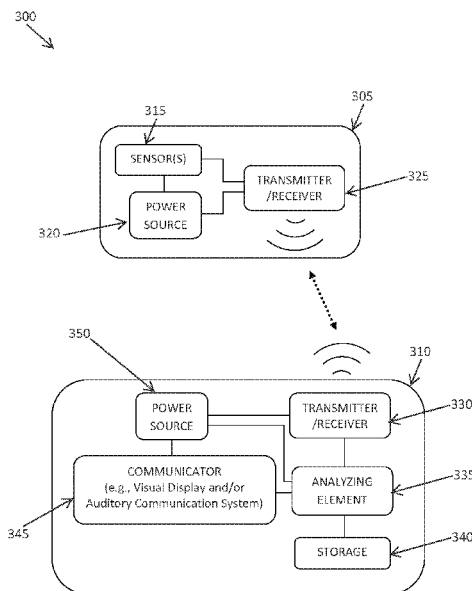




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(19) **United States**(12) **Patent Application Publication****Pease et al.**(10) **Pub. No.: US 2017/0239551 A1**(43) **Pub. Date: Aug. 24, 2017**(54) **SYSTEMS AND METHODS FOR  
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**A61B 5/486** (2013.01); **A61B 5/6807**  
(2013.01); **A61B 5/7405** (2013.01); **A61B**  
**5/742** (2013.01); **A61B 5/7455** (2013.01);  
**G06K 9/00342** (2013.01); **G01C 22/006**  
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(2013.01); **A63B 2220/56** (2013.01); **A63B**  
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**A63B 2220/34** (2013.01); **A63B 2220/20**  
(2013.01); **A63B 2220/72** (2013.01); **A63B**  
**2220/836** (2013.01); **A63B 2225/20** (2013.01);  
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Andover, MA (US); **Jean-Francois**  
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**Katherine Petrecca**, Waltham, MA  
(US); **Trampas Tenbroek**, North  
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Feb. 7, 2012, now Pat. No. 9,642,415.(60) Provisional application No. 61/440,243, filed on Feb.  
7, 2011.**Publication Classification**(51) **Int. Cl.****A63B 71/06** (2006.01)**A43B 3/00** (2006.01)**G09B 19/00** (2006.01)**G01C 22/00** (2006.01)**A61B 5/11** (2006.01)**A61B 5/00** (2006.01)**ABSTRACT**

The invention relates to devices and methods for monitoring one or more athletic performance characteristic of a user. An example apparatus includes a sensing unit adapted to be attachable to a shoe of a user, the sensing unit including a first sensor adapted to monitor an movement of a foot of the user while the user is in motion, the first sensor comprising a gyroscopic sensor, processing means for determining a first performance characteristic of the user based upon an output from the first sensor, the first performance characteristic comprising a foot strike location of a foot of the user upon striking a ground surface, and transmitting means for transmitting a data package representative of the performance characteristic to a remote receiver.



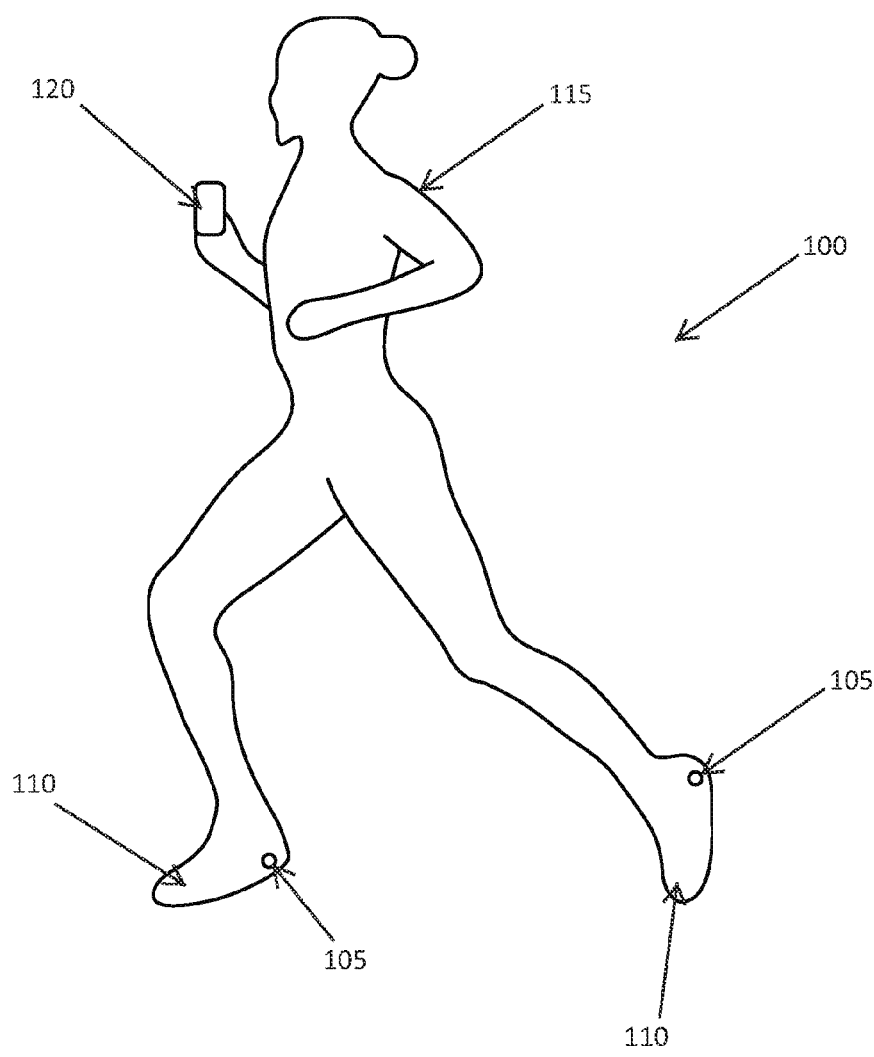
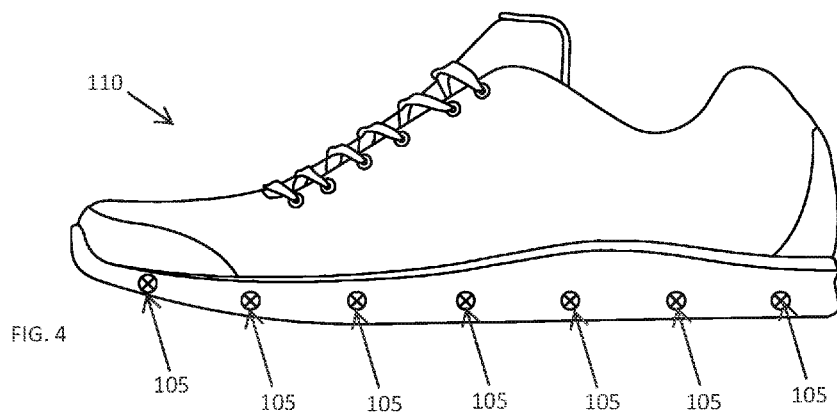
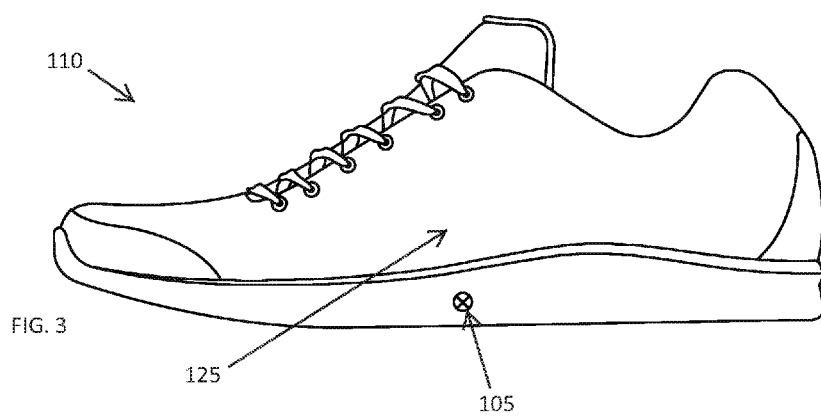
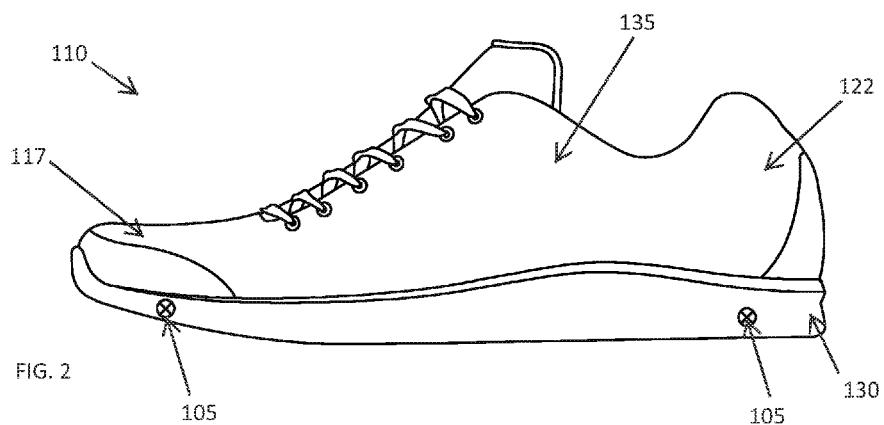


FIG. 1



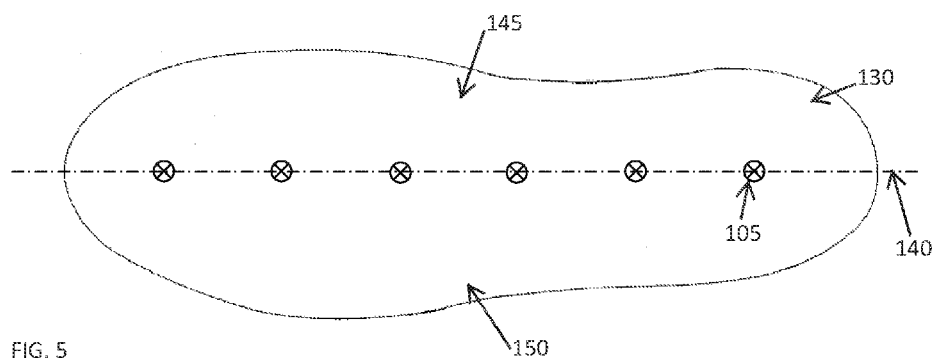


FIG. 5

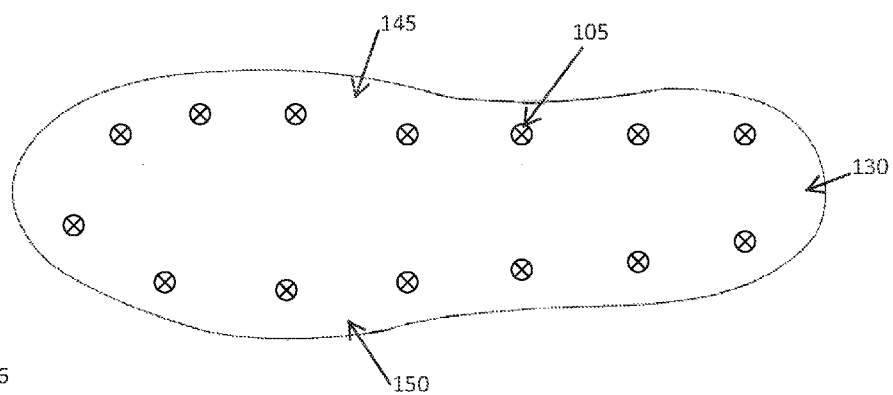


FIG. 6

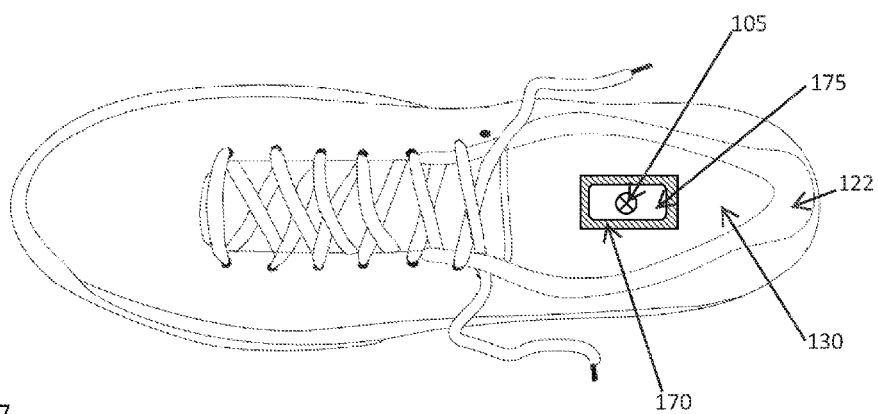


FIG. 7

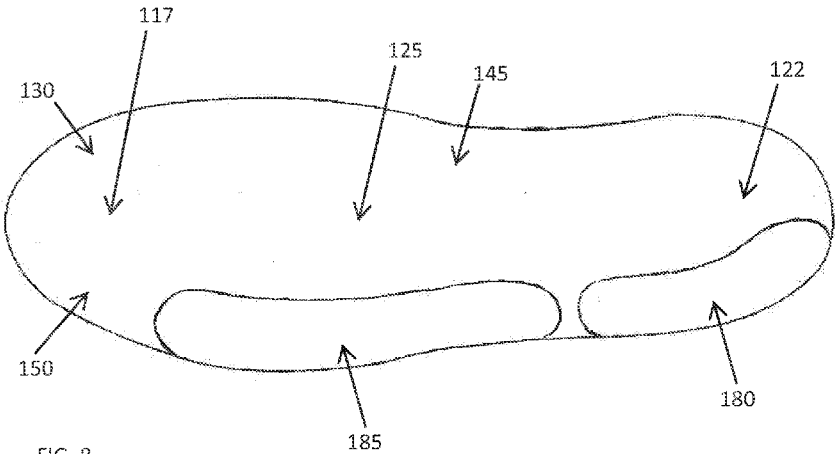


FIG. 8

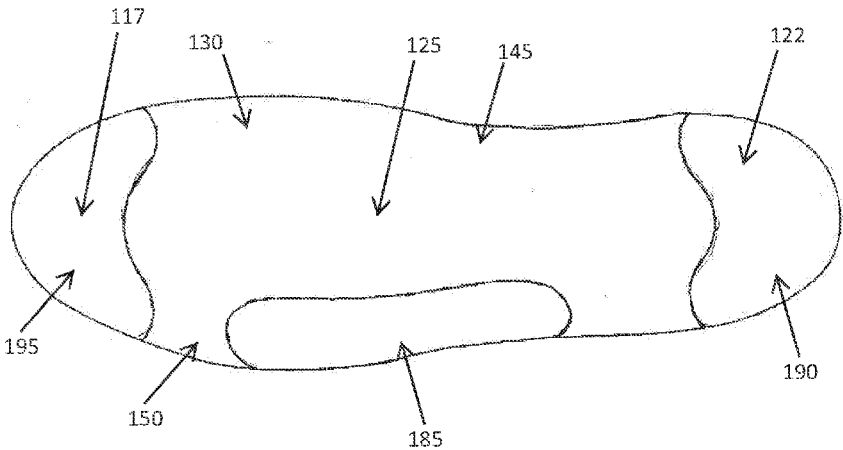


FIG. 9

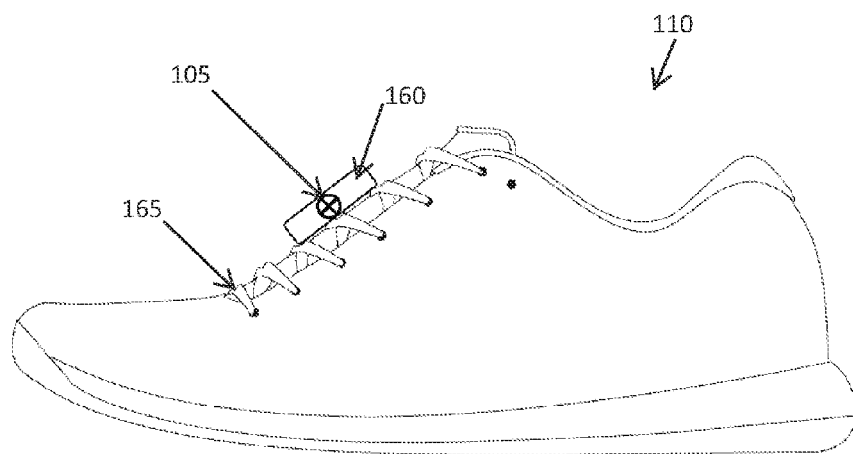


FIG. 10

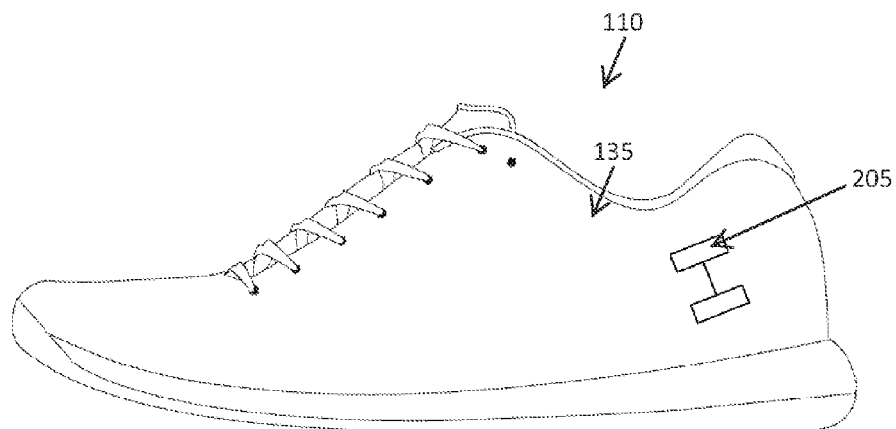


FIG. 11

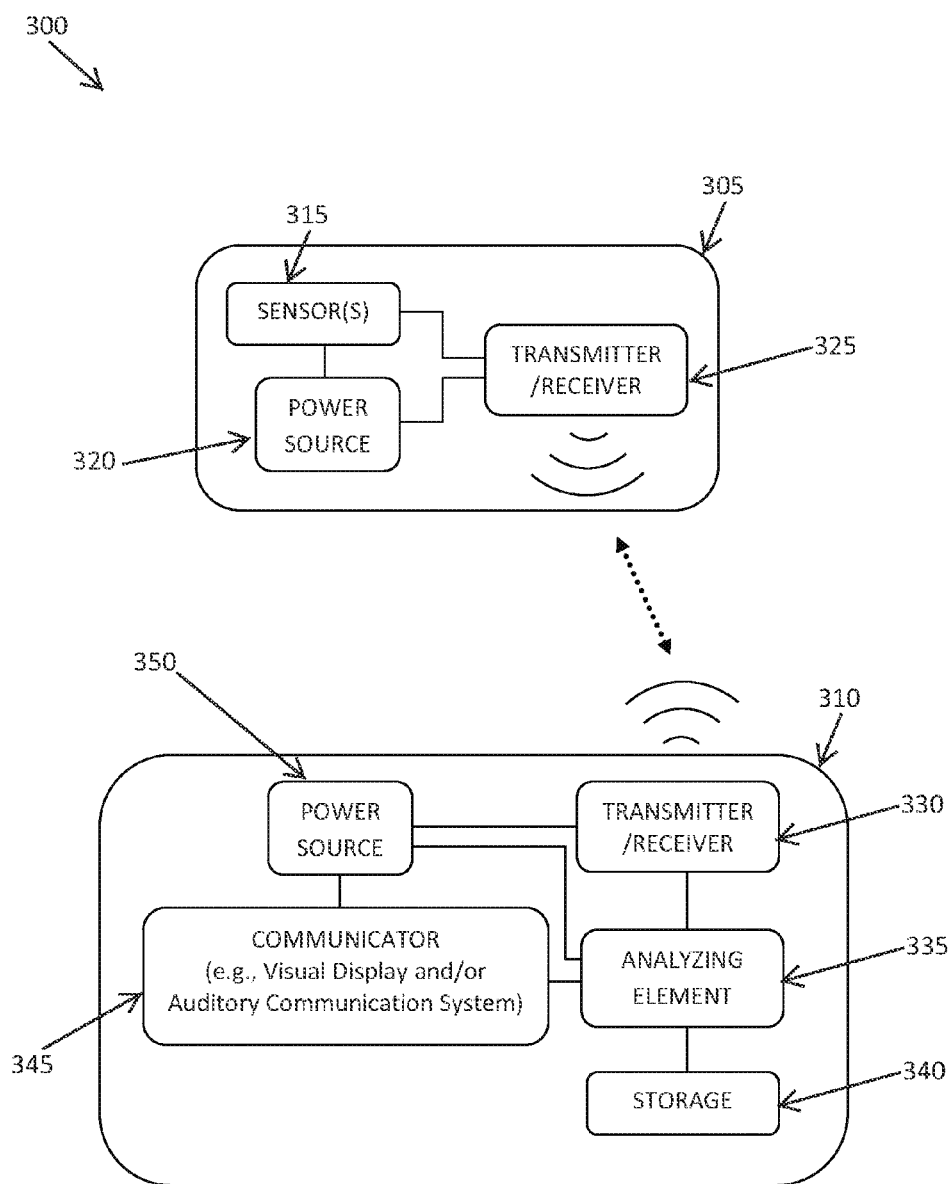


FIG. 12

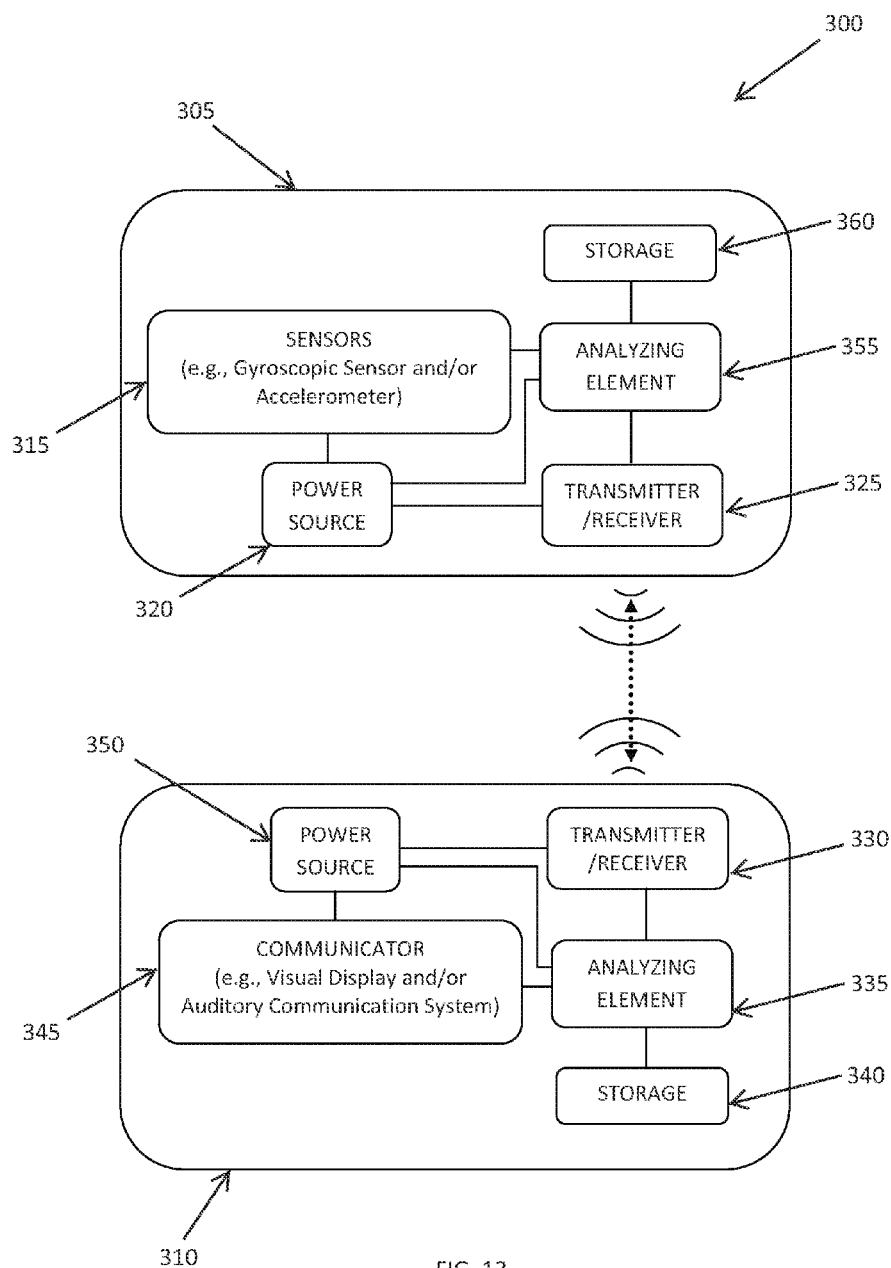


FIG. 13



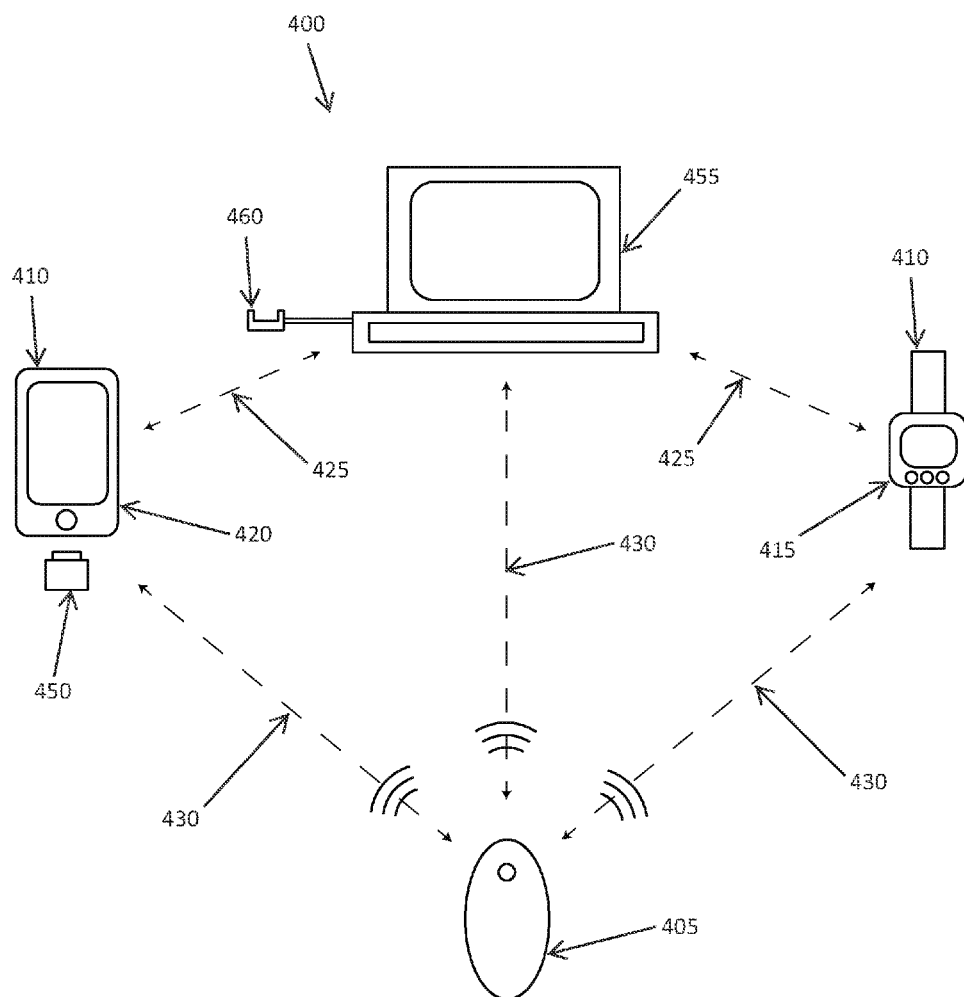


FIG. 14

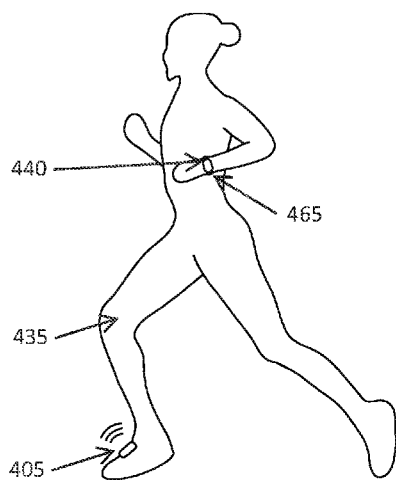


FIG. 15

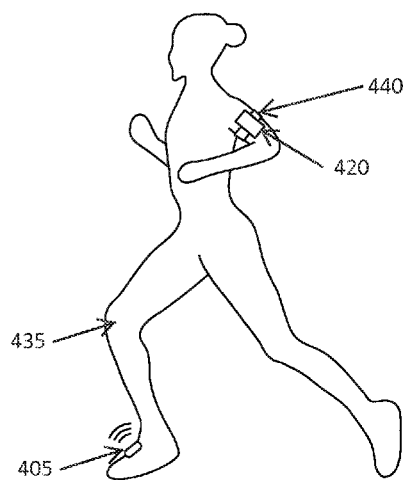


FIG. 16

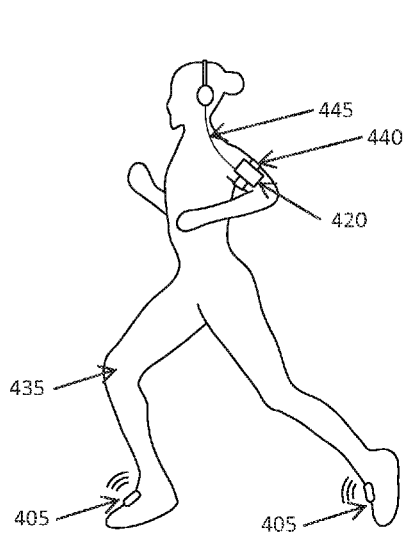


FIG. 17

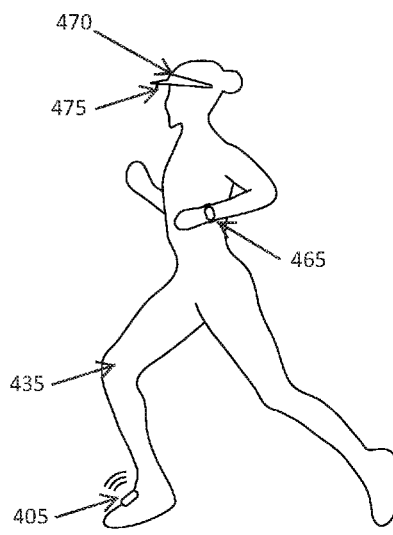


FIG. 18

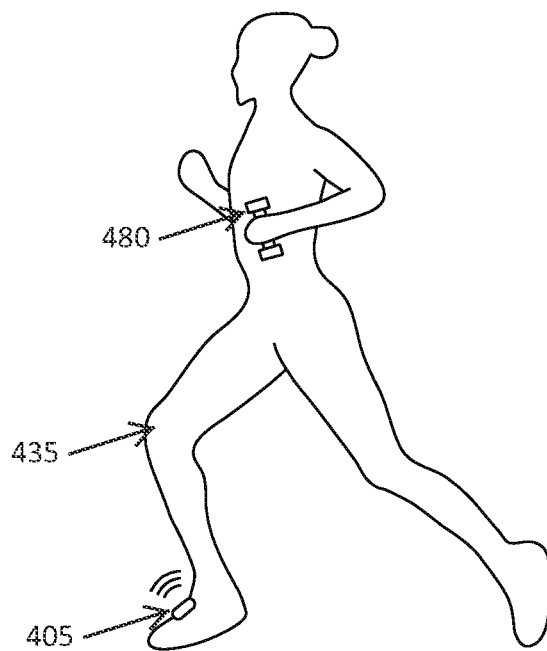


FIG. 19

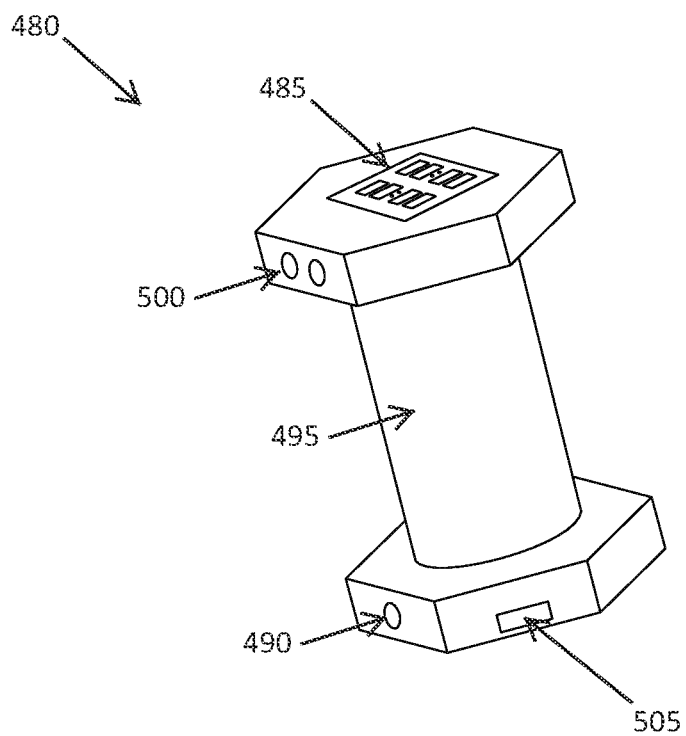
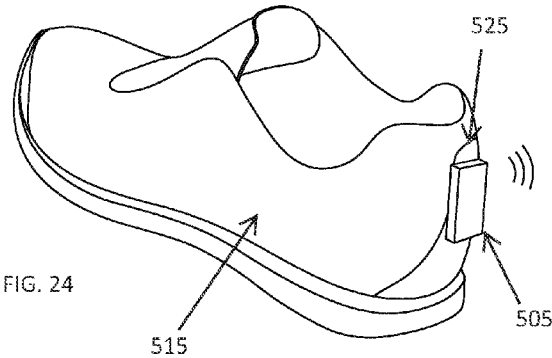
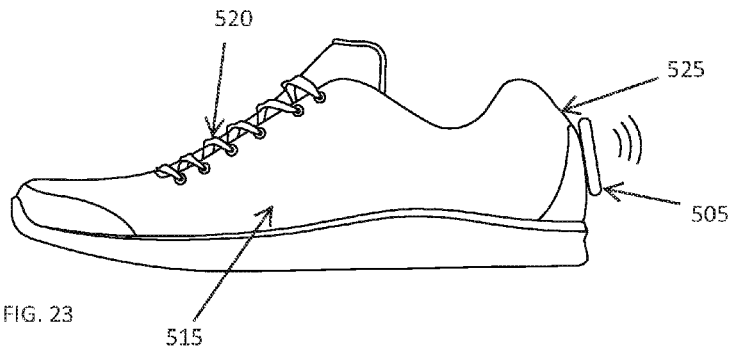
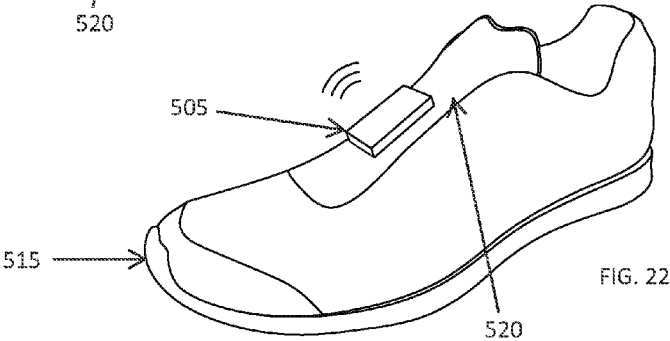
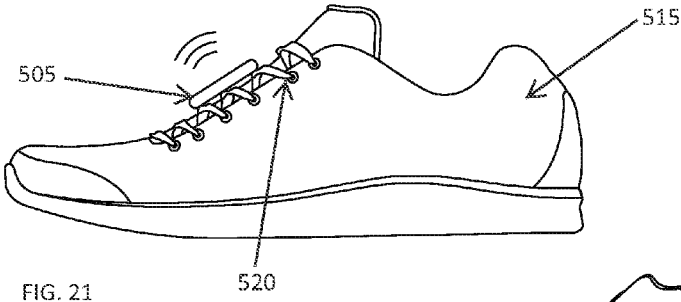


FIG. 20



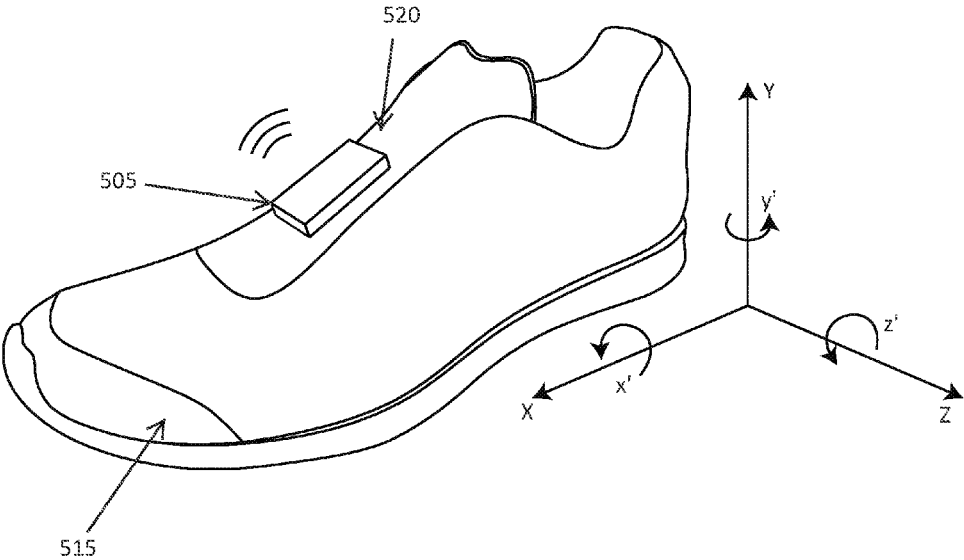


FIG. 25

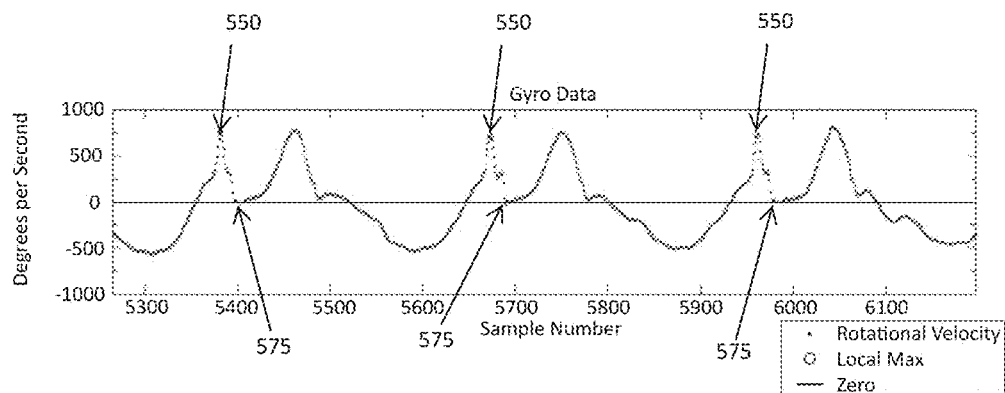


FIG. 26

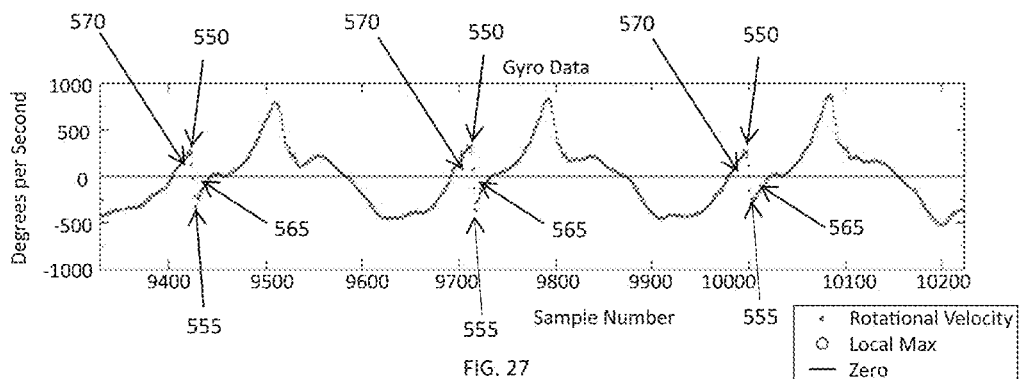


FIG. 27

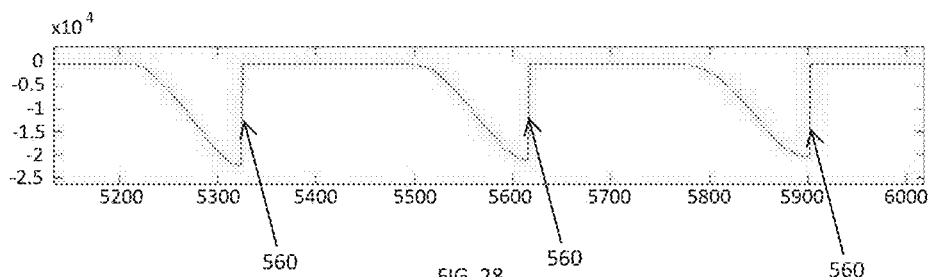


FIG. 28

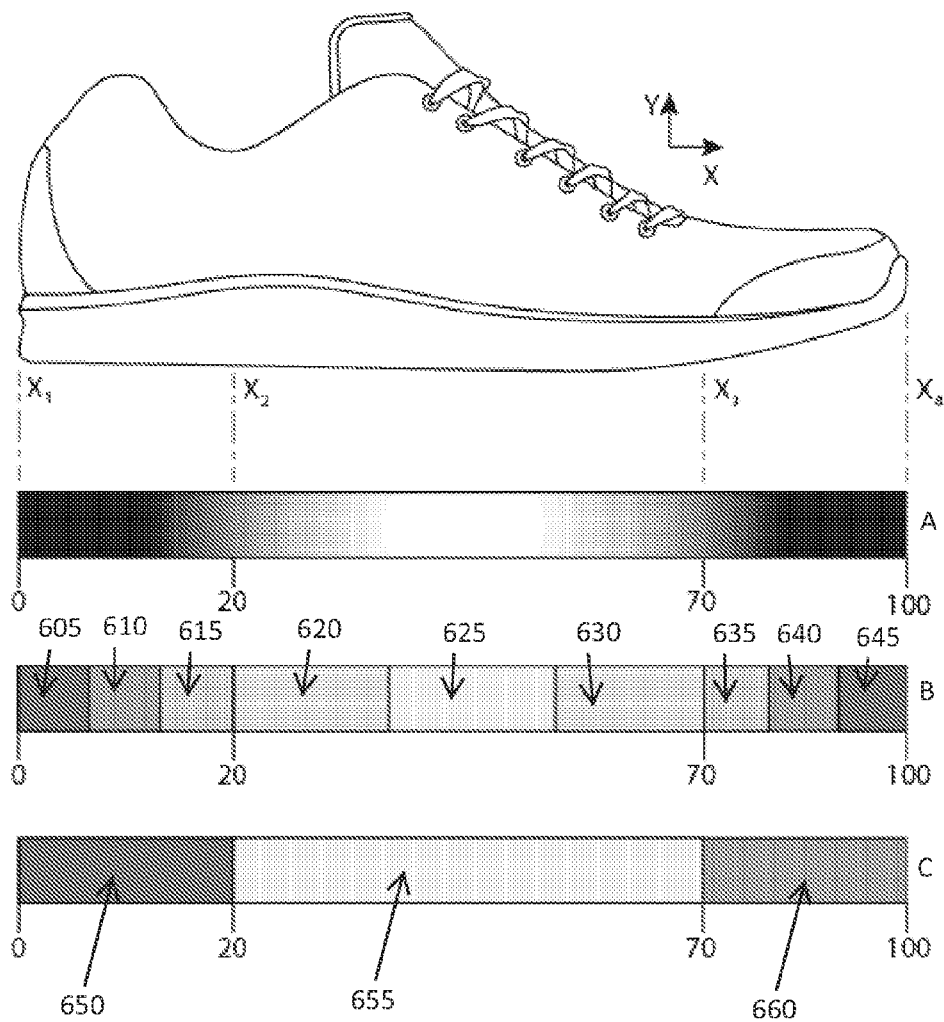
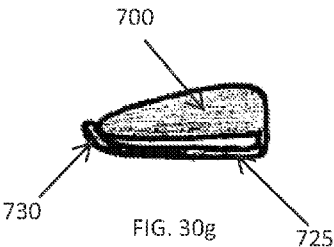
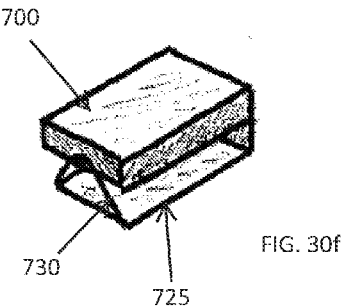
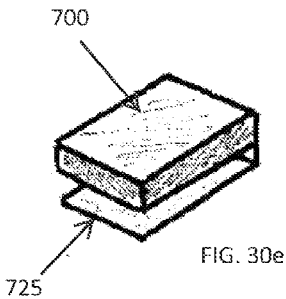
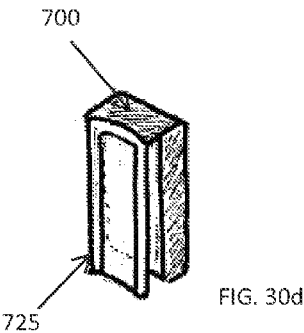
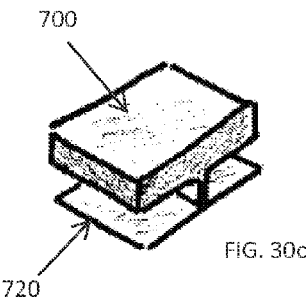
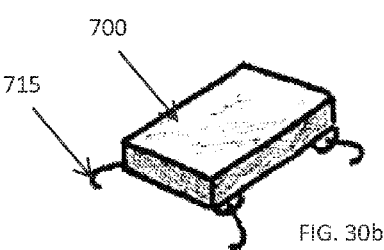
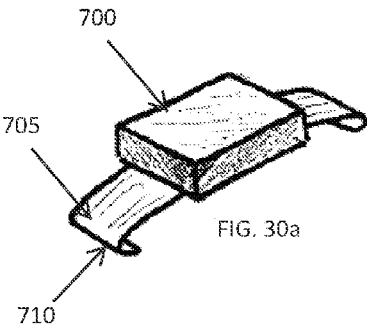
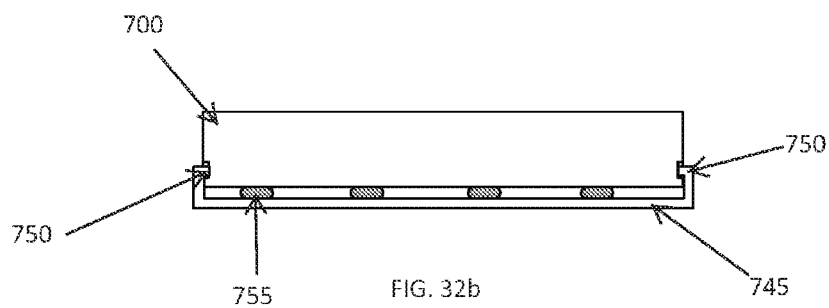
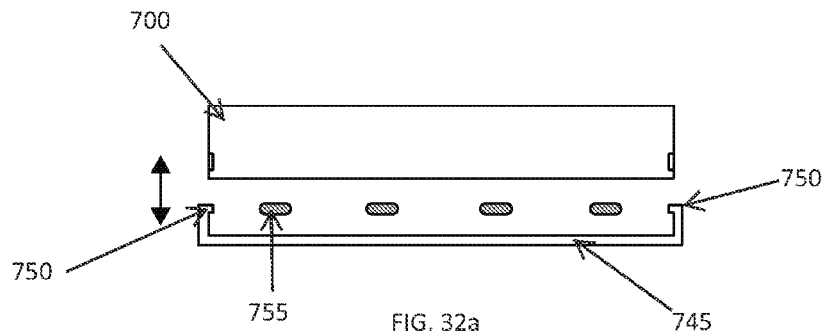
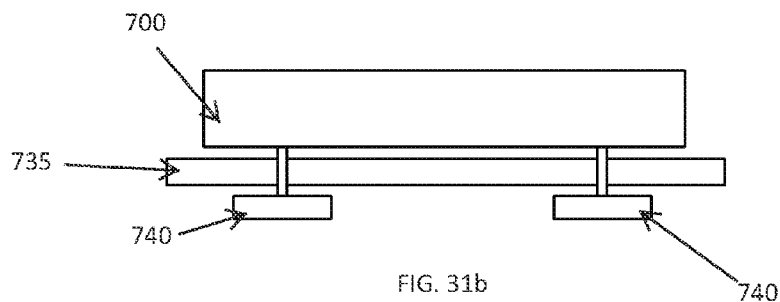
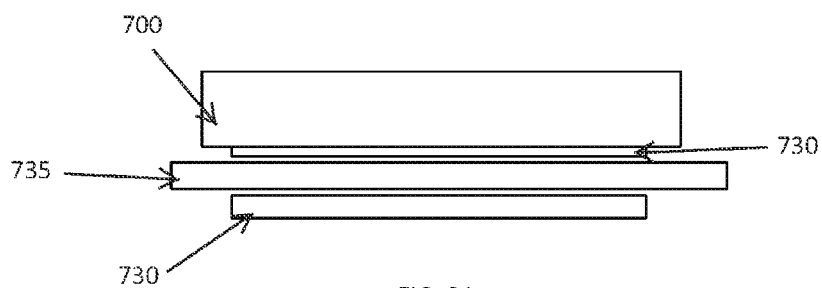
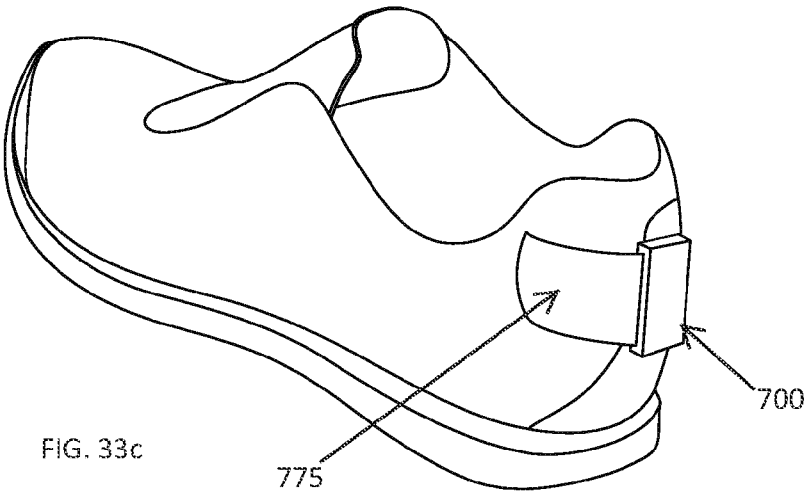
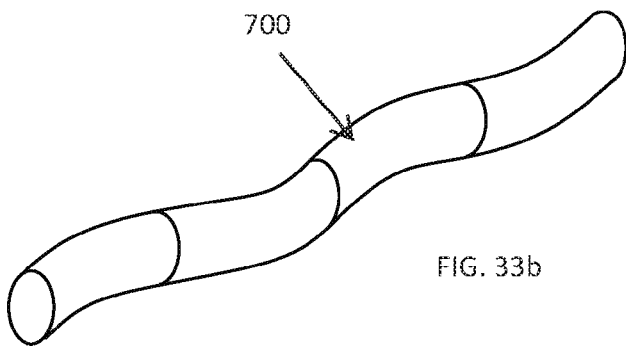
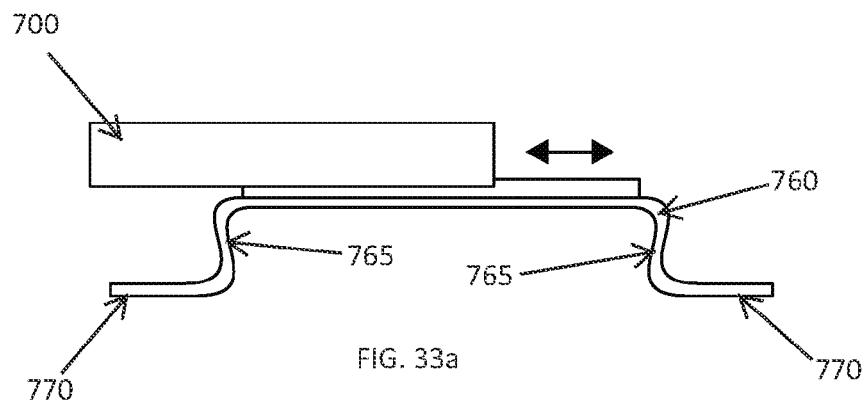


FIG. 29









## SYSTEMS AND METHODS FOR MONITORING ATHLETIC PERFORMANCE

### CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application is a continuation of U.S. patent application Ser. No. 13/368,084, filed Feb. 7, 2012, which claims priority to and the benefit of U.S. Provisional Patent Application Ser. No. 61/440,243, filed Feb. 7, 2011, the disclosure of which are incorporated herein by reference in their entirety.

### FIELD OF THE INVENTION

[0002] The present invention relates generally to the field of athletic equipment, and more particularly to systems and methods for providing training information to a runner.

### BACKGROUND OF THE INVENTION

[0003] A number of devices exist for providing a runner with basic training information. For example, systems for measuring and recording the heart rate, speed, distance, and/or stride rate of a runner using a sensor that may be clipped, for example, to workout apparel has been manufactured by adidas AG of Herzogenaurach, Germany. Similarly, Nike Inc., of Beaverton, Oreg., has produced devices that measure and record the distance and pace of a walk or run. Such devices often consist of small accelerometers attached to or embedded in a shoe, which communicate with a receiving device (e.g., a sportband or a receiver plugged into of embedded within a mobile phone). The device and receiver allow a user to track the distance, time, and pace of a training run, with the information provided to a user through audio feedback during the training run and/or recorded for later analysis. Systems also exist for measuring and recording training information such as distance, time, and pace of a training run through utilization of a mobile phone of GPS ("Global Positioning System") device without the need for a sensor in a shoe.

[0004] However, these systems only provide basic training information related, for example, to the speed and distance travelled by a runner, and cannot provide any detailed biofeedback information that may be used to improve the actual running form and technique of the runner. As a result, there still exists a need for a system and method capable of providing detailed training information to an athlete during and after a training session to assist in improving their running form.

### SUMMARY OF THE INVENTION

[0005] The present invention is directed towards novel systems, methods and devices for monitoring one or more athletic performance characteristic of a user and/or providing biofeedback information to the user to assist in training the user to run with better form and, for example, with an improved foot strike.

[0006] One aspect of the invention includes an apparatus for monitoring one or more athletic performance characteristic of a user, the apparatus including a sensing unit adapted to be attachable to a shoe of a user. The sensing unit includes a first sensor, such as a gyroscopic sensor, that is adapted to monitor a movement of a foot of the user while the user is in motion, processing means for determining a first performance characteristic of the user, such as a foot strike

location of a foot of the user upon striking a ground surface, and transmitting means for transmitting a data package representative of the performance characteristic to a remote receiver. The gyroscopic sensor may be adapted to measure an angular velocity of the foot of the user. The means for determining a performance characteristic of the user may include a microprocessor.

[0007] In one embodiment the apparatus also includes receiving means for receiving the data package transmitted from the sensing unit and communicating information representative of the performance characteristic to the user. The means for communicating information to the user may include, or consist essentially of, at least one of a visual signal, an auditory signal, and/or a tactile signal (e.g., a vibration). The information may be communicated to the user in substantially real-time and/or be stored, for example within the sensing unit and/or the receiving means, for communicating to the user at a later time and/or for further analysis.

[0008] The receiving means may include one or more remote user feedback devices, such as, but not limited to, a watch, a detachable strap, a mobile phone, an earpiece, a hand-held feedback device, a laptop computer, head-mounted feedback device (e.g., a visor or hat), and/or a desktop personal computer. Alternatively, or in addition, the receiving means may include a software application and/or hardware (e.g., a dongle) for controlling at least one function of a remote user feedback device, such as a mobile phone.

[0009] In one embodiment, the sensing unit includes a housing unit adapted to house the first sensor, the processing means, and the transmitting means. The housing unit may be adapted to be releasably attachable to a sole and/or upper of the shoe of the user, or be fixedly attached to, or embedded within, an upper and/or sole of the shoe. In one embodiment the housing unit is releasably attachable to at least one of a fastening portion (e.g., the lacing portion) of a shoe or a heel portion of the shoe.

[0010] The apparatus may include means for determining at least one second performance characteristic of the user, which can be based upon an output from the first sensor and/or be based upon an output from one or more second sensor(s). The second sensor(s) may include, or consist essentially of, one or more accelerometers, pressure sensors, force sensors, temperature sensors, chemical sensors, global positioning systems, piezoelectric sensors, rotary position sensors, gyroscopic sensors, heart-rate sensors, and/or goniometers. Other sensors, such as, but not limited to, electrocardiograph sensors, electrodermograph sensors, electroencephalograph sensors, electromyography sensors, feedback thermometer sensors, photoplethysmograph sensors, and/or pneumograph sensors may also be utilized in various embodiments of the invention. The at least one second performance characteristic may include, or consist essentially of, at least one of a cadence, a posture, a lean, a speed, a distance travelled, and/or a heart rate of the user.

[0011] In one embodiment, the processing means includes a comparison of a localized maximum angular velocity measurement and a localized minimum angular velocity measurement during a foot strike event (e.g., during a brief period immediately before, at, and/or after initial contact between a foot and the ground). For example, processing the measured data may include, or consist essentially of, dividing the localized minimum angular velocity measurement during a foot strike event by the localized maximum angular

velocity measurement during a foot strike event, and comparing the resulting calculated value with at least one predetermined comparison value to determine whether a heel strike, a midfoot strike, or a forefoot strike has occurred. Alternatively, or in addition, the processing means may include integration of measured angular velocity data during a foot strike event and comparison of the integrated positive angular velocity results and the integrated negative angular velocity results during a foot strike event.

**[0012]** Another aspect of the invention includes a method for monitoring one or more athletic performance characteristic of a user, the method including providing a sensing unit adapted to be attachable to a shoe of a user. The sensing unit may include a first sensor, such as a gyroscopic sensor, that is adapted to monitor a movement of a foot of the user while the user is in motion, processing means for determining a first performance characteristic of the user, such as a foot strike location of a foot of the user upon striking a ground surface, and transmitting means for transmitting a data package representative of the performance characteristic to a remote receiver. The method further includes providing receiving means for receiving a data package transmitted from the sensing unit and communicating information representative of the performance characteristic to the user. In one embodiment, the method allows for the communication of the information to the user in substantially real-time.

**[0013]** These and other objects, along with advantages and features of the present invention herein disclosed, will become more apparent through reference to the following description, the accompanying drawings, and the claims. Furthermore, it is to be understood that the features of the various embodiments described herein are not mutually exclusive and can exist in various combinations and permutations.

#### BRIEF DESCRIPTION OF THE DRAWINGS

**[0014]** In the drawings, like reference characters generally refer to the same parts throughout the different views. Also, the drawings are not necessarily to scale, emphasis instead generally being placed upon illustrating the principles of the invention. In the following description, various embodiments of the present invention are described with reference to the following drawings, in which:

**[0015]** FIG. 1 is a schematic perspective view of a biofeedback system as worn by a runner, in accordance with one embodiment of the invention;

**[0016]** FIG. 2 is a schematic side view of a shoe with forefoot and heel sensors embedded therein, in accordance with one embodiment of the invention;

**[0017]** FIG. 3 is a schematic side view of a shoe with a midfoot sensor embedded therein, in accordance with one embodiment of the invention;

**[0018]** FIG. 4 is a schematic side view of a shoe with a plurality of sensors embedded therein, in accordance with one embodiment of the invention;

**[0019]** FIG. 5 is a schematic plan view of a shoe with an array of sensors embedded therein, in accordance with one embodiment of the invention;

**[0020]** FIG. 6 is a schematic plan view of another shoe with an array of sensors embedded therein, in accordance with one embodiment of the invention;

**[0021]** FIG. 7 is a schematic plan view of a shoe with an sensor holding insert inserted within the sole, in accordance with one embodiment of the invention;

**[0022]** FIG. 8 is a schematic plan view of a shoe sole having midfoot and heel sensor pads, in accordance with one embodiment of the invention;

**[0023]** FIG. 9 is a schematic plan view of a shoe sole having forefoot, midfoot, and heel sensor pads, in accordance with one embodiment of the invention;

**[0024]** FIG. 10 is a schematic side view of a shoe with a sensor holding insert coupled to the shoe at a lacing portion, in accordance with one embodiment of the invention;

**[0025]** FIG. 11 is a schematic side view of a shoe with a sensor coupled to the upper, in accordance with one embodiment of the invention;

**[0026]** FIG. 12 is a schematic view of a system for providing biofeedback information for an athlete, in accordance with one embodiment of the invention;

**[0027]** FIG. 13 is a schematic view of another system for providing biofeedback information for an athlete, in accordance with one embodiment of the invention;

**[0028]** FIG. 14 is a schematic view of yet another system for providing biofeedback information for an athlete, in accordance with one embodiment of the invention;

**[0029]** FIGS. 15 to 19 are schematic views of various biofeedback systems as worn by a runner, in accordance with one embodiment of the invention;

**[0030]** FIG. 20 is a schematic perspective view of a hand held feedback device for a biofeedback system, in accordance with one embodiment of the invention;

**[0031]** FIG. 21 is a schematic side view of a sensor pod for a biofeedback system positioned on a lacing portion of a shoe, in accordance with one embodiment of the invention;

**[0032]** FIG. 22 is a perspective view of the pod of FIG. 21;

**[0033]** FIG. 23 is a schematic side view of a sensor pod for a biofeedback system positioned on a heel portion of a shoe, in accordance with one embodiment of the invention;

**[0034]** FIG. 24 is a perspective view of the pod of FIG. 23;

**[0035]** FIG. 25 is a schematic perspective view of axes of orientation for a gyroscopic sensor for a biofeedback system, in accordance with one embodiment of the invention;

**[0036]** FIG. 26 is a graph of angular velocity data from a gyroscopic sensor for a heel striking running style, in accordance with one embodiment of the invention;

**[0037]** FIG. 27 is a graph of angular velocity data from a gyroscopic sensor for a midfoot striking running style, in accordance with one embodiment of the invention;

**[0038]** FIG. 28 is a graph of data for a reset trigger for a gyroscopic sensor, in accordance with one embodiment of the invention;

**[0039]** FIG. 29 is a schematic representation of various data presentation means for foot strike location of a runner, in accordance with one embodiment of the invention;

**[0040]** FIGS. 30a to 30g are schematic views of various attachment mechanisms for a sensor pod for a biofeedback system, in accordance with one embodiment of the invention;

**[0041]** FIGS. 31a to 31b are schematic views of various attachment mechanisms for a sensor pod for a biofeedback system, in accordance with another embodiment of the invention;

**[0042]** FIGS. 32a and 32b are schematic views of various attachment mechanisms for a sensor pod for a biofeedback system, in accordance with a further embodiment of the invention; and

[0043] FIGS. 33a to 33c are schematic views of various attachment mechanisms for a sensor pod for a biofeedback system, in accordance with yet another embodiment of the invention.

#### DETAILED DESCRIPTION

[0044] The invention described herein relates generally to improved biofeedback systems, and related methods, for use in training users (e.g., runners or other athletes) to run with an improved running form or technique. The invention may be utilized by runners or other athletes of all levels of skill from professional athletes through to beginners and occasional joggers. By placing one or more sensors on the body of a runner (e.g., on or in one or more shoe and/or piece of apparel), the systems and methods described herein may be used as a coaching tool to provide substantially instantaneous feedback and coaching during athletic activity, and also store information for evaluation and further processing after the run.

[0045] Promoting better running form may be beneficial to a runner for a number of reasons such as, but not limited to, improving running efficiency (thereby increasing performance) and reducing the risk of injury. In general, coaching can be an important way to promote proper running form and keep runners injury free. However the majority of runners (including many collegiate and even some elite runners) have never been given any or significant training on how to run with proper form. As a result, many runners are unaware of problems with their running form (e.g., an improper foot strike position or a running style wherein a runner's right foot contacts the ground differently than their left foot) that may significantly affect their running efficiency and leave them more prone to injury.

[0046] The utilization of high-speed cameras during coaching may provide a runner with some feedback to assist in improving running form. However, not only do the majority of athletes not have sufficient access to professional coaching utilizing such technology to provide any substantive guidance to train them to run with an improved running form, but such coaching, even if available, can be expensive and time consuming. In addition, watching video of an athlete running does not provide instantaneous feedback that can be used by the athlete during a run. While technology has been utilized to provide some instantaneous feedback to a runner, such as the speed, distance travelled, heart rate, and calories burned during a run, the information provided by these systems does not produce biofeedback information that may be used to give a runner substantive training on proper running form. The inventions described herein address this issue by providing improved systems, and related methods, for measuring, transmitting, storing, analyzing, and/or communicating substantive biofeedback data that may be utilized instantaneously, or substantially instantaneously, to promote good running form in an athlete during and/or after a run.

[0047] Biofeedback information of use in training an athlete to run with proper running form includes, but is not limited to, foot strike position, cadence, posture, and lean information. Such information may be used to analyze a runner's technique and running traits, and identify parameters that can be adjusted by a runner during training to improve one or more performance characteristic. Good running form for an athlete may include elements such as, but not limited to, quick strides, a midfoot foot strike

location, and good posture. These elements may increase the efficiency and ease of running while reducing stresses on the runner that could result in strains and other injuries. In contrast, poor running form, which is common in untrained athletes, may include elements such as overstriding, aggressive heel-striking, and bad posture. These poor running elements may, for example, produce excessive stresses to the knee, potentially resulting in Runner's Knee/Patellofemoral Pain Syndrome or other injuries.

[0048] The posture of a runner relates to the carriage of the body of the runner during running. Good posture (generally an up-right posture) may be achieved, for example, by standing tall and running with your head up and with your gaze directed straight ahead.

[0049] The cadence of a runner (i.e., the number of foot strikes per minute) may be important in ensuring good running form. In one embodiment, a cadence of about 180 foot strikes per minute may be optimal to prevent overstriding and to ensure proper running form regardless of the pace of the runner. In alternative embodiments higher or lower cadences may be used depending, for example, on the specific physiology, age, and/or goals of the user.

[0050] The lean of a runner may be utilized to reduce the need for excessive muscle force by advantageously utilizing gravity to assist in forward motion. In one embodiment, improved lean may be achieved by utilizing a running style including a forward lean over the whole length of the body without bending at the waist and by flexing at the ankle to reduce unnecessary muscle strain caused by toeing-off.

[0051] The foot strike location (i.e., the location, on the sole of the foot, of initial impact with a ground surface during each step) can be extremely important in promoting a good running form. Runners with a midfoot striking gait distribute pressure across the foot during a running gait cycle differently than runners employing a heel striking gait. In addition, the mechanical work performed by the lower extremity of a runner using a midfoot striking gait is distributed across the joints differently than a runner employing a heel striking gait. Runners with a midfoot striking gait primarily have pressure distributed in the lateral midfoot and forefoot region of the foot at initial impact and exhibit more ankle flexion (dorsiflexion) subsequent to the initial impact. Runners with a heel striking gait primarily have pressure distributed in the lateral heel at initial impact and generally do not exhibit as much ankle flexion after impact. As a result, heel strikers tend to have larger stresses placed on their knee which can lead to injuries such as Runner's Knee/Patellofemoral Pain Syndrome. Consequently, rearfoot/heel strikers potentially have a less efficient running gait than midfoot strikers, with heel striking and overstriding often causing braking. An example shoe conducive to a midfoot striking gait is described in U.S. Patent Publication No. 2009-0145005, the disclosure of which is incorporated herein by reference in its entirety. In addition, a midfoot striking gait may provide a superior running form than a pronounced forefoot running gait (which may, for example, cause calf-strain and Achilles strain). One embodiment of the invention may include the use of one or more sensors to determine the location, on the sole of the foot, of initial impact with a ground surface during each step, and/or determine that angle of the foot with respect to the ground surface at initial impact (which may be used to determine foot strike location).

[0052] One embodiment of the invention includes a system 100 for providing biofeedback information to a runner 115 for use in improving running form. The system 100, as shown in FIG. 1, includes one or more sensors 105 attached to (e.g., embedded within, fixedly coupled to, or releasably coupled to) a portion of a shoe 110 of a runner 115 to measure one or more data conditions/performance characteristics during athletic activity (e.g., a run). The system 100 also includes one or more remote receiving systems 120 for receiving data from the sensor(s) 105 and communicating information to the runner based on an analysis of the gathered data. The analysis of the gathered data may be carried out in a processor located in the shoe 110, the remote receiving system 120, and/or a separate analyzing unit (e.g., a personal computer). One or more sensors 105 can be placed in each shoe 110 of the runner 115, or in only a single shoe 110 of the runner 115.

[0053] The sensor(s) may be integrally embedded within the shoe and, for example, within one or more portions of a sole (e.g., an outsole, midsole, or insole) of a shoe. One or more sensors may also be integrally embedded within one or more portions of an upper of a shoe. In another embodiment, one or more sensors may be releasably attachable to a portion of the sole and/or upper of a shoe. For example, a sensor unit may be adapted to clip to a portion of an upper of a shoe (e.g., an outer mesh layer of the shoe or a lacing section of the shoe), and/or be releasably attached to a portion of a sole of the shoe. The sensor(s) may be releasably attached through any appropriate attaching elements including, but not limited to, a hook and loop fastening (e.g., Velcro®), a clip, a pin, lacing, magnetic elements, and/or an adhesive.

[0054] Various sensors may be utilized to measure one or more data conditions during athletic activity. Example sensors include, but are not limited to, mechanical feedback devices (e.g., retractable pins that retract upon contact with the ground to measure and indicate a ground contact and/or a force associated therewith, or pins or other structures that provide a tactile sensation to a user during foot strike), accelerometers, piezoelectric sensors, rotary position sensors, gyroscopic sensors, temperature sensors, chemical sensors (e.g., sensors for measuring oxygen levels), GPS devices, pressure sensors (e.g., pressure transducers), force sensors (e.g., load cells, force transducers, or stress/strain sensors), and/or goniometers. Example pressure/force sensors include, but are not limited to, resistive, capacitive, impedance based, and/or piezoelectric sensors. The sensors may measure data conditions at a localized position or be strips or pads adapted to measure data conditions (e.g., pressure and/or force) over an extended area. In various embodiments other electromagnetic, mechanical, and/or optical sensors may be used in addition to, or in place of, the sensors listed above.

[0055] One or more sensors may be placed at any appropriate location on the shoe and, for example, within a forefoot portion, a midfoot portion, and/or a heel portion of a shoe sole and/or upper. In one embodiment, as shown in FIG. 2, a shoe 110 includes a forefoot sensor 105 located in a forefoot portion 117 of the shoe 110, and a heel sensor 105 located within a heel portion 122 of the shoe 110. Sensors may be placed at other locations on the shoe 110 in addition to, or in place of, the forefoot portion 117 and heel portion 122. For example, one or more midfoot sensors 105 may be located at a midfoot portion 125 of a shoe 110, as shown in

FIG. 3. The various sensors 105 may be positioned within or above a sole 130 of the shoe 110 (e.g., within a cavity in the midsole of the shoe or in an insole place within the shoe) and/or be positioned within or on an upper 135 of a shoe 110.

[0056] In one embodiment, a plurality of sensors 105 (i.e., a sensor array) are positioned at various locations along a length of the shoe 110, or a portion thereof, as shown in FIG. 4. These sensors 105 may be positioned at a number of locations substantially along a central axis 140 of the sole 130, as shown in FIG. 5, or at a number of locations along a medial side 145 and/or a lateral side 150 of the sole 130, as shown in FIG. 6. Any appropriate number of sensors 105 may be positioned at any appropriate locations over the length and width of the sole 130 of the shoe 110, with the sensors 105 embedded within, or releasably attached to, an outsole, midsole, and/or insole of the sole 130, depending upon the specific data and running traits being measured. In one embodiment, one or more of the sensors 105 may be exposed on an outer surface of the sole 130. Alternatively, or in addition, one or more of the sensors 105 may be embedded within the sole 130.

[0057] In one embodiment, one or more sensors 105 may be placed in a removable insert that may be positioned inside a shoe, for example as a removable insole or as an insert adapted to fit within a cavity or pocket formed within a portion of the shoe sole or upper (e.g., in a heel pocket or tongue pocket). For example, a shoe 110 may be formed with a sole portion 130 having a cavity 170 adapted to releasably receive an insert 175 holding one or more sensors 105 therein, as shown in FIG. 7. The cavity may include a covering portion adapted to cover and protect the insert during operation. The cavity 170, or cavities, may be placed at any location within the forefoot portion 117, midfoot portion 125, and/or heel portion 122 of the shoe 110. In various embodiments the cavity 170 may be accessed from the interior of the shoe, as shown in FIG. 7, or through an opening in an outer surface of the outsole 130 of the shoe 110.

[0058] In one embodiment, one or more sensor pads or strips may be affixed to, or embedded in, a sole 130 of a shoe 110. For example, FIG. 8 shows a sole 130 having a heel sensor pad 180 located at a heel portion 122 along a lateral side 150 of the sole 130, with a midfoot sensor pad 185 located at a midfoot portion 125 along the lateral side 150 of the sole 130. Sensor pads or strips can be positioned along a medial side, lateral side, and/or central portion of the sole, or span across a width of the shoe, or a portion thereof. For example, FIG. 9 shows a sole 130 having a midfoot sensor pad 185 located at a midfoot portion 125 along the lateral side 150 of the sole 130, but also having a heel sensor pad 190 spanning across the width of the heel portion 122 and a forefoot sensor pad 195 spanning across the width of forefoot portion 117.

[0059] In various embodiments sensor pads and/or strips may be positioned on any portion of the shoe sole. The sensor pads or strips can be embedded within an outsole, midsole, and/or insole, or be positioned between adjoining layers of the sole. Alternatively, the sensor pads or strips can be located in a removable insert (e.g., a removable insole) that can be placed into the shoe, or attached to an exterior, ground contacting, surface of the sole.

[0060] Alternatively, one or more sensors 105 may be placed within an insert 160 that may be releasably attached

to the shoe **110** at a lacing portion **165**, as shown in FIG. **10**, or on one or more portions of an upper **135** of the shoe **110**, as shown in FIG. **11**.

**[0061]** The sensors **105** may be used to measure the location and distribution of each foot strike of each foot on the ground during running and/or the force and/or pressure applied to various portions of the foot during running. The measured data may be processed to produce biofeedback information that may be used to train a runner to run with a more efficient and safer foot strike location, such as with a midfoot strike. The data may be processed and communicated to a runner instantaneously, or substantially instantaneously, to give the runner immediate feedback during a run. The data may also be stored and used to generate both mean and time dependent results after the run is completed, thereby providing a runner and/or a coach with a full analysis of the runner's performance over the course of the run.

**[0062]** The sensors **105** may also be used to measure the cadence of the runner during a run, in addition to, or instead of, the foot strike information, by recording the time between each foot strike. Again, the measured data may be processed and communicated to a runner instantaneously, or substantially instantaneously, to give the runner immediate feedback during a run and/or be stored and used to generate both mean and time dependent results after the run is completed.

**[0063]** In one example embodiment, a shoe **110** may include a sensor **105** comprising a mechanical feedback device (e.g., a pin) located in a sole of a shoe **110** and, for example at the heel portion. Data measured and transmitted from the sensor **105** can be used to determine when a runner's heel is in contact with the ground, thereby producing information that can be used to provide the runner with a better awareness of their gait.

**[0064]** One embodiment of the invention includes one or more sensors **205** positioned either in or on the upper **135** or sole **130** of a shoe **110** (as described hereinabove for the sensors **105**) to measure data that can be utilized to determine a runner's posture and/or lean during a run. For example, one or more sensors **205** (e.g., goniometers) can be fixedly embedded or releasably attached to an upper **135** of a shoe **110** to measure data that can be processed to provide biofeedback information related to a runner's posture and/or lean, as shown in FIG. **11**. The sensors **205** may operate independently from, or in concert with, sensors **105** for measuring foot strike and/or cadence. In one embodiment, the sensors **205** can communicate data to a remote receiver using the same transmitter as utilized by the sensors **105**. Alternatively, the sensors **205** may utilize a separate transmitter. In an alternative embodiment, sensors for measuring the posture and/or lean of the user may be positioned at other locations on a body of a user (e.g., on an ankle, leg, waist, arm, or chest of the user).

**[0065]** In one embodiment, one or more sensors can be embedded within, or releasably attachable to, an item of apparel wearable by a runner. Alternatively, or in addition, one or more sensors can be mounted on a strap that may be worn by a runner, or removably affixed to a portion of a runner by a skin sensitive adhesive or tape. These sensors can be used in addition to, or in place of, sensors on a shoe to provide biofeedback information related to a performance characteristic of a runner.

**[0066]** In addition to providing biofeedback information related to a runner's proper running form (e.g., foot strike, cadence, posture, and/or lean information), the systems described herein may include sensors for measuring other parameters related to a runner's performance including, but not limited to, distance, pace, time, calories burned, heart rate, breaths per minute, blood lactate level, and/or muscle activity (EMG). For example, measuring blood lactate levels may be of use in determining lactate threshold data in long-distance runners and other athletes.

**[0067]** In various embodiments, the sensors **105**, **205** may be powered by one or more battery elements coupled to the sensors **105**, **205**. The batteries may be single use, replaceable batteries or be rechargeable batteries. The rechargeable batteries may be recharged by any appropriate means. Alternatively, the sensors **105**, **205** may utilize the biomechanical action of a runner for power.

**[0068]** The sensors **105**, **205** may be coupled to one or more transmitters for transmitting measured data to a remote receiver. The transmitter may include, or consist essentially of, a wireless transmitter and, more particularly, a radio frequency transmitter and/or an infrared transmitter. For example, the transmitter may be a radio transmitter adapted to transmit short wavelength radio transmissions via Bluetooth®, Bluetooth® Low Energy, and/or ANT or ANT+ protocols. In one embodiment the system may include a transmitting system capable of transmitting over a plurality of transmission protocols, thereby allowing the device to communicate with multiple different receiving systems. The transmitter may also, in one embodiment, be capable of receiving information transmitted from a remote source. This information may be utilized, for example, to turn on/off the sensors, calibrate the sensors, and/or control one or more function of the sensing system.

**[0069]** The data measured by the sensors in or on the shoe(s) can be transmitted to a remote receiving system for recording and/or analysis. An example system **300** for providing biofeedback information including both a sensing unit **305** and a receiving/analyzing unit **310** is shown in FIG. **12**. The sensing unit **305** can include elements such as, but not limited to, one or more sensors **315**, a power source **320**, and a transmitting/receiving element **325**. The sensing unit **305** can be positioned in or on a shoe and/or piece of apparel (as described herein). The remote receiving unit **310** can include elements such as, but not limited to, a transmitting/receiving element **330** for receiving the transmitted data from the sensing unit **305**, a remote user feedback element **335** for receiving the data, a storage unit **340** for storing raw and/or analyzed data, a communication element **345** (e.g., a visual display such as a graphical user interface (GUI), an auditory communication element, and/or a tactile user interface) for communicating biofeedback information determined from the analyzed data to an athlete, and a power source **350**. The transmitting/receiving element **330** can also be used to communicate with a remote database, such as an online database for an online running/coaching community, thereby allowing biofeedback information to be transmitted to the remote database and allowing biofeedback information, training instructions, software updates, or other digital information to be transmitted from the remote database to the receiving/analyzing unit **310**.

**[0070]** Another example system **300** for providing biofeedback information is shown in FIG. **13**. In this embodiment, the sensing unit **305** additionally includes an analyz-

ing element **355** and a storage unit **360**. Including an analyzing element **355** and a storage unit **360** in the sensing unit **305** allows for initial processing of the raw data from the one or more sensors **315** to be carried out in the sensing unit **305**, with the raw and/or analyzed data stored in the storage **360** within the sensing unit **305**. As a result, only the processed data, or a small package of information representative of the processed data, need be transmitted from the sensing unit **305** to the remote user feedback element **355**, thereby reducing the quantity of information that needs to be transmitted between devices in order to provide real-time feedback to a user. This in turn reduces the drain on the power sources **320**, **350**, thereby extending the run-time and efficiency of the system **300**. In addition, storing raw and/or processed data within the sensing unit **305** allows the data to be downloaded into an analyzing device (e.g., a computer) for further processing after the run is completed, regardless of whether the data was received by a remote user feedback element **355** during the run.

[0071] The remote receiving unit **310** may, for example, be a watch, a portable media player (such as, but not limited to, an Apple Inc. iPod®), a customized receiving unit adapted to be worn by the user (e.g., attached to a detachable strap or adapted to fit in a pocket of the user's garments), a mobile phone or smart phone (such as, but not limited to, an Apple Inc. iPhone® or a Research In Motion Ltd. BlackBerry®), a portable GPS device, an earpiece, and/or an item of headgear (e.g., a hat, visor, sunglasses, etc). Alternatively, or in addition, the remote receiver may be a laptop computer, a tablet computer, a desktop personal computer, and/or an athletic training system (e.g., a treadmill). In one embodiment the transmitting/receiving element **330** can be a separate unit (for example, a dongle—i.e., a hardware or software “key” allowing two remote devices to communicate) that is adapted to plug into a smart phone or computer to allow communication between the sensing unit **305** and receiving/analyzing unit **310**.

[0072] The biofeedback information could be communicated to the runner through an auditory, optical, and/or tactile (e.g., vibratory) signal. Auditory signals can, for example, be communicated through a speaker (e.g., a small speaker within the shoe, the sensing unit, and/or receiving device) and/or in an earpiece or headphones worn by the athlete. Optical signals can, for example, be communicated through a visual display on a receiving device (e.g., a visual display on a smart phone screen) or through one or more optical transmitters such as, but not limited to, a light-emitting diode (LED) light source, coupled to the runners shoe and/or to an optical transmitter attached to a piece of apparel or strap worn by the runner. Vibratory signals may be communicated to the runner through a vibration inducing element within the receiver and/or within or attached to the shoe.

[0073] The biofeedback information generated through analysis of the measured data from the sensor(s) can be relayed back to the athlete either in any appropriate auditory form such as, but not limited to, a voice command and/or a warning signal. For example, the information may be communicated via a software generated spoken communication providing information and/or instructions to a runner (e.g., “You are now running on your heel”; “Your cadence is too low”; etc). Alternatively, or in addition, the auditory signal may include a click, beep, or other simple signal that can provide a runner with a warning if their running form does

not meet a certain requirement and/or provide a positive signal if their running form does meet the required parameters. Such simple auditory signals can also be used to provide timing information (similar to a metronome) to give a runner a target cadence during a run. In addition, or alternatively, the auditory signal may include a change in a pitch, or speed of a musical composition being played to a user depending upon the actual cadence of a user with respect to a target cadence). By providing this practically real-time feedback, the athlete is able to make quick adjustments to their gait during the run.

[0074] In various embodiments the biofeedback information may be automatically communicated to the athlete, be communicated upon prompting from the runner (e.g., by initiating a communication command in the receiver), and/or be communicated as a summarized report at set periods (e.g., at the end of a set distance or period covered the athlete could receive summarized biofeedback information relating to his/her performance over the last mile covered and/or the entire distance covered—e.g. “You spent 20% of your time on your heel over the last mile”).

[0075] One embodiment of the invention can include a system having one or more sensors that are placed inside a shoe of a runner to record foot strike. This information is converted to an auditory signal that is made through a small speaker embedded within, or attached to, the shoe of the runner. As a result, in this embodiment a separate receiving/communicating unit would not be needed to provide feedback to the runner.

[0076] In addition to, or instead of, providing real-time biofeedback information, the information may be stored by the system for later analysis by the athlete and/or a coach. This information may be used, for example, to provide an athlete with a history of their runs and their performance during each run. In one embodiment the biofeedback system merely stores data from the sensor(s) as simple raw data, with the processing and analysis of the data being performed by a processing unit upon completion of the run by downloading the raw data to the processing unit. This may be advantageous, for example, in minimizing the size, weight, and/or cost of the actual biofeedback system being carried by the athlete during a run, while still allowing for detailed analysis of the data to be communicated to the athlete and/or coach upon completion of the run.

[0077] The processed data may also be uploaded to a shared computer drive or a storage drive (e.g., a cloud computing system) for an online community, thereby allowing the information, or portions thereof, to be reviewed remotely by a coach and/or fellow athlete. In one embodiment, processing and analysis of the data transmitted from the sensors can be carried out by one or more application software programs (“Apps”) that may be downloaded onto a smart phone or other electronic device. Such “Apps” can be programmed to analyze data and present biofeedback information in any appropriate way, depending upon the specific training requirements of an athlete.

[0078] An example system **400** for monitoring one or more athletic performance characteristic of a user, providing real-time biofeedback information relating to the performance characteristic(s), and/or downloading data associated with the performance characteristic to a computer **455** is shown in FIG. 14. In this embodiment, a sensing unit **405** is adapted to be releasably or fixedly attached to a body portion of a user and, for example, a shoe of a user. The sensing unit



**405** can include one or more sensing elements (e.g., a gyroscopic sensor, an accelerometer, etc) for monitoring one or more athletic performance characteristics of the user during an athletic activity such as running. The sensing unit **405** can also include elements such as, but not limited to, one or more power sources (e.g., a rechargeable or replaceable battery), a processing/analyzing unit (e.g., a microprocessor), a memory, an RF transmitting and/or receiving unit, and/or one or more dock contacts **460** for allowing the sensing unit **405** to dock with another device. Docking with another device may, for example, allow for the transferring of measured data (raw and/or processed) from the sensing unit **405** to an analyzing device (e.g., a computer), the transmission of software applications, instructions, upgrades, or settings (e.g., firmware pushes) to the sensing unit **405** from the analyzing device, and/or the recharging of the power source of the sensing unit **405**. The dock contacts **460** may include a USB port or other appropriate port for connecting the sensing unit **405** to a receiving/analyzing device.

**[0079]** Data related to the one or more performance characteristics can be transmitted **430** from the sensing unit **405** to one or more remote real-time feedback (RTF) receiving devices **410** and/or to a remote analyzing and storing device **455** (e.g., a computer) for later analysis and long-term storage. The RTF unit **410** may be any of the devices described herein. FIG. 14 shows a system wherein a smart phone **420** and/or a watch **415** can be used to provide real-time feedback to the user. The data associated with the performance characteristic(s) of the user can be transmitted through any appropriate RF signal such as, but not limited to, Bluetooth®, Bluetooth® Low Energy, and/or ANT or ANT+ protocols. In one embodiment the RTF **410** (e.g., the smart phone **420**) can communicate directly with the sensing unit **405** without the need for any additional hardware or software. In an alternative embodiment, a dongle **450** may be used to facilitate communication between the RTF **410** and the sensing unit **405**.

**[0080]** In one embodiment, the RTF **410** can receive and analyze information from one or more sensing unit **405** and receive and analyze data from other sensors or sources in addition to the sensing unit **405** (e.g., one or more sensors embedded within or directly attached to the RTF **410** and/or one or more additional remote sensor units communicating wirelessly with the RTF **410**), thereby allowing for the simultaneous processing of information associated with multiple performance characteristics of the user. For example, the RTF **410** can include, or can communicate with, performance measuring devices such as heart-rate monitors, GPS monitors, speed/distance/time monitors, oxygen level monitors, breathing rate monitors, energy usage monitors, etc.

**[0081]** In various embodiments the RTF **410** can communicate remotely with a computer **455** or other processing/storage device (e.g., a cloud computing system) through a wireless connection, and/or dock with a docking port **460** on the processing/storage device to allow for direct communication therebetween after a run is complete. The RTF **410** may, for example, be adapted to allow for either one or two-way wireless or direct “docked” connection between the RTF **410** and the sensing unit **405**, thereby allowing the RTF **410** to download software application, instructions, upgrades, or settings to the sensing unit **405** and/or upload raw and/or processed data from the sensing unit **405** after a

run is complete. For example, the sensing unit **405** can send small data packages representative of the performance characteristic (e.g., a foot strike location of a user) to the RTF **410** wirelessly during a run, with the raw data being stored on the sensing unit **405** and downloaded to the RTF **410** and/or to a remote analyzing receiving device **455** through a physical wired connection for further processing after the user’s run is complete. The raw and/or processed data can then be stored in the RTF **410** and/or communicated **425** to an analyzing/storage device **455** or facility from the RTF **410**.

**[0082]** In one embodiment, a software application (“App”) can be provided to an RTF **410** (e.g., a smart phone **420**) to control various functions of the RTF **410** and facilitate the receiving of performance characteristic information from the sensing unit **405** and the communication of the associate performance information to the user.

**[0083]** The RTF **410** device (e.g., the smart phone **410** or the watch **415**) can communicate information to the user in a variety of ways including, but not limited to, through a visual display screen, through audio signals emitted directly from the RTF **410** or communicated to the user though a wired or wireless (e.g., Bluetooth®) headphone connection, and/or through a vibration emitted by the RTF **410**. Such information can be communicated constantly in real-time or at selected intervals. In one embodiment foot strike location information (e.g., a heel strike, a midfoot strike, or a forefoot strike) is communicated to the user, while additional performance characteristics information (e.g., cadence, heart rate, speed, distance travelled, time, etc) can be communicated at the same time, or substantially at the same time, as the foot strike information, or be communicated independently from the foot strike information.

**[0084]** The sensing unit **405** and RTF **410** may be attached to the user in various manners, depending upon the particular performance characteristics being monitored, the particular RTF **410** being used, and the particular real-time feedback being provided to the user. For example, one or more RTFs **410** can be mounted to a wrist, arm, waist, hip, shoulder, head, chest, or leg of a user **435**, or be placed in a pocket of a garment of the user **435** or in a bag carried by the user **435**. Example configurations of sensing unit **405** and RTF **410** can be seen in FIGS. 15-19. In FIGS. 15-19 the sensing unit **405** is mounted on a fastening portion of the shoe (e.g., releasably attached to the laces of a laced shoe). The biofeedback system **400** may utilize a single sensing unit **405** attached to only one foot of a user, as shown in FIGS. 15-16 and 18-19, or utilize sensing units **405** attached to both feet of the user, as shown in FIG. 17.

**[0085]** Using a sensing unit **405** on both feet allows the system **400** to accurately monitor performance characteristics such as foot strike location on both feet during a run. However, as running gait is often reasonably symmetric (i.e., it is rare for a runner to heel-strike with one foot while midfoot striking with the other foot), valuable training information and biofeedback can be obtained from the use of only one sensing unit pod **405**, with the user able to switch the foot on which the sensing unit **405** is mounted between runs (or even during a break in a run) to ensure that feedback relating to the foot strike location on both feet can be provided over time. In addition, additional performance characteristics such as cadence can be obtained through use of only a single sensing unit **405** (as the cadence will be

related to twice the number of foot strikes recorded by the sensing unit 405 on only one foot).

[0086] In the embodiment of FIG. 15, the RTF 410 is a wrist-based device 465 (e.g., a watch 415 or other appropriate RTF device such as a custom device specifically adapted to receiving information from the sensing unit 405 and communicating that information to a user) strapped to a wrist of the user 435 by a releasable strap or band 440. The wrist-based device 465 can include a visual display to provide a visual indication of the information, include a tactile device to provide a tactile sensation (e.g., a vibration) to the wrist if an event (e.g., a heel strike) occurs, and/or include a speaker to provide an auditory signal if an event (e.g., a heel strike) occurs.

[0087] The embodiment of FIG. 16 uses a smart phone 420 including a software application for controlling functionality of the smart phone 420 to allow it to act as an RTF 410. The smart phone 420 is releasably attached to the upper arm of the user 435 by a strap or band 440. As with the watch 415, the smart phone 420 can communicate information to the user 435 through a visual display, a vibration, and/or an auditory signal. For example, the smart phone 420 may output an auditory signal that may be communicated to the user 435 through a pair of headphones 445, as shown in FIG. 17. Utilizing an RTF 410 having two-way communication functionality (such as, but not limited to, a smart phone 420) allows the RTF 410 to both receive information from the sensing unit 405 and transmit information to another remote device (e.g., a computer 455) and/or back to the sensing unit 405.

[0088] In various embodiments other devices or garments may be used as an RTF 410 for receiving information from the sensing unit 405 and communicating information to the user 435. In the embodiment of FIG. 18, for example, a user 435 may wear a visor 470 that has a receiving element embedded therein or attached thereto. The receiving element may then process the data, if necessary, and communicate information to the user 435 through a visual display element 475 mounted to the visor 470. The visor can also include an auditory feedback element (e.g., a speaker or a headphone connection) and/or a vibratory feedback element in addition to, or instead of, the visual display 475.

[0089] In the embodiment of FIG. 19, the RTF 410 may include, or consist essentially of, a hand-held device 480, which can be held in a hand of a user 435 during a run. An example hand-held device 480 is shown in FIG. 20. As with other RTFs 410, the hand-held device 480 can include a variety of features such as, but not limited to, user communication elements, controls, and communication ports. As shown in FIG. 20, the hand-held device 480 can include a visual display screen 485 to provide visual information to the user 435, a headphone jack 490 to allow for auditory signals to be sent to the user 435, and a handle 495 having a vibration element held therein to provide tactile feedback to the user 435. Alternatively, or in addition, the hand-held device 480 can include one or more speakers to communicate an auditory signal to the user 435 without the need for headphones. The hand-held device 480 can also include control buttons 500 to allow the user to control one or more function of the hand-held device 480 and one or more communication ports 505 (e.g., a USB port) to allow for the downloading and uploading of information between the

hand-held device 480 and another device (e.g., a computer 455), and to provide a charging port for the hand-held device 480.

[0090] In one embodiment the sensing unit 405 includes a gyroscopic sensor that is adapted to measure an angular velocity of the shoe during athletic activity. Analysis of this angular velocity data can then be used to determine foot strike information relating to the user's running style, thereby allowing the user to be informed of whether a particular foot strike was a heel strike, a midfoot strike, or a forefoot strike. This information can be communicated to the user in real-time, at set intervals, and/or be stored in the sensing unit 405 for later analysis and processing. In addition, data from a gyroscopic sensor can be used to determine when a foot strike occurs, thereby allowing for the measurement of cadence (i.e., number of foot strikes per minute) information for the user. For example, foot strike location information (e.g., a heel strike, a midfoot strike, or a forefoot strike), cadence information, and/or other performance characteristic information can be communicated to the user upon every foot strike. Alternatively, or in addition, compiled and/or averaged performance characteristic information can be communicated to the user upon the completion of a preset or user selected number of foot strikes, upon the completion of a preset or user selected distance travelled or time travelled, upon request from the user, and/or at the end of a run.

[0091] In one embodiment, a sensing unit including a gyroscopic sensor can be releasably mounted to an upper of a shoe at a fastening portion (such as a lacing portion or hook-and-loop fastening portion) located centrally, or substantially centrally, on the top of the shoe. An example gyroscopic sensor unit 510 mounted to the lacing portion 520 of a shoe 515 is shown in FIGS. 21 and 22. Alternatively, the gyroscopic sensor unit 510 can be mounted to a heel portion 525 of a shoe 515, as shown in FIGS. 23 and 24, or to any other appropriate location on the upper or sole of the shoe 515, depending upon the shoe, the specific mounting arrangement required, and/or the measurement and calibration requirements of the sensor.

[0092] The gyroscopic sensor may be a one-axis sensor, a two-axis sensor, or even a three-axis sensor, allowing for the measurement of angular velocity ( $x'$ ,  $y'$ ,  $z'$ ) about any axis ( $X, Y, Z$ ), as shown in FIG. 25, and thereby allowing for the measurement of a variety of performance parameters associated with a foot strike. For example, careful analysis of an angular velocity measurement  $z'$  about the  $Z$ -axis allows for the identification of a foot strike location (i.e., a heel strike, a midfoot strike, or a forefoot strike) of a user during a stride, and thereby also provides information as to whether a user's foot is dorsiflexed (heel strike), plantarflexed (forefoot strike), or neutral (midfoot strike) upon impact with a ground surface. Similarly, careful analysis of an angular velocity measurement  $x'$  about the  $X$ -axis allows the system to identify whether a user's foot is pronating (wherein the ankle caves inwards towards the other foot) or supinating (wherein the ankle caves outwards away from the other foot) at impact with a ground surface. In addition, analysis of an angular velocity measurement  $y'$  about the  $Y$ -axis allows the system to identify whether a user's foot is abducting (wherein the forefoot rotates outwards away from the other foot) or adducting (wherein the forefoot rotates inwards towards the other foot) at impact with a ground surface.

**[0093]** In general, the goal of an algorithm processing raw  $z'$  angular velocity data from the gyroscopic sensor(s) is to accurately detect the direction and speed of the foot's rotation at the moment of impact with a ground surface, and to determine from this the type of foot strike (i.e., forefoot, midfoot, or heel strike) and the severity of the foot strike (e.g., severe heel strike, intermediate heel strike, mild heel strike, midfoot strike at rear of midfoot, midfoot strike at center of midfoot, midfoot strike at front of midfoot, mild forefoot strike, intermediate forefoot strike, or severe forefoot strike). An example method of calculating foot strike location information from a gyroscopic sensor reading is discussed below. In this embodiment, only data from one single-axis of a gyroscopic sensor is required to measure foot strike location and cadence.

**[0094]** The data recorded from the gyroscopic sensor may be considered to be periodic, with each gait cycle being one period. During a normal gait cycle, the foot often has a positive rotation just before the foot strike (see, for example, FIGS. 26 and 27). After the foot strike, during the stance phase of the gait, the foot is flat on the ground and is relatively motionless.

**[0095]** The foot strike occurs during a short time period (e.g., between about 10 ms to 50 ms and, for example, about 30 ms or so) between the end of the swing phase and the start of the stance phase, with the angular velocity data ( $z'$ ) about the Z-axis during that period providing information that can be analyzed to determine the type of foot strike.

**[0096]** During a heel striking event the heel touches the ground first, followed by a rapid rotation of the foot forwards until the sole is flat against the ground. As a result, a large positive rotational velocity during a foot strike event, accompanied by little or no negative rotational velocity, is measured for a heel strike. In contrast, midfoot striking is indicated by a smaller positive rotational velocity followed by a clearly defined negative rotational velocity, while a forefoot strike shows a larger negative velocity than that observed for a midfoot strike. Thus, there is a clear qualitative difference in the gyroscopic sensor data about the Z-axis between heel striking and forefoot/midfoot striking. It is often found that the maximum localized rotational velocity occurs close to, but slightly after, the initial impact during a foot strike event.

**[0097]** In one embodiment, raw data from the gyroscopic sensor can be analyzed to determine foot strike location for a foot strike event. In an alternative embodiment, pre-processing of the data (for example through amplification and/ or low-pass, high-pass, band-pass, band-stop, and/or Butterworth filtering) may be carried out prior to analyzing the data to determine foot strike information. The sample rate of the gyroscopic sensor can also be set at any appropriate rate to ensure that the sample rate is sufficient to obtain accurate information without sampling at a rate that would draw too much power and/or take up too much storage space. The sample rate may be set, for example, at between 500 to 5000 Hz or between 500 and 2000 Hz or, more particularly, between 800 and 1500 Hz and, for example, at about 900 Hz. In one embodiment, a sample rate of about 900 Hz may be set to ensure that at least about 300 samples are taken per stride.

**[0098]** Example gyroscopic sensor data for a heel strike is shown in FIG. 26, while example raw gyroscopic sensor data for a midfoot strike is shown in FIG. 27. Three foot strike events are shown in each graph. As shown, the

midfoot strike exhibits a positive spike **550** followed by a negative spike **555**, with the negative component showing that the foot is rotating "backwards" (i.e., the heel is coming down relative to the toe) after initial impact. Conversely, the heel strike has a positive spike **550** but does not have a negative component (i.e., the local minimum **575** is never less than zero), showing that the foot is rotating "forwards" (i.e., the toe is moving down relative to the heel). A forefoot strike is characterized by having a small positive peak **550** relative to the negative peak **555**, showing that the foot is rotating backwards more severely than for a midfoot strike. Cadence can be determined simply by counting the number of foot strike events over a specified time.

**[0099]** In one embodiment, a microprocessor analyzes each angular velocity sample from the gyroscopic sensor and determines whether or not a foot strike has occurred. To find the moment of foot strike, the microprocessor first needs to distinguish one stride from another with a periodic trigger, as shown in FIG. 28. When the foot is swinging forward, the toe is moving up and the rotational velocity is negative. When the rotational velocity is negative, the microprocessor adds each sample to a sum. When the sum reaches a preset level, a flag is set and the sum resets **560**. This happens once for each stride, just before the moment of the foot strike. After the flag is set, the microprocessor starts looking for a maximum value **550**. Once found, it finds the minimum value **555** within a set window. It is the ratio of this maximum and minimum value that determines the rating for the foot strike.

**[0100]** The window during which the maximum and minimum angular velocity measurements are taken for the foot strike location analysis may be set to any appropriate size and starting point to ensure that the required maximum and minimum peaks are captured without additional, non-relevant, data contaminating the calculation. For example, the window may be set to capture and analyze data starting at, and/or ending at, a particular identifying event during the periodic data cycle or a specific time period or specific number of samples prior to or after a particular identifying event during the periodic data cycle, and/or be set to cover a specific time period or a specific number of samples from a set starting point, as appropriate.

**[0101]** In one embodiment the window may begin from the moment of initial impact, or the moment of the first local maximum angular velocity after the initial impact, and continue until a point at or after a first local minimum angular velocity measurement is observed. Alternatively, the window may be set to review data captured within a specific time window (e.g., between 10 ms to 50 ms and, for example, about 30 ms) or sample size starting at the moment of initial impact, or at the moment of the first maximum rotational value peak after initial impact, or at any other appropriate time prior to, at, or after the instant of initial impact. In another embodiment, the window for analysis may open at the time at which the angular velocity is zero prior to initial impact, and close at the time at which the angular velocity transitions from negative to positive after the local minimum angular velocity is observed.

**[0102]** In one embodiment, a determination of the foot strike location can be calculated by comparing the maximum value with the minimum value within the sample window in accordance with the following equation:

$$\text{Foot strike Location Rating (F)} = \frac{(\text{Local Minimum value} * 100) / \text{Local Maximum Value}}{100}$$

The results of this calculation produce a non-dimensional value from  $F_{min}$  to  $F_{max}$  (for example, a value of between  $F_{min}=0$  and  $F_{max}=100$ ), with  $F_{min}$  indicating a severe heel strike,  $F_{max}$  indicating a severe forefoot strike, and values in the middle of the range indicating a midfoot strike. The specific values identifying each range may, for one example user, be:

$X_1$  to  $X_2$ =heel strike (with “ $X_1$ ” indicating a severe heel strike and values closer to  $X_2$  indicating a more mild heel strike)  
 $X_2$  to  $X_3$ =midfoot strike

$X_3$  to  $X_4$ =forefoot strike (with “ $X_4$ ” indicating a severe forefoot strike and values closer to  $X_3$  indicating a more mild forefoot strike)

**[0103]** The values for  $X_3$  and  $X_4$  may be either preset or be calibrated and/or selected to ensure accuracy for a specific user. Example ranges for the values of  $X_2$  may be about 15-40 or, more particularly, about 20-30 or 20-25 or, more particularly, about 20. Example ranges for the values of  $X_3$  may be about 60-80 or, more particularly, about 65-75 or 65-70 or, more particularly, about 70.

**[0104]** Additional processing may be carried out to provide accurate foot strike position information, if appropriate. For example, a Gaussian multiplier or other appropriate  $2^{nd}$  order multiplier may be applied to assist in analyzing the results. Additionally, or in the alternative, results outside a set results window (e.g., outside the ranges  $F_{min}$  to  $F_{max}$ ) may be either discarded or shifted to a preset default value. For example, any result greater than  $F_{max}$  can either be shifted to indicate a value “ $F_{max}$ ” or be discarded entirely.

**[0105]** In an alternative embodiment, a ratio of the integral of the negative portion of the curve **565** against the integral of the positive portion of the curve **570** (i.e., from calculations of the area under the negative portion of the curve **565** and the positive portion of the curve **570**) may be utilized to produce the foot strike location rating, rather than ratios of the absolute values of the minimum and maximum local peaks. The data to be integrated may be taken over any appropriate window size. Utilization of integrated results may be useful, for example, in producing accurate readings in situations where the sample rate of the gyroscopic sensor is insufficient to ensure that accurate local maximum and minimum peak values can be obtained. In addition, the integral of rotational velocity relates to a change in angle of the foot, which may produce valuable performance characteristic information relating to the foot strike of a user. Where beneficial, various other embodiments may utilize other appropriate algorithms for processing the data to determine the foot strike information.

**[0106]** In one embodiment, the sensor unit may be set to go into a “sleep-mode” (i.e., a reduced power consumption mode) during periods of inactivity. This sleep-mode may be set to turn on (when a sensor remains at rest for a given period) and off (when the sensor is moved) automatically. Alternatively, or in addition, the sensor unit may include a user interface (e.g., a hardware switch or a software “switch” initiated by a wireless signal from an RTF) allowing a user to turn the power to the sensor on and off manually.

**[0107]** In one embodiment, the gyroscopic sensor takes data continuously throughout an entire gait cycle. However, in an alternative embodiment, the gyroscopic sensor can be turned on and off during a gait cycle so that it only takes data during the foot strike event phase of the gait cycle. This may, for example, reduce power consumption by the sensor unit and/or reduce the amount of raw data being stored and/or

processed by the sensor unit. For example, a separate sensor (e.g., an accelerometer) may be used in the sensor unit in addition to the gyroscopic sensor, with the accelerometer being used to indicate when a foot strike event is taking place and the gyroscopic sensor only capturing angular velocity data upon triggering by the system when the accelerometer data indicates that a foot strike event is occurring. Additionally, or alternatively, the accelerometer data may be used to calculate the cadence information (with the gyroscopic sensor data only being used for foot strike location calculations), and/or the accelerometer may be used to determine whether a user is standing still, walking, or running, with the gyroscopic sensor only being activated when the user is running. The accelerometer can, for example, determine whether a foot strike event is a walking foot strike or running foot strike based on the magnitude of the acceleration measured at impact (with, for example, a running foot strike indicated by a higher magnitude acceleration measurement).

**[0108]** The performance characteristic information (e.g., the foot strike location information) can be processed and communicated to the user in a number of ways. For example, in one embodiment, as shown in FIG. **29(A)**, the raw data can be processed to produce a foot strike location rating value of between  $F_{min}$  and  $F_{max}$  (e.g., between 0 and 100), with that value being stored and communicated to the user. In this example, the user would be provided with an accurate calculation of exactly where on the foot the center of the initial foot strike impact occurred, with a further indication of whether this value represented a heel strike, a midfoot strike, or a forefoot strike being calculated based on the set values for  $X_2$  and  $X_3$ .

**[0109]** In one embodiment, as shown in FIG. **29(B)**, the foot strike location rating value can be placed into one of a number of “bins”, with the system communicating to the user which bin a particular foot strike (or an average foot strike) fell. In the embodiment of FIG. **29(B)** the foot strike information is divided into nine bins (severe heel strike **605**, intermediate heel strike **610**, mild heel strike **615**, midfoot strike at rear of midfoot **620**, midfoot strike at center of midfoot **625**, midfoot strike at front of midfoot **630**, mild forefoot strike **635**, intermediate forefoot strike **640**, or severe forefoot strike **645**), although a greater or lesser number of bins may be used where appropriate. In a further alternative embodiment, the foot strike location rating value can be used to merely indicate whether a heel strike **650**, a midfoot strike **655**, or a forefoot strike **660** has occurred, as shown in FIG. **29(C)**.

**[0110]** By performing the analysis described hereinabove with a microprocessor within the sensor unit the performance characteristic data transmitted to a receiving unit can be limited to merely a small package or data representing the foot strike location rating value or the appropriate “bin” into which a given value falls. The cadence information can also be transmitted along with the foot strike information, or may be determined inherently from the time at which each foot strike value is transmitted. Minimizing the data that needs to be sent from the sensing unit to the RTF can reduce the power required by the system and thereby extend the running time of the system.

**[0111]** In various embodiments this information may be communicated to the user through a visual signal, an auditory signal, and/or a tactile signal. For example, an RTF could generate a sound (e.g., a buzz), cause a vibration,

and/or flash a visual indicator only when a certain event occurs (e.g., a heel strike). Alternatively, different sounds, visual signals, and/or vibrations could be assigned to different events, thereby providing a different indicator to the user depending upon the event occurring. The severity of an event (e.g., a severe, intermediate, or mild heel strike) may be indicated, for example, by different sounds or by changes in the volume, pitch, tone, or other acoustic parameter of a given sound. Similarly, variations in the intensity or color and/or variations in the intensity of a vibration can be used to differentiate between different severities of a given foot strike event. In one embodiment the auditory, visual, and/or tactile signals associated with a specific foot strike position may be preset, or be selected by the user depending upon his/her particular preferences and the functionality of the RTF being used.

[0112] The sensing unit can, in one embodiment, include a housing unit adapted to house the sensor, a power source, a processor, and/or a transmitter. The housing unit may, for example, provide a protective casing for the sensor and other electronics and/or provide a mounting means by which the sensor can be mounted to the shoe of the user. The housing unit may be adapted to be releasably attachable to a sole and/or upper of the shoe of the user, or be fixedly attached to, or embedded within an upper and/or sole of the shoe. In one embodiment the housing unit is releasably attachable to at least one of a fastening portion (e.g., the lacing portion or a hook-and-loop fastening portion) of a shoe or a heel portion of the shoe. The housing unit may have an integrated mounting element for mounting the device to a shoe. Alternatively, the housing unit and mounting unit may be separate, attachable, elements that can be coupled together to mount the sensor package to the shoe. Example housing units 700 and mounting elements 705 are shown in FIGS. 30a to 33c.

[0113] The embodiment shown in FIG. 30a includes a housing unit 700 that is either fixedly or detachably attached to an elastic or inelastic mounting element 705 that includes hooked ends 710 for engaging the laces of a shoe. FIG. 30b includes a housing unit 700 having a plurality of elastic or inelastic hooks 715 extending from the housing unit 700 for engaging the laces or the eyelets of a shoe. FIG. 30c includes a housing unit 700 having a flexible or inflexible base unit 720 that can be placed under the laces of a shoe and be fixedly or detachably connected to the housing unit 700.

[0114] FIGS. 30d and 30e include a flexible or inflexible base unit 725 that can be slid over the heel of a shoe or slid into a pocket on the heel of the shoe (as shown in FIG. 30d), or slid under the laces of a shoe (as shown in FIG. 30e). The base unit 725 may include pins for pinning the base unit 725 into one or more layers of the upper the shoe. Again, the base unit 725 can be fixedly or detachably attached to the housing unit 700. FIGS. 30f and 30g show a similar configuration but with a latching element 730 allowing the end of the base unit 725 to latch onto the housing unit 700 to lock it in place when mounted to the shoe.

[0115] In one embodiment, as shown in FIG. 31a, magnetic elements 730 can be used to releasably attach a housing unit 700 to the upper of a shoe 735, while in FIG. 31b pins 740 may be inserted through the upper of the shoe 735 to releasably or fixedly hold the housing unit 700 thereto. In another embodiment a detachable mounting unit 745 having a plurality of latching elements 750 can be placed below the laces 755 of a shoe, as shown in FIGS. 32a and 32b, thereby

allowing the housing unit 700 to be detachably mounted to the lacing portion of the shoe.

[0116] In one embodiment, as shown in FIG. 33a, a housing unit 700 can be slideably connectable with a mounting unit 760. The mounting unit 760 may include flexible arms 765, that can be pinched in to allow the ends 770 of the arms 765 to be hooked under the laces of the shoe or the sides of the lacing portion of the upper of the shoe. The arms 765 may alternatively be fixedly mounted to the housing unit 700. In another embodiment, as shown in FIG. 33b, the housing unit 700 may be formed from a flexible elongate length of material with the sensor, a power source, a processor, and/or a transmitter held within. This flexible housing could, for example, be slid below the laces and held in place by the closing force applied by the laces to the shoe. In yet another embodiment a housing unit 700 may be releasably or fixedly mounted to a clip 775 that can be clipped onto the upper of a shoe at a heel portion (as shown in FIG. 33c) or over a lacing portion of a shoe, or be attached to the upper of a shoe through an adhesive attachment, a hook-and-loop attachment, a pinned attachment, or any other appropriate attachment means.

[0117] In one embodiment data from a gyroscopic sensor coupled, for example, to an upper body of a user can be used to provide posture and/or lean information during a run. For example, a gyroscopic sensor in a smart phone or other RTF strapped to the upper body of the user (e.g., on the torso or upper arm of the user) can be used to measure posture and/or lean information that can be coupled with the foot strike and cadence information to provide the runner with a more complete analysis of their running form. The smart phone may then act as both a sensor unit and an RTF. In one embodiment, the user can calibrate the gyroscopic sensor within the smart phone or other RTF prior to use, for example by simply strapping the smart phone to their person and then standing upright (e.g., against a wall) to “zero” the sensor prior to the run.

[0118] In one embodiment, the foot strike position information may be supported by GPS data, or other appropriate data, that can be used to determine the altitude, and more particularly the change in altitude, of the user for a particular foot strike. More particularly, the altitude data can be used to determine whether a runner was running on a flat or substantially flat stretch of ground, or was running uphill or downhill, for each foot strike. This may be beneficial in providing context for each foot strike to ensure that accurate data and instructions are communicated to the runner, as even runners with good running form will tend to heel strike when running down a substantial incline and forefoot strike when running up a substantial incline.

[0119] In one embodiment, a shoe may have one or more control elements embedded therein to adjust an element of the shoe. For example, control elements may be embedded in the sole of a shoe to adjust a stiffness, flexibility, and/or thickness of the sole in response to a signal received from a remote source. As such, a biofeedback system can be adapted to send biofeedback information measured by one or more sensors in a shoe to a remote receiver, analyze the data to determine one or more performance characteristic of the runner during a run, and send a control signal to control elements in the shoe to adjust a characteristic of the shoe to compensate for shortcomings in the runners technique and/or to assist in training the runner to run with proper form. In an alternative embodiment the analyzing and controlling

steps may be carried out by a control element embedded within, or attached to, the shoe, without the need for a remote receiver.

**[0120]** While the discussions hereinabove relate to the use of sensors to measure and provide feedback relating to a runner's form during jogging or running, in alternative embodiments the systems and methods described herein may be used to measure one or more performance characteristics related to athletic activities other than running. For example, the systems and methods described herein may be useful for training purposes in sports that require an athlete to make rapid changes of direction (e.g., soccer, football, basketball, baseball, softball, tennis, squash, badminton, volleyball, lacrosse, field hockey, ultimate Frisbee, etc), where analysis of the athlete's foot striking during a turn or "cut" may provide valuable performance information. Similarly, sports that require good jumping form when jumping (e.g., hurdling, basketball, volleyball, etc) may also benefit from devices and methods that provide accurate information relating to the position of the athlete's foot during push off and/or landing. In addition, devices that provide accurate information about the position and rotation of the feet of a user may provide valuable training information for a golfer during a swing, for a bowler during a throwing action, for a baseball pitcher during a throw, or for other athletic motions requiring a high degree of repeatability.

**[0121]** It should be understood that alternative embodiments, and/or materials used in the construction of embodiments, or alternative embodiments, are applicable to all other embodiments described herein.

**[0122]** The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments, therefore, are to be considered in all respects illustrative rather than limiting the invention described herein. Scope of the invention is thus indicated by the appended claims, rather than by the foregoing description, and all changes that come within the meaning and range of equivalency of the claims are intended to be embraced therein.

What is claimed is:

**1-23.** (canceled)

**24.** A system for monitoring at least one athletic performance characteristic of a user, the system comprising:

at least one first sensing unit adapted to be at least one of releasably attachable to, fixedly attachable to, and embeddable in a shoe worn by the user during an athletic activity;

at least one second sensing unit adapted to be positionable on an upper body of the user; and

a processor in communication with each first sensing unit and each second sensing unit,

wherein the athletic performance characteristic comprises at least one of a posture and a body lean of the user during the athletic activity, and

wherein the processor is adapted to process data from each of the first sensing unit and the second sensing unit to evaluate the at least one athletic performance characteristic of the user.

**25.** The system of claim **24** further comprising a transmitter for communicating data to the processor via a remote receiver.

**26.** The system of claim **24**, wherein each second sensing unit is at least one of positionable on and removably affixed to at least one of a wrist, an arm, and a chest of the user.

**27.** The system of claim **25**, wherein each second sensing unit is removably affixed to the user by at least one of an adhesive, a tape, a skin sensitive adhesive, and a skin sensitive tape.

**28.** The system of claim **24**, wherein each second sensing unit is at least one of embeddable within, releasably attachable to, and removable placed into an item of apparel wearable by the user.

**29.** The system of claim **24**, wherein each second sensing unit is mounted on a strap wearable by the user.

**30.** The system of claim **24**, wherein each of the first sensing unit and the second sensing unit is selected from the group consisting of: a mechanical feedback device, an accelerometer, a pressure sensor, a force sensor, a global positioning system, a piezoelectric sensor, a rotary position sensor, a gyroscopic sensor, a goniometer, and combinations thereof.

**31.** The system of claim **24**, wherein the athletic performance characteristic further comprises at least one of a cadence and a foot strike of the user.

**32.** The system of claim **24**, wherein the first sensing unit is adapted to sense at least one of the cadence and the foot strike of the user and the second sensing unit is adapted to sense at least one of a posture and body lean information.

**33.** A method for monitoring at least one athletic performance characteristic of a user during an athletic activity, the method comprising:

sensing, by at least one first sensing unit adapted to be at least one of attachable to and embedded in a shoe worn by the user, at least one of location, movement, and placement of a foot of the user during the athletic activity;

sensing, by at least one second sensing unit adapted to be positionable on an upper body of the user, an attitude of the user during the athletic activity;

evaluating, using sensed information, each athletic performance characteristic; and

identifying, based on each evaluated athletic performance characteristic, at least one parameter that can be adjusted by the user during future athletic activity.

**34.** The method of claim **33**, wherein the attitude comprises at least one of a posture and a body lean of the user during the athletic activity, wherein identifying at least one parameter comprises:

evaluating, by a processor receiving information from each of the first sensing unit and the second sensing unit, at least one of the posture and the body lean of the user.

**35.** The method of claim **33**, wherein evaluating each athletic performance characteristic comprises determining whether the user's upper body carriage is up-right.

**36.** The method of claim **35**, wherein the at least one identified parameter is selected from the group consisting of standing tall, running with the user's head up, and directing the user's gaze straight ahead.

**37.** The method of claim **33**, wherein evaluating each athletic performance characteristic comprises determining a state of the user's body lean.

**38.** The method of claim **37**, wherein the at least one identified parameter comprises at least one of a forward lean over an entire length of the user's upper body and an angle of bend at the user's waist.

**39.** The method of claim **38**, wherein the at least one identified parameter further comprises a flex at at least one of the user's ankles.

**40.** The method of claim **33**, wherein at least one sensing step comprises transmitting sensed information to a processor for evaluation.

**41.** The method of claim **40**, wherein transmitting comprises communicating sensed information to the processor via a remote receiver.

**42.** The method of claim **33** further comprising communicating biofeedback information as to each evaluated athletic performance characteristic to the user.

**43.** The method of claim **42**, wherein communicating biofeedback information comprises communicating with the user using at least one of an auditory, an optical, a haptic, and a tactile signal.

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