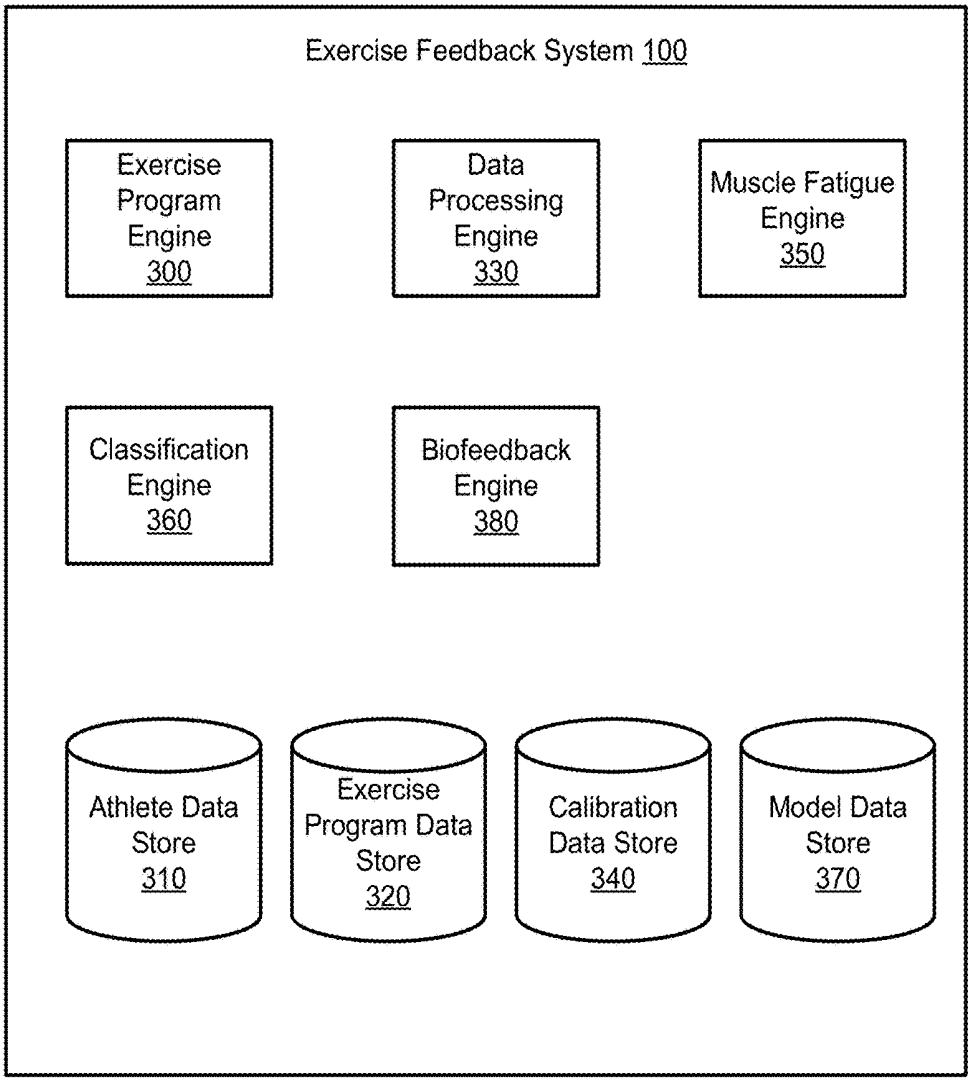

Exercise Feedback System 100
Exercise Program Engine 300
Data Processing Engine 330
Muscle Fatigue Engine 350
Classification Engine 360
Biofeedback Engine 380
Athlete Data Store 310
Exercise Program Data Store 320
Calibration Data Store 340
Model Data Store 370

FIG. 3

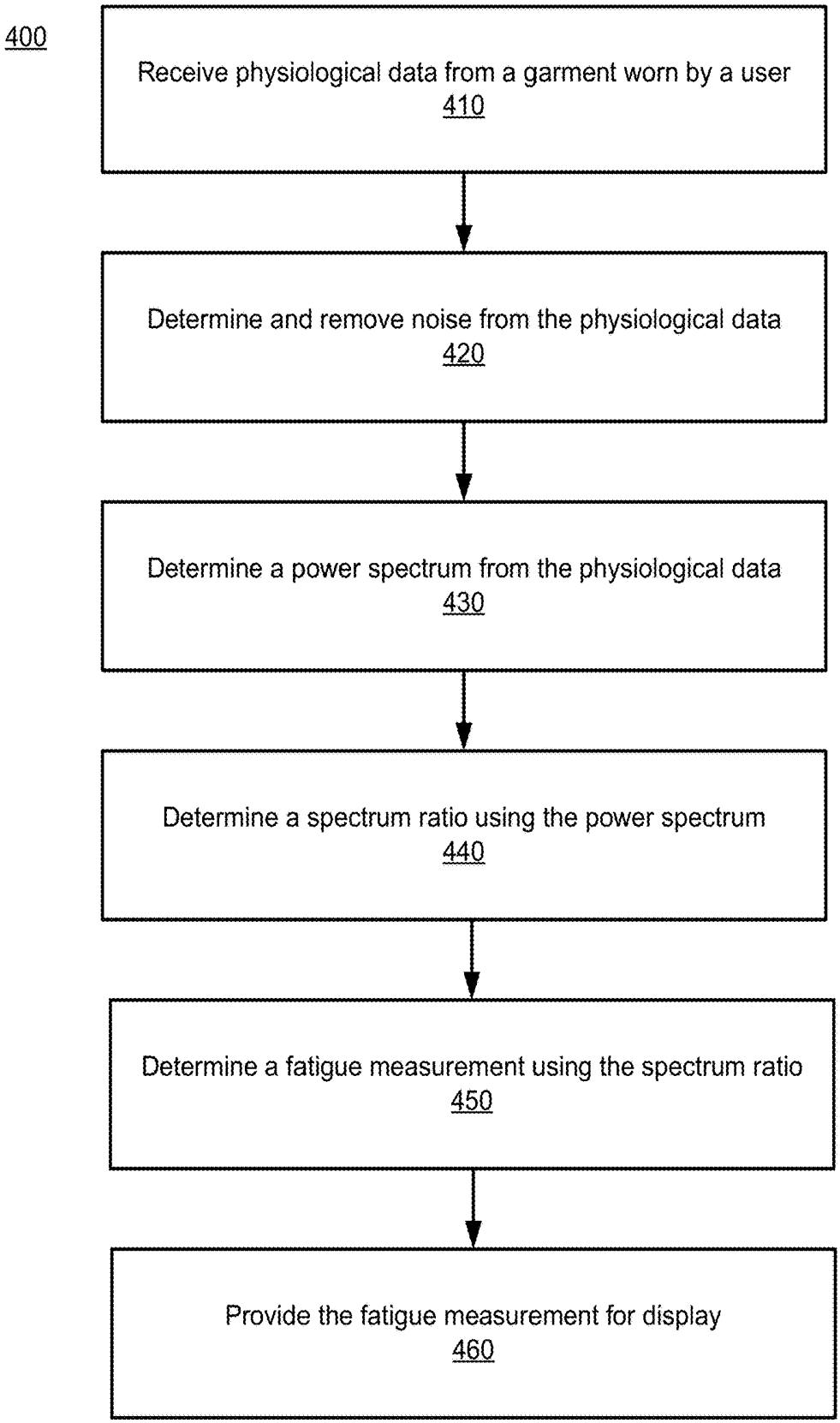

400
Receive physiological data from a garment worn by a user
410
Determine and remove noise from the physiological data
420
Determine a power spectrum from the physiological data
430
Determine a spectrum ratio using the power spectrum
440
Determine a fatigue measurement using the spectrum ratio
450
Provide the fatigue measurement for display
460

FIG. 4

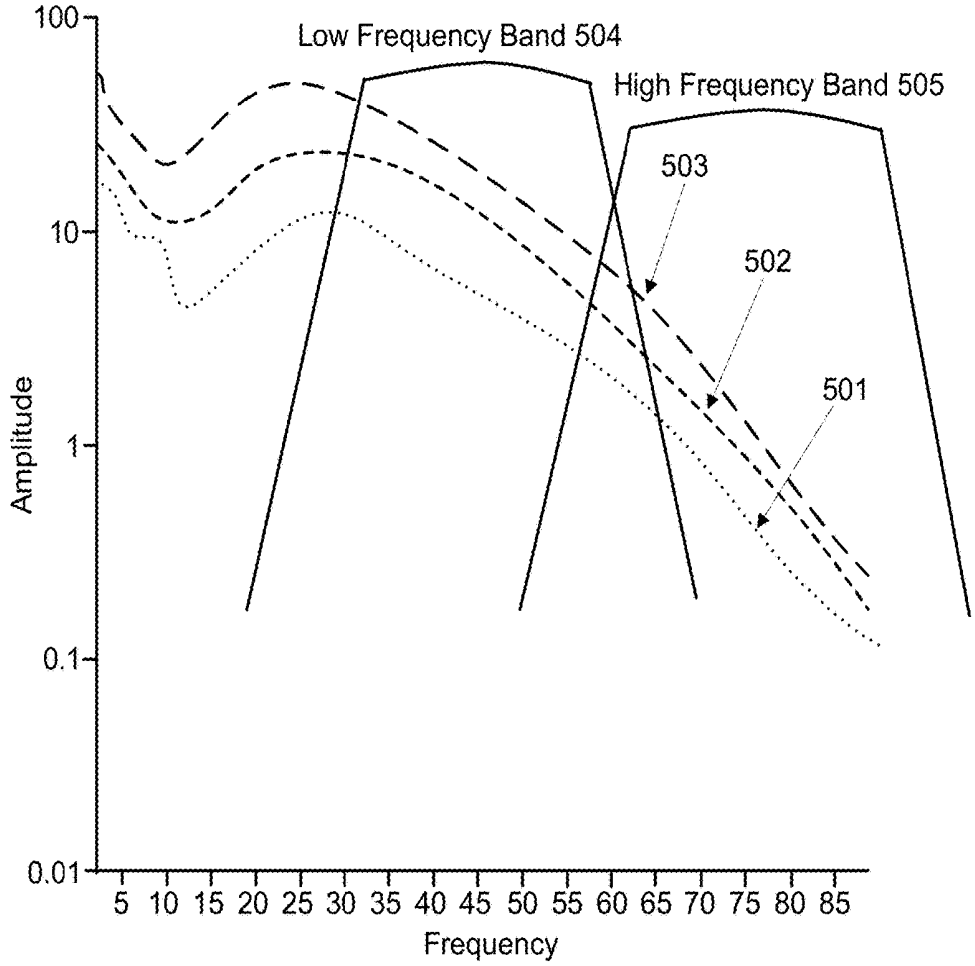

100
10
1
0.1
0.01
Amplitude
Low Frequency Band 504
High Frequency Band 505
503
502
501
5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85
Frequency

FIG. 5

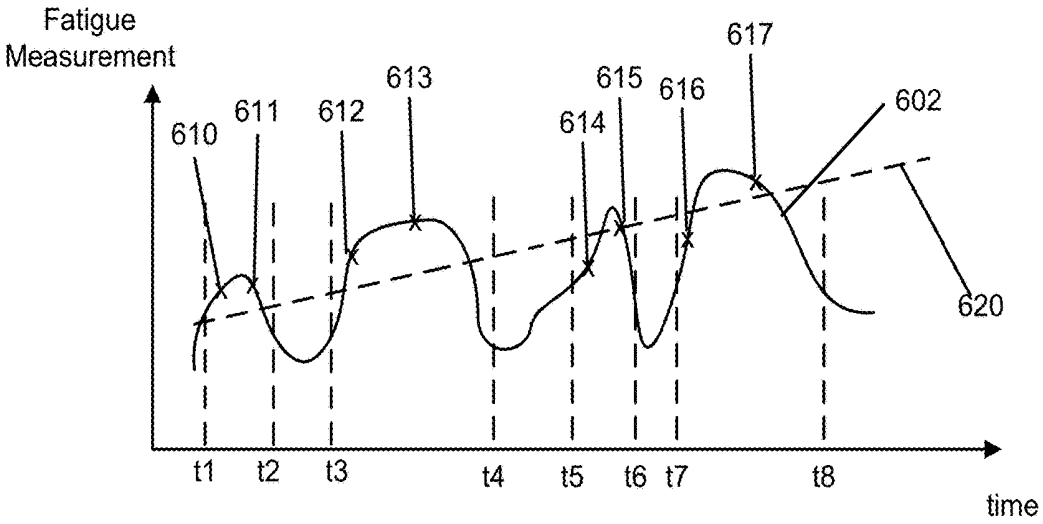

Fatigue
Measurement
610
611
612
613
614
615
616
617
602
620
t1
t2
t3
t4
t5
t6
t7
t8
time

FIG. 6

700

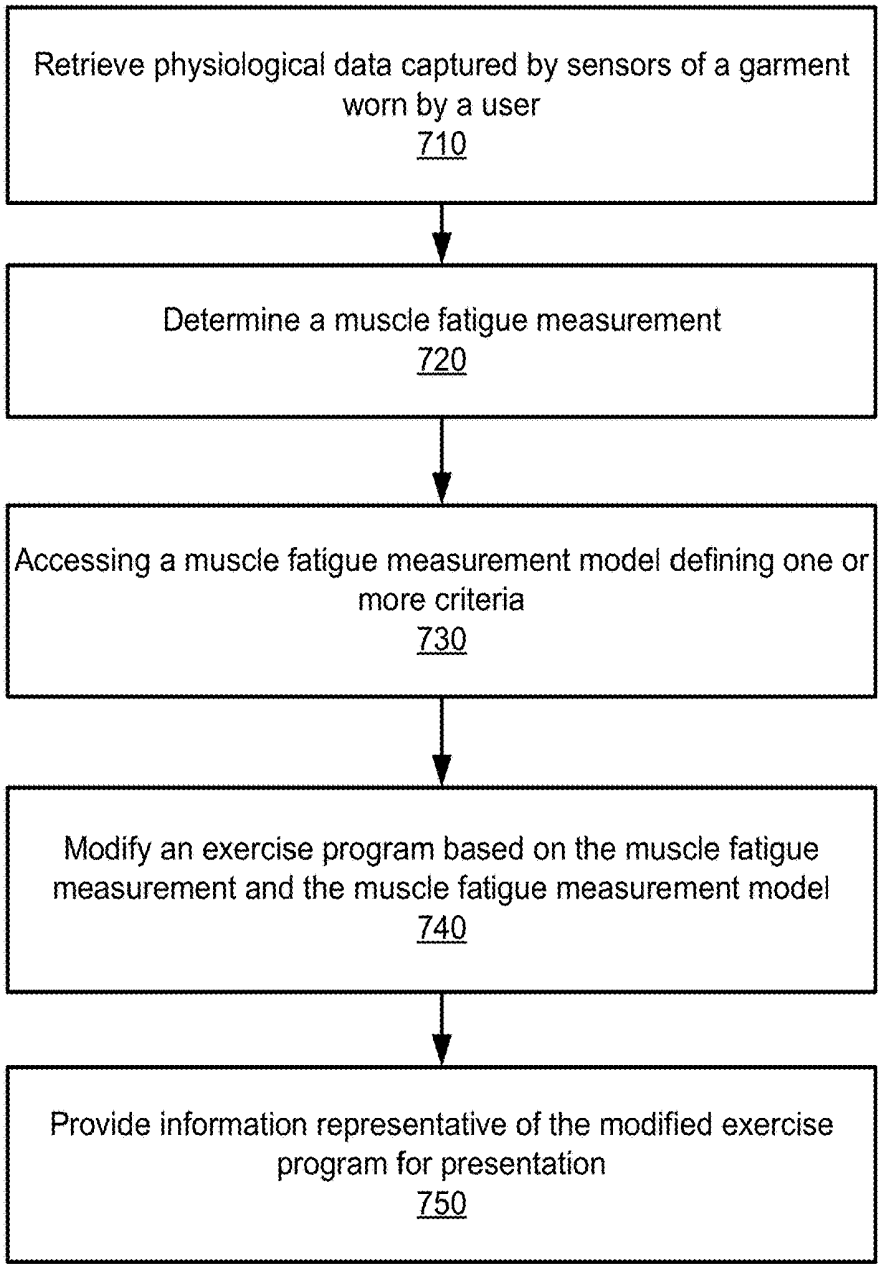

Retrieve physiological data captured by sensors of a garment worn by a user
710
Determine a muscle fatigue measurement
720
Accessing a muscle fatigue measurement model defining one or more criteria
730
Modify an exercise program based on the muscle fatigue measurement and the muscle fatigue measurement model
740
Provide information representative of the modified exercise program for presentation
750

FIG. 7

FATIGUE MEASUREMENT IN A SENSOR EQUIPPED GARMENT

CROSS REFERENCE TO RELATED APPLICATION

[0001] This application claims the benefit of U.S. Provisional Application 62/669,799, entitled "Measuring Fatigue in a Sensor-Equipped Athletic Garment," filed May 10, 2018, which is incorporated herein by reference in its entirety.

BACKGROUND

[0002] This description generally relates to sensor-equipped athletic garments, and specifically to determining muscle fatigue using physiological data from the sensors.

[0003] Sensors record a variety of information about the human body. For example, electrocardiograph (ECG) electrodes can measure electrical signals from the skin of a person that are used to determine the person's heart rate. In addition, electromyography (EMG) electrodes can measure electrical activity generated by a person's muscles. Heart rate and muscle activation information may be useful for evaluating the person's physiological condition, for instance, while exercising. It is difficult to provide comparable metrics between different muscle groups for a given athlete and between different athletes since the muscle response depends on muscle physiology and body composition, which may vary between muscles and between athletes. A system that generates inconsistent metrics of athletic performance provides a poor user experience, and the athletes may not be able to improve their athletic training with unreliable feedback on exercises.

SUMMARY

[0004] An exercise feedback system determines muscle fatigue measurements using physiological data generated by a sensor-equipped athletic garment. Muscle fatigue is characterized by a reduction in the force producing capacity of a muscle and can be measured using electromyography (EMG) signals. Muscle fatigue includes both peripheral fatigue due to changes in the muscle itself and central fatigue due to changes in the neural drive to the muscle. Surface EMG signals show signs of both peripheral and central fatigue through amplitude and frequency changes. Various embodiments described herein determine muscle fatigue measurements from electromyography (EMG) data. The exercise feedback system determines the muscle fatigue measurements from frequency or power spectrum changes because the frequency or power spectrum changes are more stable compared to amplitude changes. EMG amplitude is strongly influenced by the intensity of activation of a muscle. However, frequency changes are more influenced by muscle fatigue than changes in intensity of activation and can therefore provide more stable representation of fatigue changes of a muscle. The exercise feedback system removes artifacts such as a baseline shift from raw EMG signals. In addition, the exercise feedback system compensates for interferences caused by dynamic exercises.

[0005] The exercise feedback system may customize exercise programs, determine risks of injury, or generate biofeedback for presentation on graphical user interfaces using the muscle fatigue measurements. In an embodiment, the exercise feedback system accesses pre-determined muscle fatigue measurement models that define criteria for the aforementioned features. For instance, responsive to determining that an athlete is becoming fatigued, the exercise feedback system modifies the athlete's exercise program to help target and improve the athlete's weaknesses. Additionally, if the exercise feedback system determines that the athlete is susceptible to injury, the exercise feedback system notifies the athlete of the risk of injury.

BRIEF DESCRIPTION OF DRAWINGS

[0006] FIG. **1** is a diagram of a system environment for determining muscle fatigue measurements according to one embodiment.

[0007] FIG. **2** is a diagram of a sensor-equipped athletic garment according to one embodiment.

[0008] FIG. **3** is a block diagram of an exercise feedback system according to one embodiment.

[0009] FIG. **4** is a flowchart of a process for determining muscle fatigue measurements according to one embodiment.

[0010] FIG. **5** is a diagram illustrating a power spectrum of an EMG signal according to one embodiment.

[0011] FIG. **6** is a diagram illustrating an example of a muscle fatigue engine determining the muscle fatigue measurements only during active regions according to one embodiment.

[0012] FIG. **7** is a flowchart of a process of managing an exercise program according to one embodiment.

[0013] The figures depict embodiments of the present invention for purposes of illustration only. One skilled in the art will readily recognize from the following discussion that alternative embodiments of the structures and methods illustrated herein may be employed without departing from the principles of the invention described herein.

DETAILED DESCRIPTION

I. System Overview

[0014] FIG. **1** is a diagram of a system environment for monitoring exercise data according to one embodiment. The system environment includes an exercise feedback system **100**, client device **110**, and athletic garment **130** communicatively coupled together via a network **140**. Users **120** of the exercise feedback system **100** are also referred to herein as "athletes." In other embodiments, different and/or additional entities can be included in the system architecture.

[0015] The client device **110** is a computing device capable of receiving user input as well as transmitting and/or receiving data via the network **140**. A client device is a device having computer functionality, such as a smartphone, personal digital assistant (PDA), a mobile telephone, tablet, laptop computer, desktop computer, a wearable computer (such as a smart watch, wrist band, arm band, chest band, or the like), or another suitable device. In one embodiment, a client device executes an application allowing a user of the client device to interact with the exercise feedback system **100**. For example, a client device executes a browser application to enable interaction between the client device and the exercise feedback system **100** via the network **140**. In another embodiment, a client device **110** interacts with the exercise feedback system **100** through an application programming interface (API) running on a native operating system of the client device, such as IOS® or ANDROID™.

[0016] An athlete **120** wears the athletic garment **130** (further described below with reference to FIG. **2**) while performing exercises. The athletic garment **130** records physiological data, e.g., muscle activation data or heart rate data, of the athlete. Based on the physiological data, the exercise feedback system **100** determines muscle fatigue measurements or biofeedback customized for the athlete. The muscle fatigue measurements may correspond to any muscle, portion of a muscle, or set of muscles of the athlete. For example, the athlete's biceps may include a left and right biceps muscle, and the biceps may be part of a group of upper body muscles. As described herein, a muscle includes soft tissue for the purpose of producing force or motion of the human body, and may be a slow twitch or fast twitch type of muscle. Further, a coach of the athlete can view the biofeedback on a client device **110** and provide additional feedback for the athlete. In some embodiments, the exercise feedback system **100** can communicate feedback using audio output or haptic feedback of the client device **110**.

II. Example Athletic Garment

[0017] FIG. **2** is a diagram of a sensor-equipped athletic garment **200** according to one embodiment. The athletic garment **200** includes sensors that contact the skin of an athlete wearing the athletic garment **200**. For example, the sensors can be electrodes that measure electromyography (EMG) signals (electrical signals caused by muscle cells) also referred to as muscle activation data or muscle activation levels, electrocardiograph (ECG) signals (electrical signals caused by depolarization of the user's heart muscle in particular) also referred to as heart rate data, electrical signals modified by the tissue of the user (also referred to as bioimpedance data), electroencephalograph (EEG) signals, magnetoencephalograph (MEG) signals, among other types of signals associated with physiological data. The sensors may also include other types of sensors such as accelerometers and gyroscopes (which generate motion data based on the athlete's movement), temperature sensors, pressure sensors, humidity sensors, geographical location sensors, etc. The sensors generate physiological data of the athlete based on the measured signals. The sensors are communicatively coupled to a processing unit **290**. The processing unit **290** can aggregate and analyze the physiological data from the sensors. The processing unit **290** can also provide the physiological data to the client device **110** or exercise feedback system **100** via the network **140**.

[0018] In the embodiment shown in FIG. **2**, the athletic garment **200** includes eight sensors that record muscle activation data from the athlete's muscles nearby each sensor. In particular, sensors **210** and **220** located on the right and left shoulder of the athletic garment **200** can record muscle activation data of the athlete's deltoid muscles. Sensors **230** and **240** located on the right and left sleeves of the athletic garment **200** can record muscle activation data of the athlete's triceps and/or bicep muscles. Sensors **250** and **260** located on the right and left chest of the athletic garment **200** can record muscle activation data of the athlete's pectoral muscles. Sensors **270** and **280** located on the right and left abdomen of the athletic garment **200** can record muscle activation data of the athlete's abdominal and oblique muscles. Though the athletic garment **200** shown in FIG. **2** includes eight sensors and the processing unit **290**, in other embodiments, the athletic garment **200** can include any number of sensors or other types of components or electronics at any location or configuration within the athletic garment **200**.

[0019] It should be noted that while the athletic garment **200** shown in FIG. **2** is a long sleeve shirt, the principles described herein apply equally to any garment, including but not limited to a short sleeved shirt, a tank top, pants, shorts (e.g., the athletic garment **130** shown in FIG. **1**), or any other suitable garment. In embodiments where the athletic garment is a pant or shorts, sensors of the athletic garment can record muscle activation data from muscles on an athlete's lower body, e.g., inner and outer quadriceps (also referred to as "quads"), gluteus maximus (also referred to as "glutes"), hamstrings, calves, and the like.

III. Example Exercise Feedback System

[0020] FIG. **3** is a block diagram of the exercise feedback system **100** according to one embodiment. The exercise feedback system **100** includes an exercise program engine **300**, an athlete data store **310**, an exercise program data store **320**, a data processing engine **330**, a calibration data store **340**, a muscle fatigue engine **350**, a classification engine **360**, a model data store **370**, and a biofeedback engine **380**. In other embodiments, the exercise feedback system **100** may include additional, fewer, or different components for various applications, which are not shown for purposes of clarity.

[0021] The exercise program engine **300** manages exercise programs for athletes of the exercise feedback system **100**. In some embodiments, an athlete joins the exercise feedback system **100** by completing an onboarding process during which the exercise program engine **300** receives user information and physiological data associated with the athlete and stores the user information and physiological data in the athlete data store **310**. User information includes, for example, demographic data (e.g., age, gender, ethnicity, etc.), geographic data, exercise related data (e.g., sports played, a specific position for sport, or sports team information), or physiological data (e.g., height or weight). Physiological data may include data generated by the sensors of athletic garment **200** while the user performs prescribed onboarding baseline exercises. The sensor data generated during the onboarding baseline may be used to set calibration parameters or reference levels for each muscle group such that subsequent metrics for that muscle can be reported as a relative percentage from the onboarding baseline. Calibration parameters are stored in the calibration data store **340**. Exercise programs may include various exercises or other athletic related activities (e.g., diet or medical health data), and the exercise program engine **300** may customize the types and number of exercises for a given athlete based on user information retrieved from the athlete data store **310**.

[0022] In some embodiments, heart rate variability can be used to determine a beginning or pre-workout fatigue measurement for a user. In these embodiments, the initial heart rate variability of the user can be used to calibrate or set a baseline fatigue level for the athlete. Increases to the fatigue level of the athlete during workout calculated based on the EMG signal as described herein can be used to show the relative increase of fatigue to the user.

[0023] The exercise program engine **300** may generate or update exercise programs based on information from the exercise program data store **320**, which includes a database of exercises and other types of athletic training information

or guidelines and/or fatigue-associated measurements for a user, as described in more detail below. An exercise program may include exercise sets (also referred to as a "set"), where a set includes a number of repetitions of an exercise to be performed in sequence. As an example use case, the exercise program engine **300** determines that a given athlete is a basketball player aiming to increase their vertical jump height. Thus, the exercise program engine **300** updates an exercise program for the given athlete that includes exercises for developing lower body strength such as squats and calf raises. Moreover, the exercise program engine **300** may determine a suitable weight for the exercises and update the weight over time based on the athlete's performance, e.g., responsive to determining that the athlete has increased strength, the exercise program engine **300** increases the amount of weight to lift per repetition of an exercise. By personalizing exercise programs, the exercise program engine **300** determines strengths and weaknesses specific to an athlete, which helps improve the effectiveness of the athlete's training.

[0024] The data processing engine **330** conditions physiological data generated by sensors of an athletic garment (e.g., athletic garment **200** shown in FIG. **2**) for muscle fatigue measurements determination. The data processing engine **330** can receive the physiological data from the client device **110** or the processing unit **290** of the athletic garment **200**. In some embodiments, the data processing engine **330** pre-processes the physiological data by performing noise filtering techniques.

[0025] The data processing engine **330** removes artifacts from the physiological data. As described herein, artifacts refer to noise signals that interfere with a power spectrum of the portion of the physiological data that measures the muscle fatigue. Artifacts may be periodic or nonperiodic and may result from different causes such as loose sensor contacts, movement between the sensor contact and athlete's body and movement or impact of the athlete's body experienced during exercise. The artifacts have a greater magnitude when the contact between the sensor and athlete's body is less stable or at a higher impedance. EMG signals can include many artifacts that can both corrupt the useful portions of EMG signals and unpredictably alter the power spectrum of the EMG signals. Removing artifacts in the EMG signals efficiently can allow subtle power spectrum changes to be detected while increasing the portions of the EMG signals that are preserved.

[0026] A baseline shift is one type of artifact. The baseline shift occurs as a result of a baseline movement change (e.g., from sitting to standing, electrode movement). The data processing engine **330** determines a baseline shift and removes the baseline shift from the physiological data. For example, the data processing engine **330** applies a Wavelet-based trend estimator to the EMG signals to determine the baseline shift. The EMG signals are transformed using a continuous wavelet transform and the higher order wavelets are removed. The baseline shift signal is determined by applying an inverse wavelet transform to only lower order coefficients. In some embodiments, the wavelet transform applied to the EMG signals is the 7-th order Symmlets wavelet transform (Sym7), and the cutoff threshold is 0.017. The baseline shift signal is then filtered out from the original EMG signal to reduce the baseline noise.

[0027] The data processing engine **330** may apply one or more of a low pass filter, a high pass filter, a band pass filter, and a band stop filter to remove artifacts. The low pass filter can function to remove higher frequency noise and the high pass filter can function to remove lower frequency noise (e.g., due to waist movement/pressure artifacts). The band pass filter can function to remove frequency noise beyond a particular frequency band. The band stop filter is used to attenuate signals of a particular frequency band and may be used to filter out the mains hum. However, different combinations of filters can be used to process different datasets. Additionally, the data processing engine **330** can perform other suitable condition processes such as smoothing, clipping, deconvolving, detrending/offsetting, standardizing, resampling, hard-binding, predicting, windowing, and the like. In one embodiment, the data processing engine **330** applies a band pass filter that outputs signals of which the frequency is in the range of 30 Hz and 300 Hz.

[0028] Additionally, physiological data generated by the sensors may vary due to athlete-to-athlete differences in physiological traits, sensor contact quality, among other factors. For instance, thicker hair on the athlete's skin or skin dryness may result in poor sensor contact quality, and thus reduce the amplitude of physiological data generated by the sensors and increase the amplitude of measured noise. As another example, skin oiliness or sweat may improve sensor contact quality, and thus increase the amplitude of physiological data generated by the sensors and reduce the amplitude of measured noise. The data processing engine **330** may determine a quality of physical contact between a sensor and the athlete's skin based on a measure of impedance between the sensor and athlete's skin, which is generated by another sensor or the same sensor. In some embodiments, the amplitude of physiological data generated by a sensor and the signal to noise ratio is inversely proportional to the impedance between the sensor and the skin of the athlete.

[0029] The data processing engine **330** normalizes physiological data between different types of muscles and different athletes to account for the above described sources of physiological data variation. The physiological data may vary based on parameters associated with the athlete wearing the athletic garment, e.g., differences in the physiology between multiple types of muscles influences the physiological data representing contraction of the muscles. For instance, the glutes and quads differ in the number of muscle fibers, fiber size, fiber type distribution (e.g., slow twitch or fast twitch), and thickness of adipose tissue between the muscle tissue and skin surface. The amplitude of physiological data (e.g., muscle activation level) may be proportional to the muscle fiber size and/or inversely proportional to the amount of fat between the muscle and the portion of skin.

[0030] Using normalized physiological data, the exercise feedback system **100** may provide biofeedback for a given type of muscle relative to other types of muscles. For example, the exercise feedback system **100** may provide a graphical user interface including a comparison of muscle fatigue measurements for multiple lower body muscles. Further, the data processing engine **330** may perform normalization using calibration parameters retrieved from the calibration data store **340**. As an example, the glutes and quads have different calibration parameters, which are used by the data processing engine **330** to adjust raw amplitude values of the physiological data received for the two types of muscles. The data processing engine **330** may normalize physiological data by scaling the physiological data for a

muscle corresponding to one of the sensors of an athletic garment **200** by a calibration parameter. In some embodiments, the data processing engine **330** generates a pre-processed EMG signal of the physiological data before normalization. For instance, the data processing engine **330** determines a power representation of the EMG signal by using averaging, a linear envelope, rolling root mean square or any other suitable technique to generate a pre-processed EMG signal. Additional filtering may be applied to the pre-processed signal to further filter and reduce potential noise sources. In an embodiment, the amplitude of the pre-processed EMG signal represents the power of contraction at a point in time, and the data processing engine **330** can determine the relative level of contraction by normalizing the pre-processed signal using the calibration parameters. As described below, normalization can also be attributed to determination of ratios of different frequency components of a signal (e.g., in the frequency domain).

[0031] The muscle fatigue engine **350** determines a muscle fatigue measurement for a muscle. The muscle fatigue measurement is determined by using conditioned signals output from the data processing engine **330**. In various embodiments, the muscle fatigue engine **350** determines a spectrum ratio of a first frequency band to a second frequency band of the conditioned signals. The spectrum ratio of the first frequency band to the second frequency band is a ratio between power of signal components in the first frequency band to power of signal components in the second frequency band. In one embodiment, the first frequency band is 30 to 60 Hz and the second frequency band is 60 to 150 Hz. If a particular muscle is closer to the fatigue state, the biggest change in spectrum power in the EMG signal is in the 30 to 60 Hz band. For example, as illustrated in FIG. **5**, the change in power for signals in the low frequency band **504** is much greater than the change in power for signals in the high frequency band **505**. Curves **501**, **502**, **503** represent the EMG signal captured from the quad muscle during an isometric hold at 5:00:00 pm, 5:00:10 pm, 5:00:20 pm. As a muscle fatigues, the frequency spectra of the EMG signal shifts to lower frequencies. As illustrated, the spread in the low frequency band **504** is much larger than the spread in the high frequency band **505**, because the low frequency power increased more compared to high frequency. The ratio of low to high frequency therefore increases as the muscle fatigues. In other embodiments, the system can use other numbers of frequency bands (e.g., a low, medium, and high frequency band, more than 3 frequency bands, less than two frequency bands, etc.), other ranges of frequency bands, harmonics of frequency bands, frequency bands determined from other windows of data having other associated durations (e.g., less than 10 second windows, more than 10 second windows), etc.

[0032] The muscle fatigue engine **350** determines a power spectrum of the conditioned signal x(t). That is, the muscle fatigue engine **350** determines the distribution of power into frequency components of the conditioned signal x(t). In some embodiments, the muscle fatigue engine **350** determines the power spectrum ratio by using fast Fourier transform (FFT) or other signal processing techniques such as Welch method, Bartlett method. For example, the muscle fatigue engine **350** calculates the spectrum ration R by comparing signals in the high frequency band (e.g., 60-150 Hz) to signals in the low frequency band (e.g., 30-60 Hz) by applying FFT over a moving time window. In various embodiments, the spectrum is calculated over a moving time window (e.g., 10 seconds.)

[0033] In some embodiments, the muscle fatigue engine **350** applies a low frequency filter (e.g., 30-60 Hz) and a high frequency filter (e.g., 60-150 Hz) to obtain the signals in the low and high frequency bands. The muscle fatigue engine **350** then calculates the spectrum ratio R according to Equation (1):

$$R=A1(t)/A2(t) \quad (1),$$

where A1(t) and A2(t) represent the envelope of the low frequency (e.g., 30-60 Hz) and high frequency (e.g., 60-150 Hz) portions of the signal, respectively. The fatigue measurement may be interfered by a dynamic interference caused by repetitive movements. To substantially minimize the effect of these repetitive movements in measuring fatigue, the muscle fatigue engine **350** determines and removes dynamic interference from the fatigue measurement. The muscle fatigue engine **350** determines the dynamic interference by using the envelope H(x(t)) of the conditioned signal x(t). The muscle fatigue engine **350** applies a linear operator (e.g., Hilbert transform) to the conditioned signal x(t) to calculate the envelope H(x(t)) of the conditioned signal x(t). The muscle fatigue engine **350** determines the envelope of the conditioned signal x(t) using the envelope H(x(t)) according to Equation (3):

$$A(t)=|x(t)|+|H(x(t)| \quad (3).$$

The muscle fatigue engine **350** may calculate a series of simple moving averages SMA of the amplitudes A(t) to represent the envelope of signal x(t) Each simple average is calculated for a time interval. In some embodiments, the time interval is 5 seconds. In other embodiments, this time interval can be longer or shorter. The fatigue measurement calculates the dynamic interference according to Equation (1) or (2). The muscle fatigue engine **350** removes the dynamic interference from the spectrum ratio determined by using the conditioned signal x(t).

[0034] In an embodiment, the muscle fatigue engine **350** determines a start and stop time bound over which the muscle fatigue measurement is to be calculated. The start and stop time bound may indicate the start and end of a set of repetition. The muscle fatigue engine **350** may determine the start and stop time bound by examining the signal activity (e.g., by retrieving outputs of other sensors of the garment and/or associated with the user, such as accelerometers, gyroscopes, activity sensors, etc.). In one example, the muscle fatigue engine **350** compares the amplitudes of the conditioned signal x(t) to identify a pattern of the conditioned signal x(t) thereby to identify active regions and inactive regions. The muscle fatigue engine **350** determines active regions are time intervals during which the signals have substantially the same or similar curvature. For example, a change in amplitudes can be used to determine the curvature. During inactive regions, there is low signal activity and the calculation of muscle fatigue measurement is likely to be inaccurate and unstable. This also improves the system performance (e.g., determining a more accurate measurement of the muscle fatigue) as well as reduces the power consumption because the muscle fatigue engine **350** avoids calculating the muscle fatigue during the resting periods when the athlete is not performing the exercises (e.g., while resting between sets of exercises). The muscle

fatigue engine **350** discards the physiological data generated by the sensors during inactive regions.

[0035] FIG. **6** illustrates one example of the muscle fatigue engine **350** determining the muscle fatigue measurements only during active regions. The muscle fatigue engine **350** determines that the time intervals t**1**-t**2**, t**3**-t**4**, t**5**-t**6**, t**7**-t**8** are active regions. As illustrated, during the active regions, the muscle fatigue curve **602** reaches its local peaks indicating that the muscle fatigues during an exercise. During the inactive regions, the muscle fatigue curve **602** reaches its local minima indicating that the muscle recovers during a break. The muscle fatigue engine **350** calculates the fatigue measurements only during the active regions. The values **610**-**617** are example fatigue measurements that the muscle fatigue engine **350** determines. From the example values **610**-**617** an example overall fatigue progression can be derived. Taking fatigue measurements only during active periods provides a more accurate representation of fatigue progression during the workout.

[0036] In some embodiments, the muscle fatigue engine **350** accumulates normalized physiological data based on classifications determined by the classification engine **360**. As an example, the classification engine **360** classifies normalized physiological data by determining a period of time during which an athlete actively performed an exercise or periods of time during which the athlete did not actively perform the exercise. The classification engine **360** can determine these periods of time without requiring manual input from the athlete. For instance, the classification engine **360** uses physiological data generated by the EMG sensors and motion data received from motion sensors of the athletic garment to determine whether the athlete is actively training, performing exercises, or performing a particular type of exercise. Based on the type of classification, the muscle fatigue engine **350** may perform active segmentation of sensor data received from the athletic garment, e.g., to provide exercise metrics and biofeedback. Similar to the time bound feature described above, the muscle fatigue engine **350** may improve the accuracy of muscle fatigue measurements by accumulating normalized physiological data received (or generated) during the active periods of time and not the inactive periods of time. In addition to resting between sets, an athlete may also briefly rest between repetitions or otherwise temporarily interrupt the exercise, e.g., to adjust the athletic garment. Classifying the active and inactive periods of time helps the muscle fatigue engine **350** account for these discrepancies in the physiological data.

[0037] In some embodiments, the classification engine **360** determines active or inactive periods of time for a given muscle or type of exercise. As an example, while an athlete is performing squat exercises, the classification engine **360** classifies the received sensor data to differentiate between physiological data for upper body muscles and lower body muscles. Since squat exercises are intended to train the lower body muscles, the classification engine **360** may determine active periods of time when the received physiological data for the lower body muscles has an amplitude or accumulated muscle fatigue greater than a threshold value. On the other hand, the classification engine **360** may process received physiological data for the upper body muscles when the athlete is performing exercises such as pullups, overhead lifts, pushups, or curls. In some embodiments, the classification engine **360** disregards physiological data—for determining muscle fatigue measurements of a particular muscle—generated during a given exercise responsive to determining that the given exercise is not directed to training that particular muscle. For instance, physiological data of the glutes and quads generated while the athlete is performing certain upper body exercises may not be normalized or accumulated for determining muscle fatigue measurements of the lower body muscles.

[0038] The classification engine **360** may also classify normalized physiological data based on quality of physical contact between a sensor and the athlete's skin. In particular, responsive to determining that the quality of physical contact during a period of time is less than a threshold quality (e.g., indicative of poor contact quality), the muscle fatigue engine **350** may exclude or modify the physiological data received during the period of time for determining muscle fatigue measurement. Other types of classification include, e.g., determining whether the received physiological data corresponds to a low, medium, or high intensity level of exercise; aerobic or anaerobic exercise; or a power, strength, endurance, speed, or hypertrophy type of exercise.

[0039] In some embodiments, the muscle fatigue engine **350** modifies or interprets physiological data received from a sensor over periods of poor contact quality, as classified by the classification engine **360**. For example, if the contact quality is intermittently poor over short periods, the muscle fatigue engine **350** interprets physiological data during these short periods using sensor data received during other periods of good contact quality as boundary conditions for linear or polynomial curve fitting. Additionally, physiological data corresponding to sensors with poor contact quality (e.g., less than a given threshold) may be modified or interpreted by the muscle fatigue engine **350** using data from other sensors with good contact quality (e.g., equal to or greater than the given threshold). For example, when determining a fatigue measurement for the right hamstring muscle during a period of poor contact quality, the muscle fatigue engine **350** may use alternate physiological data corresponding to the left hamstring muscle, after determining that the alternate physiological data has good contact quality. Additionally, the muscle fatigue engine **350** may combine physiological data from multiple sensors to determine an approximate data set during a period of poor contact quality.

[0040] The muscle fatigue engine **350** may determine muscle fatigue measurements for a group of muscles. In addition, an athlete's general fatigue level can be computed based on these measurements. For instance, the various fatigue measurements for an athlete can be averaged, weighted and then averaged, or otherwise combined to produce a general fatigue measurement. In some embodiments, only the fatigue measurement corresponding to muscle groups used by the user during a particular workout may be combined to determine the user's general fatigue measurement. For example, if, during the course of a particular workout, a user receives a fatigue score of 60 for biceps, 70 for shoulders, and 92 for back, and if these muscle groups are the primary muscle groups exercised by the user during the particular workout, then an average fatigue score of 74 can be computed for the user for the workout. In other embodiments, a fatigue measurement for each of a set of muscle groups is determined and averaged, regardless of whether the user has exercised the muscle group during the workout. The muscle fatigue engine may assign a higher weight to fatigue measurements associated with muscle groups more correlative to general fatigue as compared to

those associated with muscle groups less correlative to general fatigue. Fatigue in particular muscle groups can be more correlative to general fatigue measurements than others. For instance, back and core muscles may be more correlative to general fatigue than bicep muscle.

[0041] The muscle fatigue engine **350** may compute fatigue measurements repeatedly or continually over the course of a workout. For instance, as a user performs sets of exercises corresponding to a particular workout, a fatigue measurement can be computed for each set of exercises performed by the user. These computed fatigue measurements can be displayed on a graph indicating an increase in fatigue over the course of the workout. In some embodiments, such temporal displays of fatigue measurements can be displayed in conjunction with a "maximum fatigue" for a user. As used herein, "maximum fatigue" can refer to a threshold level of fatigue at which a user is no longer effectively able to use a particular muscle group to perform a particular exercise. The maximum fatigue for a user can vary based on the type of exercise being performed by the user, the muscle group being exercised, demographic data associated with the user (e.g., the user's weight, age, etc.), the maximum fatigue for users demographically similar to the user, historical fatigue data and maximum fatigue thresholds determined for the user, and the like. In some embodiments, the maximum fatigue can refer to a threshold at which a user is at an increased risk of injury or at which the benefits of the training have diminished. A trajectory of the athlete's fatigue can be compared to this maximum threshold to give the athlete an estimate of when the fatigue accumulation could become too high, potentially putting the athlete at risk of injury or decreasing the benefits of training. Additionally the maximum can correspond to a numerical upper bound for the fatigue measure, e.g. 100 as a muscle fatigue limit.)

[0042] The muscle fatigue engine **350** provides the muscle fatigue measurements for display. The muscle fatigue engine **350** may generate one or more user interfaces for presenting the muscle fatigue measurements or provide the muscle fatigue measurement to the client device for display. In some embodiments, the muscle fatigue engine **350** displays a fatigue measurement as a numerical value from 0 (not fatigued) to 100 (a muscle or movement capacity limit). Alternatively, the fatigue measurement can be displayed in a suitable form. In some embodiments, the muscle fatigue engine **350** displays the fatigue measurements on a muscle group-by-muscle group basis. For instance, a first fatigue measurement for a user's hamstrings can be displayed (for instance, on an overlay of a human body), a second fatigue measurement for a user's quads can be displayed, and a third fatigue measurement for a user's glutes can be displayed.

[0043] In some embodiments, the muscle fatigue engine **350** calculates a fatigue measurement for a first user, and display the result in conjunction with fatigue measurements computed for demographically similar users. For instance, the muscle fatigue engine **350** presents to the first user that the computed fatigue score of 80 in conjunction with an average fatigue score of 60 for users of a similar size/weight/height/age performing the same workout. Beneficially, such a system enables a user to evaluate the user's performance and athleticism relative to similar other users, enables the user to establish performance goals related to fatigue measures, and the like. In some embodiments, the muscle fatigue engine **350** provides an overall fatigue measurement of the athlete both during training and during recovery periods between training sessions using a combination of HRV and the EMG signal as described above.

[0044] The muscle fatigue engine **350** may present fatigue measurements over time. For instance, if fatigue measurements are computed for a user after each workout over the course of an interval of time (such as a month, a year, etc.), the computed fatigue measurements can be displayed in a graph or chart that shows a change in fatigue measurement over time for the user. Such a display can beneficially enable a user to visualize athletic progress over time, thereby encouraging the user to continue with a particular exercise regimen or program. For example, the user can compare fatigue changes for the same workout. A lower fatigue measurement for a given workout over time demonstrates improved training performance.

[0045] The exercise program engine **300** modifies an exercise program based on a muscle fatigue measurement determined by the muscle fatigue engine **350**. For instance, if a user is performing a workout consisting of sets of exercises, and one or more measures of fatigue of the user indicate that the user is becoming fatigued faster than normal, or is exceeding a threshold level of fatigue, the workout of the user can be modified to remove sets of exercises, to remove exercise reps, to reduce various weights or durations associated with the sets of exercises, and the like. Alternatively, if a user is performing the workout and one or more fatigue measurements indicate that the user is becoming fatigued slower than normal or is falling below a threshold level of fatigue, the workout of the user can be modified to add sets of exercises, to add exercise reps, to increase weights or durations associated with the sets of exercises, and the like. In some embodiments, trends in fatigue measurements associated with the user can result in the modification of the user's training plan, for instance by adding additional workouts if a user is generally becoming less fatigued over time, or by subtracting workouts if a user is generally becoming more fatigued over time.

[0046] It should be noted that fatigue measurements can be used to modify which muscle groups are being exercised during a workout. For instance, if a user is participating in a shoulders-focused workout, and one or more fatigue measurements indicate that the user's shoulder muscles are becoming fatigued, one or more future shoulder exercises in the workout can be changed to bicep exercises, leg exercises, or the like.

[0047] In some embodiments, one or more notifications or suggestions can be provided to the user based on fatigue measurements, where notifications can be provided to the user or an entity associated with the user (e.g., a coach, through a coaching tool or device). For instance, a rest interval between sets or exercises can be recommended in the event that one or more fatigue measurements indicate that the user is becoming tired more quickly than this user's historical average or a demographically similar average user. Alternatively, notifications or suggestions can be provided to the user in response to fatigue measurements indicating that the user is becoming tired slower than normal. For instance, if the user is running and one or more fatigue measurements indicate that the user is becoming less tired than normal, the user can be encouraged to run faster/pick up the pace.

[0048] In some embodiments, the muscle fatigue engine **350** accesses a pre-determined muscle fatigue measurement model (also referred to herein as a "model") stored in the

model data store **370**. The model defines one or more criteria for modifying the exercise program. For example, a set of criteria may be satisfied by the muscle fatigue engine **350** determining that a muscle fatigue measurement of an athlete exceeds a threshold deviation relative to athlete population norms, e.g., based on aggregate data retrieved from the athlete data store **310**. Specifically, the model may indicate a target motion profile (e.g., indicative of proper form of an exercise to avoid injury) or muscle fatigue profile (e.g., indicating a decline in a muscle's ability to generate force), which may be customized based on the athlete's demographic or physiological data. If the athlete exceeds the threshold deviation, the muscle fatigue engine **350** may determine that the exercise program is currently too challenging (e.g., resulting in improper exercise form), not challenging enough (e.g., resulting in under-utilization of muscles) for the athlete, or not aligned with the user's goal. Thus, responsive to the muscle fatigue engine **350** determining that the set of criteria is satisfied by the muscle fatigue measurement, the exercise program engine **300** may adjust the difficulty of the exercise program to provide an appropriate level of challenge to the athlete.

[0049] The exercise program engine **300** may also modify an exercise program based on fatigue measurements, for example, to train imbalances. As such, an athlete can understand the accumulated fatigue placed on different muscle groups across multiple workouts and adjust if certain muscle groups are being biased over others. Imbalances can also be surfaced within a workout. For example, if a user is performing a bench press exercise, and is exerting more force with the user's left arm than the right arm, the left arm may become fatigued quicker, and this imbalance between measures of fatigue for the left arm and the right arm can be flagged to the user with a notification that the user's form was incorrect while performing the exercise.

[0050] The muscle fatigue engine **350** may determine the imbalance by examining the fatigue measurements determined across different muscle groups. If a fatigue measurement for one muscle group is greater than that of for other muscle groups by at least a threshold difference, the exercise program engine **300** determines that there is an imbalance. In response to this determination, the exercise program engine **300** may add or remove an exercise from the exercise program to address the imbalance. For instance, the exercise program engine **300** adds exercises to increase the force to be exerted by the "weaker" side of the body that currently fatigues more slowly.

[0051] Moreover, the muscle fatigue engine **350** may use fatigue measurements in combination with the user's strength in order to determine the user's performance for a particular exercise. For instance, during the performance of a bench press exercise, a user's right arm is associated with a greater measure of strength than the user's left arm, but the left arm is associated with a greater measure of fatigue than the right arm. In such an instance, a user can be determined to be strength imbalanced (e.g., stronger on the right side than the left side). Alternatively, if the user's right arm is associated with both greater measures of strength and fatigue, the user can be determined to be form imbalanced (e.g., using an improper form during the performance of the exercise). Such determinations can beneficially be communicated to the user. In the event that the user is form imbalanced, a notification to perform the exercise with proper form can be provided to the user. Likewise, if the user is strength imbalanced, additional exercises can be presented to the user to increase the strength in the under-strengthened muscle groups.

[0052] Further, the exercise program engine **300** may modify exercise programs based on other factors such as a measurement of strength, which may be determined based on historical muscle stress measurement and/or logs of how much weight has been involved or logs of other output the user has provided in relation to an activity. For instance, responsive to determining that the fatigue level is greater than a threshold level (e.g., indicative of chronic fatigue), the exercise program engine **300** removes exercises from the exercise program to alleviate the stress experienced by the athlete and mitigate injury risk from over training. In addition, the exercise program engine **300** may reduce the number or training stress of exercises during a period of time prior to an identified high stress event in the exercise program such as an athletic competition at which the athlete plans to participate. The exercise program engine **300** may provide a notification to an athlete describing a modification to an exercise program as well as relevant context. For example, the exercise program engine **300** notifies the athlete that chronic fatigue is detected and that the number of exercise sessions per week will be reduced accordingly, e.g., to mitigate injury risk. In some embodiments, the exercise program engine **300** presents an exercise program modification in a graphical user interface, e.g., highlighting an updated number of repetitions, sets, or weight for an exercise in a list, timeline, or calendar display of the athlete's exercise program. Additionally, the exercise program engine **300** may dynamically reformat or resize components of a graphical user interface based on modifications. For instance, a calendar display shows graphics (e.g., a window indicating a number of reps and weight for a particular type of exercise) corresponding to exercises for completion by the athlete on various days or times of the week. Responsive to a modification, the exercise program engine **300** removes existing graphics (e.g., with a cross mark or a faded color) or adds new graphics to the calendar (e.g., which may be emphasized in bold, with brighter colors, or with enlarged size).

[0053] Since the exercise program engine **300** can dynamically modify an exercise program and provide a notification of the modification while the athlete is performing the exercise program, the exercise feedback system **100** improves the athlete's training in real-time, instead of having the athlete or a coach review the athlete's performance after an exercise workout or session has been completed. Additionally, the exercise feedback system **100** may maintain accurate and continuous accumulation of physiological data even as the exercise program is modified. The exercise feedback system **100** may automatically update physiological data normalization or classifications for any number or type of modification of an exercise program, which allows athletes and coaches to receive reliable metrics and biofeedback while training.

[0054] In some embodiments, the exercise feedback system **100** uses the models to perform other functionality such as providing biofeedback by the biofeedback engine **380**. The biofeedback engine **380** may generate or update various graphical user interfaces to present biofeedback via a client device **110**. As an example, a model defines a set of criteria for determining a risk of injury. Responsive to the muscle fatigue engine **350** determining that the set of criteria is

satisfied by an athlete's muscle fatigue measurement, the biofeedback engine **380** notifies the athlete of the risk of injury. In some embodiments, the biofeedback engine **380** communicates the risk of injury via a push notification presented by a client device **110** while an athlete is exercising, so that the athlete can promptly stop or adjust an exercise to avoid the injury. Further, an athletic garment worn by the athlete may also communicate the notification by providing haptic feedback, e.g., vibrating at a certain position on the athlete's body during an exercise to alert the athlete to reduce the weight being lifted or to correct improper form of an exercise. The biofeedback engine **380** may provide context with a notification of injury risk, for example, indicating a type of risk (e.g., straining a muscle or wearing out a joint), severity of the risk, or remedial action such as performing stretches, icing or heating a muscle, resting, or switching to a different type of exercise. In an example, the risk of injury may be determined based on an identified imbalance of muscle stress or a fatigue level of the athlete, and the biofeedback engine **380** provides context informing the athlete to increase training on the left or right side upper arm muscles (e.g., to address the identified imbalance) or reduce the amount of weights overall to recover from a high-risk fatigue level and avoid injury.

[0055] In addition to providing the notification of injury risk, the biofeedback engine **380** may also generate and provide other types of biofeedback for athletes based on the muscle fatigue measurements. The biofeedback indicates, for example, a metric of athletic performance such as a percentage value, a Boolean value (e.g., satisfactory or unsatisfactory), or any suitable type of value. In some embodiments, the biofeedback indicates a measure of progress of an athlete over a period of time and is generated based on context describing the corresponding exercise (e.g., using information from the athlete data store **310** or exercise program data store **320**). The context may include a type of exercise, or a volumetric load based on a product of a number of repetitions and corresponding weights lifted by an athlete. The biofeedback may be generated based on heart rate data captured by sensors of an athletic garment or associated with a particular muscle, muscle group, repetition, or set. Based on normalized physiological data, the biofeedback engine **380** may generate biofeedback including a comparison between contributions of a set of muscles with that of a different set of muscles of the athlete while performing an exercise.

[0056] In some embodiments, the biofeedback engine **380** generates a graphical depiction of muscles of an athlete. In particular, the biceps and quads (among other types of muscles) may be overlaid on the arm and leg portions, respectively, of a human body graphic (e.g., resembling a silhouette, avatar, or the like) of the athlete. The biofeedback engine **380** may present muscle fatigue measurements, biofeedback, or other metrics of the muscles by dynamically updating a color or size of the graphic depiction of the corresponding muscle. For instance, as the muscle fatigue measurement increases, the graphic of the muscle becomes a brighter color, different color or increases in size to illustrate that the muscle is being fatigued for an exercise. Thus, the athlete can view a real-time progression of multiple muscles that increase or decrease in fatigue throughout stages of an exercise, e.g., the athlete utilizes the arm and leg muscles for different motions of an Olympic lift.

[0057] In some embodiments, some or all of the functionality of the exercise feedback system **100** may be performed by or implemented within a client device **110**. For example, the client device **110** stores pre-determined muscle fatigue measurement models and uses a local muscle fatigue engine to determine whether a model's criteria for modifying an exercise program is satisfied. This can be advantageous because the client device **110** may not always have a network connection while an athlete is exercising (e.g., the athlete's gym does not have internet available). Thus, muscle fatigue measurements are determined and analyzed locally on the client device **110** without having to upload the physiological data to the exercise feedback system **100** for processing.

V. Example Process Flows

[0058] FIG. **4** is a flowchart of a process **400** for determining muscle fatigue measurement according to one embodiment. In some embodiments, the process **400** is performed by the exercise feedback system **100**—e.g., modules of the exercise feedback system **100** described with reference to FIG. **3**—within the system environment in FIG. **1**. The process **400** may include different or additional steps than those described in conjunction with FIG. **4** in some embodiments or perform steps in different orders than the order described in conjunction with FIG. **4**.

[0059] In one embodiment, the data processing engine **330** receives **410** physiological data from an athletic garment worn by a user (athlete), where the physiological data describes muscle activation of muscles of the user while performing an exercise. The data processing engine **330** determines and removes **410** artifacts from the physiological data. For a particular muscle, the muscle fatigue engine **350** determines **430** a power spectrum of the conditioned data. The muscle fatigue engine **350** determines a spectrum ratio using the power spectrum. The muscle fatigue engine **350** determines a fatigue measurement using the spectrum ratio. For example, the muscle fatigue engine **350** may determine the spectrum ratio as the fatigue measurement or normalize the spectrum ratio relative to a distribution of spectrum ratio as the fatigue measurement. Alternatively, instead of determining a power spectrum and determining the ratio between frequency bands in the frequency domain, the muscle fatigue engine **350** filters the conditioned signal in the time domain using different frequency filters and calculates the ratio by using amplitudes of the output signal of the frequency filters. In some embodiments, the fatigue engine **350** determines and removes dynamic interference from the spectrum ratio to determine the fatigue measurement. The exercise feedback system presents **750** the muscle fatigue measurement to the user, e.g., by displaying biofeedback generated by the biofeedback engine **380** via a client device **110**.

[0060] Now referring to FIG. **7** that is a flowchart illustrating a process **700** of a process of managing an exercise program using a muscle fatigue measurement model according to one embodiment. In some embodiments, the process **700** is performed by the exercise feedback system **100**—e.g., modules of the exercise feedback system **100** described with reference to FIG. **3**—within the system environment in FIG. **1**. The process **700** may include different or additional steps than those described in conjunction with FIG. **7** in some embodiments or perform steps in different orders than the order described in conjunction with FIG. **7**.

[0061] In one embodiment, the data processing engine **330** retrieves **810** physiological data captured by sensors of an athletic garment worn by a user (athlete) while performing an exercise using a set of muscles for an exercise program presented to the user by a client device **110**. The muscle fatigue engine **350** determines **720** a muscle fatigue measurement for the set of muscles that is representative of a fatigue degree of muscles over the course of the exercise (e.g., using the process **400** shown in FIG. **4**). The muscle fatigue engine **350** accesses **730** a pre-determined muscle fatigue measurement model defining one or more criteria for modifying the exercise program. In response to at least one of the criteria being satisfied by the muscle fatigue measurement, the exercise program engine **300** modifies **740** the exercise program. The exercise program engine **300** presents **750** information representative of the modified exercise program by the client device **110**. In other embodiments, the pre-determined muscle fatigue measurement model defines criteria for determining a risk of injury of the user. If the criteria being satisfied, the biofeedback engine **380** may provide a notification of the risk of injury to the user.

VI. Additional Considerations

[0062] The foregoing description of the embodiments of the invention has been presented for the purpose of illustration; it is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Persons skilled in the relevant art can appreciate that many modifications and variations are possible in light of the above disclosure.

[0063] Some portions of this description describe the embodiments of the invention in terms of algorithms and symbolic representations of operations on information. These algorithmic descriptions and representations are commonly used by those skilled in the data processing arts to convey the substance of their work effectively to others skilled in the art. These operations, while described functionally, computationally, or logically, are understood to be implemented by computer programs or equivalent electrical circuits, microcode, or the like. Furthermore, it has also proven convenient at times, to refer to these arrangements of operations as modules, without loss of generality. The described operations and their associated modules may be embodied in software, firmware, hardware, or any combinations thereof.

[0064] Any of the steps, operations, or processes described herein may be performed or implemented with one or more hardware or software modules, alone or in combination with other devices. In one embodiment, a software module is implemented with a computer program product including a computer-readable non-transitory medium containing computer program code, which can be executed by a computer processor for performing any or all of the steps, operations, or processes described.

[0065] Embodiments of the invention may also relate to a product that is produced by a computing process described herein. Such a product may include information resulting from a computing process, where the information is stored on a non-transitory, tangible computer readable storage medium and may include any embodiment of a computer program product or other data combination described herein.

[0066] Finally, the language used in the specification has been principally selected for readability and instructional purposes, and it may not have been selected to delineate or circumscribe the inventive subject matter. It is therefore intended that the scope of the invention be limited not by this detailed description, but rather by any claims that issue on an application based hereon. Accordingly, the disclosure of the embodiments of the invention is intended to be illustrative, but not limiting, of the scope of the invention, which is set forth in the following claims.

What is claimed is:

1. A method comprising:

receiving physiological data from a set of sensors of a garment worn by a user, the physiological data describing muscle activation of a muscle of the user while performing an exercise, the set of sensors configured to be positioned abut the muscle and to generate the physiological data;

selecting a first portion and a second portion of the physiological data, the first portion corresponding to a first frequency band and the second portion corresponding to a second frequency band, the second frequency band higher than the first frequency band;

determining a muscle fatigue measurement of the muscle by determining a ratio between a power of the first frequency band and a power of the second frequency band; and

providing the muscle fatigue measurement for display to the user via a client device.

2. The method of claim **1**, wherein the sensors include an electromyography (EMG) electrode and the physiological data includes electromyography data generated by the muscle.

3. The method of claim **1**, wherein selecting the first portion and the second portion of the physiological data comprises removing a baseline shift amount from the physiological data, the baseline shift amount corresponding to a third frequency band lower than a threshold frequency.

4. The method of claim **1**, further comprising generating an electromyography signal represented by the physiological data, and calculating a frequency spectrum of the electromyography signal over a time interval, wherein the first portion and the second portion correspond to the time interval.

5. The method of claim **1**, wherein determining the muscle fatigue measurement further comprises determining a dynamic interference by:

generating an envelope of the physiological data,

selecting a first portion and a second portion of the envelope, the first portion corresponding to the first frequency band and the second portion corresponding to the second frequency band, and

determining a ratio between a power of the first frequency band of the envelope to a power of the second frequency band of the envelope.

6. The method of claim **5**, further comprising removing the dynamic interference from the ratio between the power of the first frequency band of the physiological data and a power of the second frequency band of the physiological data.

7. The method of claim **1**, further comprising heart rate variability data including a heart rate variability, further comprising:

determining a reference fatigue level based on the heart rate variability; and

determining a fatigue level of the user based on the reference fatigue level and the muscle fatigue measurement.

8. The method of claim **1**, further comprising determining a start and stop time bound over which the muscle fatigue measurement is to be calculated, wherein the physiological data is accumulated over the determined time bound.

9. The method of claim **1**, further comprising normalizing the physiological data using one or more calibration parameters determined based on a muscle type of the muscle.

10. The method of claim **1**, wherein determining the muscle fatigue measurement of the muscle for the exercise is further based on historical muscle fatigue measurements of exercises previously performed by the user, the muscle fatigue measurement indicating a pattern of performance of the muscle.

11. The method of claim **1**, wherein the physiological data is accumulated over a time interval, further comprising determining the time interval by classifying the physiological data.

12. The method of claim **11**, wherein classifying the normalized physiological data comprises:

determining active periods of time during which the user actively performed the exercise, the physiological data received during the active periods of time accumulated for the muscle fatigue measurement.

13. The method of claim **11**, wherein classifying the physiological data comprises:

determining an inactive period of time during which the user did not actively perform the exercise, the physiological data received during the inactive period of time not accumulated for the muscle fatigue measurement.

14. The method of claim **11**, wherein classifying the physiological data comprises:

determining a quality of physical contact between the sensor and a portion of skin of the user during a period of time; and

responsive to determining that the quality of physical contact is less than a threshold quality, modifying the physiological data received during the period of time.

15. A computer program product comprising a non-transitory computer readable storage medium having instructions encoded thereon that, when executed by a processor, cause the processor to:

receive physiological data from a set of sensors of a garment worn by a user, the physiological data describing muscle activation of a muscle of the user while performing an exercise, the set of sensors configured to be positioned abut the muscle and to generate the physiological data;

select a first portion and a second portion of the physiological data, the first portion corresponding to a first frequency band and the second portion corresponding to a second frequency band, the second frequency band higher than the first frequency band;

determine a muscle fatigue measurement of the muscle by determining a ratio between a power of the first frequency band and a power of the second frequency band; and

provide the muscle fatigue measurement for display to the user via a client device.

16. The computer program product of claim **15**, wherein the sensors include an electromyography (EMG) electrode and the physiological data includes electromyography data generated by the muscle.

17. The computer program product of claim **15**, wherein the computer instructions configured to cause the processor to select the first portion and the second portion of the physiological data comprises the computer instructions configured to cause the processor to remove a baseline shift amount from the physiological data, the baseline shift amount corresponding to a third frequency band lower than a threshold frequency.

18. The computer program product of claim **15**, wherein the computer instructions are further configured to cause the processor to generate an electromyography signal represented by the physiological data, and calculate a frequency spectrum of the electromyography signal over a time interval, wherein the first portion and the second portion correspond to the time interval.

19. The computer program product of claim **15**, wherein the computer instructions configured to cause the processor to determine the muscle fatigue measurement further comprises computer instructions configured to cause the processor to determine a dynamic interference by:

generating phase-shifted physiological data based on the physiological data, a phase difference between a first signal represented by the physiological data and a second signal represented by the phase-shifted physiological data being 90 degrees,

selecting a first portion and a second portion phase-shifted physiological data, the first portion corresponding to the first frequency band and the second portion corresponding to the second frequency band, and

determining a ratio between a power of the first frequency band of the phase-shifted physiological data to a power of the second frequency band of the phase-shifted physiological data.

20. The computer program product of claim **19**, wherein the computer instructions are further configured to cause the processor to remove the dynamic interference from the ratio between the power of the first frequency band of the physiological data and a power of the second frequency band of the physiological data.

21. A system comprising:

a garment comprising a set of sensors and configured to be worn by a user; and

a computing system comprising:

a processor, and

a memory storing instructions configured to cause the processor to perform:

receiving physiological data from a set of sensors of a garment worn by a user, the physiological data describing muscle activation of a muscle of the user while performing an exercise, the set of sensors configured to be positioned abut the muscle and to generate the physiological data;

selecting a first portion and a second portion of the physiological data, the first portion corresponding to a first frequency band and the second portion corresponding to a second frequency band, the second frequency band higher than the first frequency band;

determining a muscle fatigue measurement of the muscle by determining a ratio between a power of the first frequency band and a power of the second frequency band; and

providing the muscle fatigue measurement for display to the user via a client device.

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申请(专利权)人(译)	MAD服装，INC.		
当前申请(专利权)人(译)	MAD服装，INC.		
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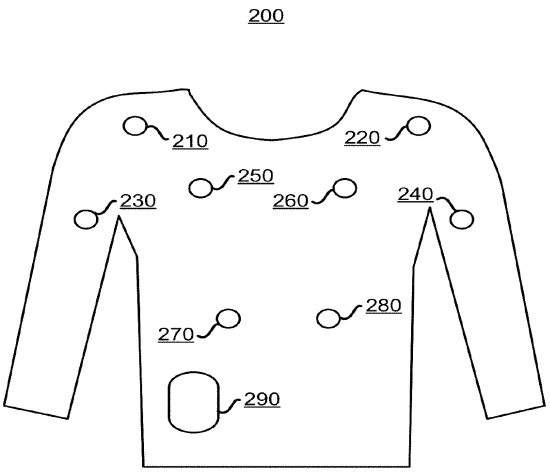
运动反馈系统使用配备传感器的运动服生成的生理数据确定肌肉疲劳测量值。肌肉疲劳测量通过分析生理数据的频率分布来确定。运动反馈系统可以自定义运动程序，确定受伤风险或生成生物反馈，以便使用肌肉疲劳测量结果显示在图形用户界面上。运动反馈系统访问为上述特征定义标准的预定的肌肉疲劳测量模型。例如，如果运动员变得疲劳并且根据肌肉疲劳测量值以不正确的形式进行锻炼，则运动反馈系统会修改运动员的运动程序，以帮助瞄准和改善运动员的弱点并防止受伤。