(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) **World Intellectual Property Organization**
International Bureau

(43) **International Publication Date**
6 May 2010 (06.05.2010)

PCT

(10) **International Publication Number**
WO 2010/049725 A2

(51) **International Patent Classification**:
A43B 13/14 (2006.01) *A43B 13/22* (2006.01)

(21) **International Application Number**:
PCT/GB2009/051440

(22) **International Filing Date**:
26 October 2009 (26.10.2009)

(25) **Filing Language**: English

(26) **Publication Language**: English

(30) **Priority Data**:
0819840.0 29 October 2008 (29.10.2008) GB

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

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

Declarations under Rule 4.17:

— *of inventorship (Rule 4.17(iv))*

Published:

— *without international search report and to be republished upon receipt of that report (Rule 48.2(g))*

(54) **Title**: IMPROVEMENTS IN OR RELATING TO FOOTWEAR

(57) **Abstract**: The application provides a shoe comprising a solepiece having a ground engaging bottom surface and a top surface on which a wearer's foot is received,wherein the solepiece has differential resistance to longitudinal flexing in a direction along or parallel to at least part of the length of the metatarsal break of the wearers foot, and wherein either: (i) the resistance to longitudinal flexing is relatively lower at the lateral side of the metatarsal break and relatively higher at the medial side of the metatarsal break, (ii) the resistance to longitudinal flexing is relatively lower when the wearers speed of motion relative to the ground is below a predetermined speed and relatively higher when the wearers speed of motion relative to the ground is at or above the predetermined speed, or (iii) the resistance to longitudinal flexing has a first value at the lateral side of the metatarsal break and a second value which is higher than the first value at the medial side of the metatarsal break, when the wearers speed of motion relative to the ground is below a predetermined speed, and the resistance to longitudinal flexing at the lateral side of the metatarsal break has a third value which is higher than the first value and has a fourth value which is higher than the second value at the medial side of the metatarsal break, when the wearers speed of motion relative to the ground is greater than a predetermined speed.

Improvements in or relating to footwear

The present invention relates to footwear, in particular to footwear having differential resistance to longitudinal flexing in the region proximate to the metatarsal break of the wearer.

A typical shoe represents a combination of many elements that have specific functions. These various elements must work together for the support and protection of the foot during various activities, for instance walking or athletic activity. A shoe is divided into two general parts, an upper and a sole.

The upper is designed to snugly and comfortably enclose the foot. Typically, the upper of an athletic shoe will have several layers, for instance a weather resistant outer layer, an inner liner for foot comfort and perhaps an intermediate layer of a synthetic foam material. The layers of the upper may be fastened together by stitching, cementing, or a combination of these. In areas of maximum wear or stress, reinforcements of leather and/or hard-wearing synthetic material can be attached to the upper.

The sole of a shoe also often has a multilayered construction, typically with an outsole, a midsole and an insole. The outsole represents the ground engaging bottom surface and is usually very durable. The midsole ordinarily forms the middle layer of the sole and is often designed to attenuate and dampen impact energy and distribute pressure placed upon the foot during athletic activities. The insole is usually a thin, padded member located above the midsole for the wearer’s comfort.

The shoes worn can affect performance of the wearer and contribute to overall success in athletic activities, with a shoe configured for one athletic activity often not suitable for use in another athletic activity. In part this is due to biophysical requirements of the human foot during the gait cycle, with specific requirements for different activities.

For instance, the human foot contains metatarsals and phalanges, which are separated at the metatarsophalangeal joints (MPJs), collectively known as the metatarsal break Bosjen-Møller (1978) (Bosjen-Møller F., The Human Foot, A Two Speed Construction). In International Series of Biomechanics VI (Eds, Asmussen, E. and Jorgensen, K.) University Park Press. Baltimore, pp. 261-266, (1978)) determined that push off of the human gait cycle can be performed about a transverse axis through the MPJs of the first and second toes or about an oblique axis through the MPJs of the second to fifth toes. The transverse and oblique axes are used for high-gear and low-gear push off respectively. It is therefore known that athletic footwear requires flexibility in the region proximate to the MPJs of the wearer.

With regards to footwear there is some early evidence which suggests that footwear with high levels of longitudinal bending stiffness affect the high and low-gear functionality of the foot. Thus there have been various attempts to reduce the longitudinal bending stiffness of footwear in the region of metatarsal break, illustrated, for example, in US 4,262,435, WO 99/48397 or US 4,562,651.

US 4,262,435 and its divisional US 4,354,319 recognise the need for an athletic shoe with enhanced flexibility around the two axes of the metatarsal break. They disclose a solepiece with a flexure break segment that has a reduced thickness, with the segment traversing a course which underlies and substantially follows the MPJ line of the human foot, thereby allowing transverse flexing of the solepiece along the joint line. The flexibility of the sole piece is enhanced along the length of the reduced thickness break segment. However, a resistance point is created where the two segments of the break are joined in the interior area of the sole. Thus, while these patents recognize the desirability of enhancing the flexibility of a sole piece to accommodate the natural motions of the foot, the particular technique disclosed in the patent provides for greater stiffness and less flexibility in the interior region where the two segments join.

WO 99/48397 also recognises the need enhanced flexibility in an area corresponding to the MPJs, specifically for lasted footwear. It provides this by introducing a zone of weakness extending generally transversely with respect to the last board along a curve extending through locations generally corresponding to the five MPJs of the foot of a wearer. This zone of weakness provides greater flexibility of the footwear, for easier articulation of the metatarsals relative to the phalanges of the foot, but there is no differential flexibility revealed across the metatarsal break.

Another arrangement for providing enhanced flexibility in the region of the MPJs is disclosed in US 4,562,651, which provides footwear with a sole having flex grooves in a V-orientation. The sole exemplified in US 4,562,651 includes a first flex groove along a first line extending substantially parallel to a medial metatarsal-phalanges line which extends between the first and second MPJs and a second flex groove for enhancing the flexibility of the material along a second line extending substantially parallel to a lateral metatarsal-phalanges line which extends along the second through fifth MPJs. The first and second flex means join one another at the medial edge of the sole. The maximum flexibility in this design is provided at the point of the V, that is in the region adjacent to the first MPJ.

US 7,096,605 provides an article of footwear intended for both cycling and running. The sole of the footwear includes a midsole plate with a lateral fork member and a medial fork member configured to provide flexibility to the phalanges bones during ground engaging actions. The midsole plate can be designed so that the fork members have a stiffness which is less than the stiffness of the metatarsal portion or the midfoot portion of the midsole plate, but there is no mention of differential stiffness between the lateral and midsole forks. Furthermore, as illustrated in figure 7 of US 7,096,605, it is a feature of the design that the phalanges of the second toe are located over a voided section of the midsole plate not supported by either of the fork members. This is necessary to allow independent flexing of the lateral and medial fork members, but would provide greater flexibility at the second MPJ compared to the other MPJs.

The foot has different requirements for high gear and low gear motion, as identified by Bosjen-Møller (1978). Existing footwear suffer from various limitations in flexibility and stiffness. There is thus a need for an athletic shoe that provides an improved interaction between the foot of the wearer and the shoe at different speeds of motion. Ideally, the shoe should provide support that complements the biomechanical requirements of the foot at these different speeds of motion.

It is also an aim of the present invention to provide a shoe that assists the natural motion of the foot at different speeds of motion and during acceleration and deceleration.

According to the present invention, there is provided a shoe comprising a solepiece having a ground engaging bottom surface and a top surface on which the wearer's foot is received, wherein

the solepiece has differential resistance to longitudinal flexing in a direction along or parallel to at least part of the length of the metatarsal break of the wearer's foot, and wherein either:

(i) the resistance to longitudinal flexing is relatively lower at the lateral side of the metatarsal break and relatively higher at the medial side of the metatarsal break,

(ii) the resistance to longitudinal flexing is relatively lower when the wearer's speed of motion relative to the ground is below a predetermined speed and relatively higher when the wearer's speed of motion relative to the ground is at or above the predetermined speed, or

(iii) the resistance to longitudinal flexing has a first value at the lateral side of the metatarsal break and a second value which is higher than the first value at the medial side of the metatarsal break, when the wearer's speed of motion relative to the ground is below a predetermined speed, and the resistance to longitudinal flexing at the lateral side of the metatarsal break has a third value which is higher than the first value and has a fourth value which is higher than the second value at the medial side of the metatarsal break, when the wearer's speed of motion relative to the ground is greater than a predetermined speed.

The region of the shoe in which the differential flexing is intended to be effective is in the region which lies within 20% relative to the length of the sole either side of the metatarsal break of the wearer's foot. Normally, the metatarsal break starts on the medial side of the foot, at a point approximately 60 to 80% along the length of the solepiece from the rear of the solepiece. It is also possible that differential flexing is effective over the whole length of the sole and specifically including the region of the metatarsal break.

In one embodiment, the predetermined speed is at least 1.5 ms^{-1}, preferably at least 2 ms^{-1}, more preferably at least 3 ms^{-1}, even more preferably at least 4 ms^{-1}, still more preferably at least 5 ms^{-1}, further preferably at least 7 ms^{-1}.

In an embodiment the resistance to longitudinal flexing in a direction along or parallel to at least part of the metatarsal break increases linearly as the speed of motion of the wearer increases relative to the ground.

In another embodiment the resistance to longitudinal flexing in a direction along or parallel to at least part of the metatarsal break increases non-linearly as the speed of motion of the wearer increases relative to the ground.

In an embodiment the solepiece includes one or more voids extending from the medial to lateral side of the solepiece in a direction along or parallel to at least part of the metatarsal break. The voids are normally present in the ground engaging surface. Such a void or voids may, for example, be in the form of a groove, or in the form of a geometric shape, for instance a circular cutout. The voids are thus exposed to view. Equally, however, the voids could be internalised within the sole and thus hidden from view.

In a further embodiment at least one void has varying width from the medial to the lateral side of the solepiece, with a wider portion on the lateral side and a narrower portion on the medial side, optionally wherein the width increases gradually from the medial to the lateral side.

In a further embodiment at least one void has varying depth from the medial to the lateral side of the solepiece, with a deeper portion on the lateral side and a shallower portion on the medial side, optionally wherein the depth increases gradually from the medial to the lateral side.

In another embodiment at least one void further comprises baffles that interrupt the void, optionally wherein more than one void further comprises such baffles. The baffles may partially or completely fill the at least one void, so as to sit in line with the bottom surface of the solepiece.

In one embodiment the voids comprise a series of discrete voids located in the region of the MPJs of a wearer.

In another embodiment the at least one void comprises a primary void in communication with one or more secondary voids, where the secondary voids extend outwards from the primary void. The arrangement of the secondary voids around the primary void may be symmetric, for example the arrangement may form a herringbone pattern. The arrangement of the secondary voids around the primary void may also be asymmetric.

In an embodiment the least one void comprises one or more enlarged regions, in which the width and/or depth of the void is greater than in the parts of the void in the area immediately surrounding each enlarged region, optionally when the surrounding area includes the parts of the void 2 mm to the lateral side and 2 mm to the medial side of each enlarged region. Where such an enlarged region is located in the area of the solepiece that is proximate to the junction between the transverse and oblique axes of the MPJs, it can act to decouple longitudinal flexing of the transverse axis from longitudinal flexing of the oblique axis.

In one embodiment the solepiece further comprises a midsole comprising one or more flexible resilient elements capable of providing the differential resistance to longitudinal flexing.

In an embodiment the flexible resilient elements comprise one or more strain rate hardening elements. Suitable materials for use in the strain rate hardening elements, for example in shoes generally requiring high levels of bending stiffness, especially around MPJ1 and MPJ2 such as sprinting shoes, include elastomeric materials having a Young's modulus of 500 – 1000 psi at 100% strain, which include, for example, some polyurethanes and some polyureas.

In another embodiment the flexible resilient elements comprise one or more elastic elements. The flexible resilient elements can comprise a first elastic element on the medial side of the solepiece and a second elastic element on the lateral side of the solepiece, with the first elastic element is subject to higher tension than the second elastic element. Suitable materials for use in elastic elements include various rubbers and elastomers.

In an embodiment the solepiece comprises a void in the midsole. This void acts to decouple longitudinal flexing between the medial and lateral sides of the metatarsal break. In a further embodiment the solepiece comprises more than one void, with a combined effect that acts to decouple longitudinal flexing between the medial and lateral sides of the metatarsal break.

In one embodiment the flexible resilient elements comprise a rear section located at least predominantly behind the medial region of the metatarsal break as defined by metatarsophalangeal joints (MPJs) 1 and 2 of the wearer's foot; a front section located at least predominantly in front of the medial region of the metatarsal break, and a hinge joint which serves to connect the front and rear sections and which is located proximate to the medial region of the metatarsal break. The hinge joint comprises a hollow cylinder filled with a shear thickening fluid and incorporating a paddle adapted to rotate about the axis of the cylinder in response to relative movement of the front and rear sections, and one of the front and rear section includes the cylinder and the other includes the paddle.

In a further embodiment, the flexible resilient elements further comprise a second rear section located at least predominantly behind the lateral region of the metatarsal break as defined by MPJs 2 to 5 of the wearer's foot; a second front section located at least predominantly in front of the lateral region of the metatarsal break, and a second hinge joint which serves to connect the second front and second rear sections and which is located proximate to the lateral region of the metatarsal break. The second hinge joint comprises a second hollow cylinder filled with a second shear thickening fluid and incorporating a second paddle adapted to rotate about the axis of the second cylinder in response to relative movement of the second front and second rear sections, and one of the second front and second rear section includes the second cylinder and the other includes the second paddle. Rotation of the paddle through the shear thickening fluid generates a greater resistance than rotation of the second paddle through the second shear thickening fluid. In a preferred embodiment, the shear thickening fluid is more viscous than the second shear thickening fluid.

The front and rear sections, paddles and cylinders described above can be made of any material that is sufficiently stiff and robust, as would be appreciated by the skilled person. For example, suitable materials include metals, ceramics and plastics, including the thermoplastics nylon and polyvinylchloride, and the thermosetting plastics ethylene vinyl acetate and polyurethane. Shear thickening fluids are non-Newtonian fluids that exhibit increasing viscosities with increasing shear rates. Examples of shear thickening fluids useful in the present invention include, but are not limited to, dispersions of cornstarch in water, dispersions of silica in ethylene glycol, dispersions of clays in water, dispersions of titanium dioxide in water, and dispersions of silica in water.

In an embodiment the differential resistance to longitudinal flexing between the medial and lateral sides of the metatarsal break is provided by one or more grooves in the solepiece, wherein the groove or grooves are proximate to or parallel to the metatarsal break of the wearer. The required differential resistance to longitudinal flexing is provided, for example, by different depths, lengths or widths in the groove or grooves. Differential resistance can also be provided by partially infilling the one or more grooves with material having different stiffness to the bulk of the sole. Alternatively, the one or more groves can be partially or completely infilled with materials having variable stiffness. It will be appreciated that a combination of the listed approaches may be used to provide one or more grooves which provide increased stiffness on the medial side and decreased stiffness on the lateral side of the metatarsal break.

In an embodiment the resistance to flexing is higher along or proximate to the transverse axis defined by MPJs 1 and 2 of the wearer’s foot, and lower along or proximate to the oblique axis defined by MPJs 2 to 5 of the wearer’s foot.

In an embodiment the resistance to flexing along or proximate to the transverse axis is at least 10% greater than the resistance to flexing along or proximate to the oblique axis, preferably at least 15% greater, more preferably at least 20% greater. In another embodiment the resistance to flexing along or proximate to the transverse axis is between 10% to 400%, preferably between 10% and 60% greater than the resistance to flexing along or proximate to the oblique axis, more preferably between

15 and 30% greater. In a further embodiment the resistance to flexing along or proximate to the transverse axis is 20% to 25% greater than the resistance to flexing along or proximate to the oblique axis. These relative differences can be determined, for example, when the resistance to longitudinal flexing of both the transverse and oblique axes of the shoe are measured in accordance with the flexing test procedure described herein.

In one embodiment, the oblique axis may for example have minimal or no stiffness whilst the transverse axis has stiffness which is the same or greater than the bulk of the sole.

In another embodiment the resistance to flexing is higher in the region proximate to MPJ 1 of the wearer's foot than in the region proximate to MPJ 2 of the wearer's foot. Alternatively, or in addition, it may be higher in the region proximate to MPJ 2 of the wearer's foot than in the region proximate to MPJ 3. Again, alternatively or in addition, the resistance to flexing may be higher in the region proximate to MPJ 3 of the wearer's foot, than in the region proximate to MPJ 4. Similarly alternatively or in addition the resistance to flexing is higher in the region proximate to MPJ 4 of the wearer's foot than in the region proximate to MPJ 5 of the wearer's foot.

In an embodiment the shoe is an athletic shoe. In another embodiment the shoe is a shoe for an activity comprising at least one of sprinting, running, or jogging, preferably a shoe for sprinting. For example, the shoe can be a shoe for an activity such as soccer, rugby, basketball, American football or field hockey. The shoe can in principle be used for any ambulatory activity.

The present invention will now be illustrated by the following figures in which:

Figure 1 is a diagram of the foot from a top view showing the bonestructure and axes of the metatarsophalangeal joints of the human foot.

Figure 2 is a diagram of the foot from a bottom view, illustrating the location of the plantar fascia and plantar aponeurosia.

Figure 3 illustrates the generation of tension in the plantar aponeurosis during dorsiflexion.

Figure 4 shows a soleplate suitable for use in a shoe in outline, with the transverse and oblique axes in the region of a wearer's metatarsal break indicated.

Figure 5 shows a soleplate comprising materials of differential stiffness in the region proximate to the transverse and oblique axes in the region of a wearer's metatarsal break.

Figure 6 shows a soleplate comprising materials of differential stiffness in the forward part of the soleplate.

Figure 7 shows a soleplate with a number of discrete regions proximate to a wearer's metatarsal break.

Figure 8 shows a soleplate comprising a groove of variable depth in a region proximate to the wearer's metatarsal break.

Figure 9 shows a soleplate with a groove of variable width in a region proximate to a wearer's metatarsal break, where the width gradually increases from the medial to lateral side.

Figure 10 shows a soleplate with a groove of variable width in a region proximate to a wearer's metatarsal break, where the width is smaller when on or approximately parallel to the transverse axis larger when on or approximately parallel to the oblique axis.

Figure 11 shows a soleplate with several grooves in a region proximate to a wearer's metatarsal break. A single grove approximately parallel to the transverse axis is located predominantly on the medial side, while three grooves approximately parallel to the oblique axis are located predominantly on the lateral side.

Figure 12 shows a soleplate comprising multiple circular cutouts in the region proximate to a wearer's metatarsal break.

Figure 13 shows a soleplate with the lateral region forward of a curve approximately parallel with oblique axis of a wearer's metatarsal break detachably associated with the remainder of the soleplate.

Figure 14 shows elements of a midsole aligned with the corresponding regions of a wearer's foot, with two front elements of the midsole located predominantly forward of the wearer's metatarsal break and two rear elements located predominantly behind the wearer's metatarsal break.

Figure 15 illustrates the connectivity of a forward and corresponding rear midsole element of figure 14, with an end view (a), top view (b) and side view (c).

Figure 16 shows an exploded view of the device of figure 15.

Figure 17 shows components of test apparatus used to measure flexibility about the transverse and oblique axes of a shoe.

Figure 18 is a plan view of a shoe showing clamping arrangements in the apparatus of figure 17.

Figure 19 shows an adapted test apparatus with a shoe installed and either no bending force applied (a) or a bending force applied (b).

Figure 20 shows a schematic of the apparatus of Figure 19.

Figure 21 shows the apparatus of Figure 19, but with an outsole unit secured for testing about an oblique axis.

Figure 1 shows the bonestructure of the human foot (1) viewed from above, which comprises a medial (2) and lateral (3) side. The metatarsals (4a – 4e) and phalanges (5a – 5e) are separated at the metatarsophalangeal joints (MPJs). The region of the five MPJs is also collectively known as the metatarsal break. MPJ 1 is defined as the joint between the first metatarsal on the medial side (4a) and its corresponding phalanges (5a), with MPJs 2 to 5 defined in a similar fashion, moving from the medial to the lateral end of the metatarsal break. Extension of the MPJs and dorsiflexion of the phalanges occurs throughout the stance period of gait and primarily throughout the second half of stance. Dorsiflexion of these joints are usually accompanied by plantarflexion about a secondary axis in the ankle complex. Bosjen-Møller, (1978) determined that push off of the human gait cycle can be performed about a transverse axis (6) through the MPJs associated with the first and second phalanges (5a and 5b) or about an oblique axis (7) through the MPJs associated with the second to fifth phalanges (5b to 5e). It was found that the transverse and oblique axes are used for a high-gear and low-gear push-off respectively.

Figure 2 shows the plantar fascia (10) and plantar aponeurosis (11), which are subject to tension during dorsiflexion. During high-gear push-off the contact area is transferred from the heel to the medial part of the forefoot and onto the great toe and its phalanges (5a). Just prior to toe-off the foot remains in a pronated position with the lateral part of the ball of the foot elevated off the ground. Dorsiflexion about the MPJs associated with the first and second phalanges (5a and 5b) is facilitated from this position, generating tension in the plantar aponeurosis (11) as it is stretched over the heads of the metatarsals (illustrated in figure 3). At low-gear push-off the contact area is transmitted from the heel to the lateral part of the ball of the foot. The lateral toes dorsiflex about the oblique axis (7) and the great toe stabilises the medial side of the foot. Less tension is generated in the plantar fascia (10) during low gear push off when compared to the motion of high-gear push-off.

It has been reported that the resistance arm is 20% longer when push off is performed about the transverse axis (6) than when it is performed about the oblique axis (5). In motion utilising the transverse axis (7) the leverage is further stepped up with the final advancement of the axis to the tip of the great toe (8). Conversely, with the oblique axis (7) push off continues as a roll over the ball of the foot with the lateral toes yielding dorsally. Conventionally, it is thought that the mechanical demands of the motion, such as walking and sprinting, determine which axis the MPJs will rotate about.

Previous researchers have found that the demands of locomotive propulsion during sprinting are different throughout the progress of a race. More specifically, the previous researchers have found that a low gear should be selected for the start and acceleration phase and that a higher gear should be selected for maximal speed sprinting. However, by adapting the mechanical properties (resistance to longitudinal flexing) of footwear in the manner envisaged by the invention, improvements in performance have been measured by the current inventors. The inventors determined that a lower resistance to longitudinal flexing is required during acceleration to facilitate bending about the oblique axis (5) and activation of low-gear. A higher resistance to longitudinal flexing is beneficial and more efficient at higher speeds as rotation occurs about the transverse axis (4) to facilitate high-gear) motion. The solepiece of the present invention accommodates the finding of the inventors by allowing varying stiffness in the sole.

The inventors used a squat jump technique to replicate starting and acceleration of sprinting. A bounce drop jump was used to replicate maximal speed sprinting. Squat jump performance was maximised in a shoe with a low resistance to longitudinal flexing, facilitating appropriate use of the oblique axis in the foot. Bounce drop jump performance was maximised in a stiffer shoe, which had a high resistance to longitudinal flexing, as the efficiency of propulsion was improved when rotation occurred about the transverse axis in the foot.

The shoes of the present invention provide suitable longitudinal support and flexibility in the region of the metatarsal break for both low-gear and high gear motion. Figure 4 illustrates this for the solepiece of a shoe of the present invention, shown in a cross section through the plane of the solepiece. The solepiece has an oblique axis (7) on the lateral side of the shoe with a relatively low resistance to longitudinal flexing and a transverse axis (6) on the medial side of the shoe with high bending stiffness. The oblique and lateral axes are in a region of the shoe that is proximate to the metatarsal break of a wearer.

The exact location of the metatarsal break varies between individuals and also varies along the length of the metatarsal break. For instance, MPJ 5 is closer to the heel than MPJ 1. The metatarsal break is located at typically 60 to 80% of the total distance from the back of the heel to the tip of the great toe. Often the metatarsal break is located between 65 and 75% of this distance, or at approximately 70% of this distance. It will be appreciated that the provision of suitable longitudinal support and flexibility in the region of the metatarsal break does not require the various flexing means to be located at the portion of the solepiece directly at the wearer's metatarsal break. We have found that the elements providing differential flexing can be provided within ±20% of the overall length of the solepiece either side of the metatarsal break. However elements providing differential flexing could also be provided over the entire length of the solepiece either side of the metatarsal break. In an embodiment, this distance may be within ±10%. Thus in an embodiment of the invention, the flexing means proximate to the metatarsal break or parallel to the axes of the metatarsal break are located between 50 and 90%, optionally 60 to 80%, of the distance from the heel end (20) to the toe end (21) of the solepiece. The flexing means may also be located between 55, 60, 65 or 70 and 90% of the distance from the heel end (20) to the toe end (21) of the solepiece. In some embodiments the flexing means is located between 50, 55, 60, 65 or 70 and 80% of the distance from the heel end (20) to the toe end (21) of the solepiece. Certain embodiments locate the flexing means between 50, 55, 60, 65 or 70 and 75% of the distance from the heel end (20) to the toe end (21) of the solepiece.

It will also be appreciated that the distinction between the oblique and transverse axes will vary between individuals and therefore in some instances the solepiece may include a gradual decrease in bending stiffness from the first to fifth MPJ.

The solepiece may be constructed from suitable materials, which would be selected according to the types of use expected of the shoe as would be understood by a person skilled in the art. Examples of suitable materials include thermoplastics, thermosetting plastics and elastomers, or mixtures thereof. Suitable thermoplastics include nylon (PA), thermoplastic polyurethane (TPU), thermoplastic polyester elastomer (for instance TPC-RT Hytrel® from Du Pont) or Polyvinylchloride (PVC).

PA in particular is useful in areas that require increased stiffness. Composite forms of PA with fillers to provide increased stiffness could also be used for areas and activities requiring increased stiffness. Many thermosetting plastics are available in forms that provide different levels of hardness and stiffness, making these materials particularly suitable for applications that require a solepiece with variable resistance to longitudinal flexing, as harder or stiffer forms can be used in the regions of the solepiece that require a higher resistance to longitudinal flexing. Suitable thermosetting plastics include ethylene vinyl acetate (EVA) and polyurethane (PU). EVA is available in both soft and hard formulations and PU is available in different stiffness formulations. Suitable elastomers are formed from formulations comprising natural latex or at least one synthetic rubber and are especially used to provide grip for the ground engaging bottom portion of the sole.

Where materials of different stiffness as described above are used, various arrangements provide for increased resistance to longitudinal flexing on the medial side of the metatarsal break compared to the lateral side of the metatarsal break. For instance, as illustrated in figure 5, the region of the solepiece on the medial side proximate to the transverse axis of the metatarsal break, eg in the region of MPJ 1 and 2 can have a section (30) made from a suitable material with a first stiffness, while the region of the solepiece on the lateral side proximate to the oblique axis of the metatarsal break, eg in the region of MPJ 2 to 5 can have a section (31) made from a suitable material of a second stiffness, where the first stiffness is higher than the second stiffness. The remainder of the solepiece can be constructed of a material having a third stiffness.

It is also possible, as illustrated in figure 6, to provide differential resistance to longitudinal flexing with a design that incorporates a first element in the front medial section of the solepiece (32) and a second element in the front lateral section of the solepiece (33). Each of the first and second elements may partially or completely fill the thickness of the midsole. The first element will have a higher resistance to longitudinal flexing than the second element. The higher resistance can be provided using a variety of methods. For instance, the first element may be thicker than the second element, or the first element may be formed from a stiffer material. It will be appreciated that it is possible to also provide for a more gradually changing resistance to longitudinal flexing from the medial to lateral side of the metatarsal break with variants of the design of figure 6, for instance by gradually changing the thickness of the first and second elements, with the lateral sides of each of the first and second element having decreased thickness.

It will be appreciated that where the first element (32) and/or second element (33) comprise a strain rate hardening material, the resistance to longitudinal flexing of the given element will be higher when the wearer's speed of motion relative to the ground is at or above a predetermined speed. Examples of useful strain rate hardening materials include elastomeric materials having a Young's modulus of 500 – 1000 psi at 100% strain, which include, for example, some polyurethanes and some polyureas.

It is also possible to provide differential resistance to longitudinal flexing along the length of the metatarsal break by providing a solepiece where the region along or parallel to the metatarsal break comprises a plurality of elements of differential stiffness (35a to 35j), as illustrated in figure 7. These elements could comprise materials of different stiffness, with, for example, the elements decreasing in stiffness from the medial to lateral sides of the solepiece, i.e. with stiffness decreasing from 35a to 35j. Alternatively, the differential stiffness may be provided where each of these elements comprises a void, with shallower voids for higher resistance to longitudinal flexing and deeper voids a lower resistance to longitudinal flexing. For example, where the elements comprise voids, the elements predominantly on the medial side, e.g. 35a, 35b and 35c, may comprise voids at least 10% or 20% deeper than the voids on with the voids on the lateral side, e.g. 35d, 35e, 35f, 35g, 35h, 35i and 35j.

Figures 8 to 12 illustrate arrangements that include one or more voids extending from the medial to lateral side of the solepiece in a direction proximate to, along or parallel to at least part of the region of the solepiece that would be proximate to the metatarsal break of a wearer during use. These arrangements are able to provide differential resistance to longitudinal flexing in a direction along or parallel to at least part of the length of the metatarsal break of a wearer's foot. The void in figure 8 is a single groove (40) extending from the ground engaging bottom surface and into the midsole. Differential resistance to longitudinal flexion is provided by varying the depth of the groove, as can be seen in the inset cross sections of the groove (41 to 43), with a shallower groove providing a thicker midsole and a deeper groove providing a thinner midsole, with the thicker midsole providing greater resistance to longitudinal flexing. The groove is shallowest (41) on the medial side of the solepiece (44), deepest (43) on the lateral side of the solepiece (45) and may have an intermediate depth, eg as illustrated (42), in at least part of the interior region. The groove may gradually increase in depth from the medial to lateral side, or may consist of one or more regions of fixed depth. In a variant of the design illustrated in figure 8, the groove may also not extend fully to the medial and lateral edges of the solepiece. Where greater stiffness is required, for example in the region of MPJ1 and MPJ2, a protruding rib may be preferable to a depth reduce cut-out in order to provide a higher level of resistance to longitudinal bending.

The void in figure 9 comprises a single groove of variable width (50) extending from the ground engaging bottom surface and into the midsole. Differential resistance to longitudinal flexing is provided by varying the width of groove, with the narrowest portion of the groove on the medial side (44) and the widest portion of the groove on the lateral side (45). The resistance to longitudinal flexing decreases with increasing width of the groove. Thus the design of figure 9, with gradually increasing width from the medial to lateral side of the solepiece, provides for a gradual decrease in longitudinal stiffness from the medial to the lateral side.

Figure 10 also illustrates a solepiece where the void comprises a single groove. This groove is divided into two sections, a first section (55) parallel to the transverse axis of a wearer's metatarsal break and a second section (56) parallel to the oblique axis of a wearer's metatarsal break. The width of the groove in the second section is greater than in the first section, and the width of the groove increases when moving from the medial to the lateral side of the second section of the groove. Thus the first section of the groove will have a higher resistance to longitudinal bending stiffness than the second section of the groove, and the resistance to longitudinal flexing will be higher at the medial side and lower at the lateral side of the metatarsal break.

The solepiece of figure 11 provides for the variation in longitudinal bending stiffness at the medial and lateral sides of the metatarsal break by providing a single void (60) on the medial side of the metatarsal break, approximately parallel to the transverse axis, and three voids (61a, 61b and 61c) on the lateral side of the metatarsal break, approximately parallel to the transverse axis and each other. The voids in this instance comprise grooves of similar thickness and the presence of a single groove on the medial side and several parallel grooves on the lateral side provides for higher resistance to longitudinal flexing on the medial side and lower resistance to longitudinal flexing on the lateral side. It will be appreciated that different numbers of parallel grooves can be used from that illustrated 11, with the medial side of the metatarsal break having higher resistance to longitudinal flexing than the lateral side of the metatarsal break , provided that the lateral side of the metatarsal break comprises a larger number of parallel grooves.

In figure 12 the voids (65) comprise geometric shapes, namely cylindrical or hemi-spherical or similarly shaped voids that appear circular when viewed in cross section through the plane of the solepiece, as illustrated in figure 12. The voids are distributed in the region of the metatarsal break and the number and distribution of the voids provides the required differential resistance to longitudinal flexing in a direction along the metatarsal break, with regions having a larger number of voids having a lower resistance to longitudinal flexing. Thus the area of the solepiece corresponding to MPJs 1 and 2, where few voids are present, will have a greater resistance to longitudinal flexing than the region corresponding to MPJs 3 to 5, where a larger number of voids are present. In variation of this design, the voids can also have variable depth, with deeper voids used in regions where a higher degree of flexibility is desired. It will also be appreciated that a similar effect may be obtained by using voids which have other geometric shapes when viewed in cross section, for instance polygons, ovals or irregular shapes.

In figure 13 the front lateral region of the solepiece (90), namely the lateral region of the solepiece forward of a curve approximately parallel with the oblique axis of a wearer’s metatarsal break, is detachably associated with the remainder of the solepiece (91). Such an arrangement may be provided, for instance, by two grooves, as illustrated in figure 5. The grooves extend into the midsole region and act to decouple longitudinal flexing of the transverse axis from longitudinal flexing of the oblique axis. In addition, the groove also provides for decreased resistance to longitudinal flexing on the lateral side of the metatarsal break compared to medial side of the metatarsal break. In a variant of this arrangement, the front lateral region of the solepiece (90) predominantly comprises a void in the misole.

Figures 14 to 16 illustrate an arrangement whereby differential resistance to longitudinal flexing is provided by a mechanical hinge arrangement, which can be located, for example, in the midsole of a solepiece. The arrangement comprises a front section (100) and a rear section (101) connected by a hinge joint (102) located on the medial side; as well as a second front section (110) and a second rear section (111) connected by a second hinge joint (112) located on the lateral side. This arrangement is illustrated, superimposed onto a foot, in figure 14. Figures 15 and 16 show various views of the front section (100), rear section (101) and their hinge joint (102) in more detail.

The rear section (101) is located at least predominantly behind the medial region of the metatarsal break as defined by metatarsophalangeal joints (MPJs) 1 and 2 of the wearer's foot, while the front section (100) is located at least predominantly in front of the medial region of the metatarsal break. The hinge joint (102) serves to connect the front (100) and rear (101) sections and is located proximate or parallel to the medial region of the metatarsal break. The hinge joint (102) comprises a hollow cylinder (103) filled with a shear thickening fluid and incorporating a paddle (104) adapted to rotate about the axis of the cylinder (105) in response to relative movement of the front and rear sections, and one of the front and rear section includes the cylinder and the other includes (for example, by being attached to it) the paddle.

The second rear section (111) is located at least predominantly behind the lateral region of the metatarsal break as defined by MPJs 2 to 5 of the wearer's foot, while the second front section (110) is located at least predominantly in front of the lateral region of the metatarsal break. The second hinge joint (112) serves to connect the second front (110) and second rear (111) sections and is located proximate or parallel to the lateral region of the metatarsal break. The second hinge joint comprises a second hollow cylinder filled with a second shear thickening fluid and incorporating a second paddle adapted to rotate about the axis of the second cylinder in response to relative movement of the second front and second rear sections, and one of the second front and second rear section includes the second cylinder and the other includes (for example, by being attached to it) the second paddle. Rotation of the paddle through the shear thickening fluid generates a greater resistance than rotation of the second paddle through the second shear thickening fluid. In a preferred embodiment, the shear thickening fluid is more viscous than the second shear thickening fluid.

The front and rear sections, paddles and cylinders described above can be made of any material that is sufficiently stiff and robust, as would be appreciated by the skilled person. For example, suitable materials include metals, ceramics and plastics, including the thermoplastics nylon and polyvinylchloride, and the thermosetting plastics ethylene vinyl acetate and polyurethane. Shear thickening fluids are non-Newtonian fluids that exhibit increasing viscosities with increasing shear rates. Examples of shear thickening fluids useful in the present invention include, but are not limited to, dispersions of cornstarch in water, dispersions of silica in ethylene glycol, dispersions of clays in water, dispersions of titanium dioxide in water, and dispersions of silica in water.

Test Procedure

The force required for longitudinal flexing of both the transverse and oblique axes of a shoe can be measured in accordance with the following flexing test procedure. The test procedure is based on the American Society for Testing and Materials (ASTM) Standard Test Method for Flexibility of Running Shoes F911-85. Figure 17 provides a schematic showing the key components of the test apparatus. Figure 18 illustrates a plan view of shoe mounted on the apparatus of figure 17 showing the transverse and oblique clamping arrangements. It is understood that figures 17 and 18 illustrate the use of important components in outline, allowing the skilled person to provide the exact apparatus used to follow the procedure.

The apparatus used comprises two clamps, a forefoot hold-down clamp (120) and a heel hold-down clamp (121). The forefoot hold-down clamp (120) is a 20 mm wide (122) x 30 mm long solid metal piece. Its periphery is in contact with the shoe has a radius of 10 mm (123). If assembled shoes are tested, the forefoot hold-down clamp can be split such that a bottom half may be inserted into the shoe and a top half aligned to the bottom half and positioned exterior to the shoe. The forefoot hold-down clamp's position can be altered to be central to the oblique (130) or transverse (131) test regions. The heel hold-down clamp (121) is a 30 mm diameter (124) cylindrical solid metal piece. The periphery of the heel hold-down clamp in contact with the shoe has a radius of 10 mm (125). The heel hold-down clamp is positioned along the centerline of the shoe at 45% of shoe length (126) from the axis of rotation (127).

The test specimens shall consist of at least three pairs of shoes sufficient to achieve statistical confidence. Each shoe shall be tested about a transverse axis (132) at 70% of shoe length (133) towards the frontmost part of the shoe (134) from the rearmost part of the shoe (135), perpendicular to the shoe centre line (136). Each shoe shall also be tested about an oblique axis (137) running from a point coincident with the centre line of the shoe and the transverse axis, at an angle of 10 - 30° to the transverse axis.

Before performing measurements the apparatus and test specimens are conditioned, being held in a standard atmosphere for testing, which is 23 ± 2°C and 50 ± 5% relative humidity, for 24 hrs prior to testing.

The flexing test procedure comprises the following steps:

(a) Condition the shoe and apparatus.

(b) Position the shoe such that the transverse axis (132) is coincident with the axis of rotation (127) of the apparatus.

(c) Clamp the forefoot of the shoe with forefoot hold-down clamp (120) on the medial side coincident with the transverse axis at 70% of shoe length (131).

(d) Apply a 350 N (to prevent movement) clamping force to the forefoot hold-down clamp.

(e) Clamp the rearfoot of the shoe with the heel hold-down clamp (121) central to the rearfoot at a distance 45% of shoe length from the transverse axis (137).

(f) Apply 20 – 50N (to prevent movement) clamping force to the heel hold-down clamp.

(g) Flex the shoe about the axis of rotation to establish the minimum flex angle, where the periphery of the heel hold-down clamp in contact with the shoe is at the minimum flex angle position (128).

(h) Flex the shoe between minimum (128) and maximum (129) flex angles about the axis of rotation for 50 cycles at a rate of 1 Hz.

(i) Measure the mean flexion force for 1 complete cycle for each of the last 10 cycles.

(j) Rotate the shoe such that the oblique axis is coincident with the axis of rotation of apparatus (138). The heel hold-down clamp (121) should be moved with rotation of the shoe to the new position (139) without being removed from the shoe.

(k) Clamp the forefoot of the shoe with forefoot hold-down clamp (120) on the lateral side of the shoe coincident with the oblique axis (130).

(l) Apply a 350 N (to prevent movement) clamping force to the forefoot hold-down clamp.

(m) Repeat steps (g) to (i).

The following data are reported from the results obtained with the test procedure:

Report the ensemble mean flexion force for each of the last 10 cycles for testing about the transverse axis.

Report the ensemble mean flexion force for each of the last 10 cycles for testing about the oblique axis.

Report the percentage difference between ensemble mean data for transverse and oblique axes flexion force.

The invention is based on the understanding that stiffness affects natural functionality of the foot. A study of the lower extremity kinematics of 4 sprinters showed that the angular range and velocity of the segments in the foot proximal to the metatarsalphalangeal joint (MPJ) are significantly reduced in shoes of high stiffness. During the start / acceleration phase this was particularly apparent as the angular range was reduced by 11°, 13° and 5° for the phases of initial flexion, extension and the final phase of flexion respectively when compared to nominal stiffness conditions. (flexion = joint closes, extension = joint opens). These quantified changes in angular range, induced by higher stiffness, compromise foot function which subsequently compromises sprinting performance.

Stiffness also affects the performance of an athlete. Performance was maximised in an intermediate stiffness shoe for techniques relating to sprint starting and a high stiffness shoes for techniques relating to maximal speed sprinting. The results for the test relating to starting performance show that jump height was higher in the intermediate stiffness shoe compared to the nominal, low and high stiffness shoes. Maximum dynamic strength of the athlete (a proven performance indicator) was also higher in the intermediate stiffness shoe. The results for the test relating to maximal speed sprinting show that jump height was higher in the stiffest shoe compared to the nominal, low and intermediate stiffness shoes and maximum dynamic strength was also higher in the stiffest condition compared to the other conditions.

Ideally, a shoe of the invention provides a differential stiffness of at least 50 N, and preferably at least 100 N, more preferably at least 200 N. In absolute terms, the range of stiffness is from 5 N to 300 N and is preferably in the range 50 N to 250 N. These stiffness values can also represent the solepiece’s resistance to longitudinal flexing.

A shoe which offers high stiffness for maximal performance during high-speed locomotion without compromising the requirements of low speed locomotion (or in the example of sprinting, the start and acceleration phases) provides an optimal solution. In accordance with foot anatomy and foot function this is best achieved in a shoe with high stiffness corresponding to the transverse axes between the 1st and 2nd metatarsal heads and low stiffness corresponding with the oblique axes between the 2nd to 5th metatarsal heads.

A number of materials can be used for the production of shoes in accordance with the invention. Thus certain combinations of conventional materials, provided they offer the required differential stiffness, may be used. The uppers may be leather or manmade / synthetic leather materials, or mesh. The exact materials used vary considerably from natural materials such as cotton to man made fibres such as polypropylene. Spacer materials or padding materials also vary considerably from recycled synthetic materials to open cell foams.

The solepiece of an athletic running shoe is generally manufactured from a number of different components and materials in order to achieve a range in mechanical performance that matches the demands of the gait cycle and/or the activity that the shoe is designed for. For example, materials that can be used in midsoles of the present invention include Polyurethane (PU) and Ethylene vinyl acetate (EVA), with variation in formulations and processing techniques employed to achieve different properties. Outsoles (the ground engaging bottom surface) may be constructed, for example, from various synthetic or natural rubber compounds in the same way as conventional outsoles. Again, the important factor is maintaining the differential resistance to longitudinal flexing at or near the metatarsal break.

Mechanical testing of sprint spikes

The adapted apparatus is pictured in Figure 19, with a shoe (150) installed. Figure 19(a) illustrates the apparatus when no bending load is applied while 19(b) shows a side view when a bending load is applied. A simplified schematic is shown in Figure 20. As can be seen from Figure 20, the shoe (150) is held to the apparatus with two fixing points near the rear of the shoe (151) and a further fixing point (152) at or near the shoe centre line, located approximately 17.5 mm from the bend axis. The bend axis (153) is at 70% of the shoe length. A bending load is applied as needed for the required amount of angular displacement (154). For the bending stiffness procedure, the shoes were positioned for bending to occur about an axis perpendicular to the longitudinal axis of the shoe.

The moment (N.m) was calculated using a bending beam load cell (HBM Wagezelle 20kg G48921) positioned such that the force was recorded at 90 mm from the axis of rotation. Angular displacement was simultaneously measured and the torsional stiffness coefficient was calculated as the ratio of torque divided by angle of twist. Dynamic calibration was carried out prior to each test to ensure accurate angular displacement and torque. In addition static calibration using a 5 kg mass secured to the forefoot loading plate was also recorded.

The required amount of angular displacement for the bending tests has been correlated with the functional angular range of the MPJ during sprinting. High speed video analysis of foot contacts during sprinting was used to determine that the range in MPJ extension was approximately 40°. Consequently the bending tests were carried out over an angular range of 50° to ensure complete data capture over the functional range.

The shoe fixing method was designed to accommodate testing about a transverse axis at 90° to the longitudinal midline of the foot at 70% of shoe length and also about an oblique axis which can be varied between 90 – 70°. Figure 21 shows an outsole unit (160) secured for testing about an oblique axis of 70° from the longitudinal midline of the foot.

The mean transverse axis bending stiffness coefficient for all of the tested sprint spikes was 1.31 ± 0.44 N•m deg-1 and the range was 1.42 N•m deg-1. The mean oblique axis bending stiffness coefficient at 30° bend angle for all of the tested sprint spikes was 1.41±0.41 N•m deg-1 and the range was 1.50 N•m deg-1.

The results show that there is no significant difference between the bending stiffness in the oblique and transverse axes of 11 tested sprint spikes of conventional construction.

Alternative Test Procedure

- Condition the shoe and apparatus.
- Position the shoe such that the transverse axis is coincident with the axis of rotation of the apparatus.
- Clamp the forefoot of the shoe with forefoot hold-down clamp on the medial side coincident with the transverse axis at 70% of shoe length.
- A stirrup was positioned central to the rearfoot at a distance 45% of shoe length from the transverse axis.
- Flex the shoe cyclically for10 cycles between 0 and 90mm vertical displacement at a rate of 1000m/min
- Measure the max flexion force for 1 complete cycle for each of the 10 cycles.
- Rotate the shoe such that the oblique axis is coincident with the axis of rotation of apparatus.

- Repeat the procedure with the forefoot hold-down clamp on the lateral side of the shoe coincident with the oblique axis.

Report

- Report the ensemble mean maximum flexion force for each of the 10 cycles for testing about the transverse axis.
- Report the ensemble mean maximum flexion force for each of the 10 cycles for testing about the oblique axis.
- Report the percentage difference between ensemble mean data for transverse and oblique axes flexion force.

Results

The Alternative Test Procedure was applied to a range of 20 pairs of shoes representing different footwear categories, brands and price points. These included athletic running shoes, trail running shoes, sandals and general casual footwear. The mean maximum bending stiffness was 21.3 ± 9.5N and 22.3 ± 10.9N about the transverse and oblique axes respectively.

When the Alternative Test Procedure is used with shoes of the invention, the mean maximum bending stiffness (and ensemble mean maximum flexion force) for the transverse axis is higher than the mean maximum bending stiffness for the oblique axis. The absolute percentage difference between transverse axis mean maximum flexion force and oblique axis mean maximum flexion force for shoes according to embodiments of the invention must be at least 5%, and preferably at least 50%. More preferably, the absolute percentage difference is at least 100% and may be as high as at least 150% or at least 200%.

Claims

1. A shoe comprising a solepiece having a ground engaging bottom surface and a top surface on which a wearer's foot is received, wherein

the solepiece has differential resistance to longitudinal flexing in a direction along or parallel to at least part of the length of the metatarsal break of the wearer's foot, and wherein either:

(i) the resistance to longitudinal flexing is relatively lower at the lateral side of the metatarsal break and relatively higher at the medial side of the metatarsal break,

(ii) the resistance to longitudinal flexing is relatively lower when the wearer's speed of motion relative to the ground is below a predetermined speed and relatively higher when the wearer's speed of motion relative to the ground is at or above the predetermined speed, or

(iii) the resistance to longitudinal flexing has a first value at the lateral side of the metatarsal break and a second value which is higher than the first value at the medial side of the metatarsal break, when the wearer's speed of motion relative to the ground is below a predetermined speed, and the resistance to longitudinal flexing at the lateral side of the metatarsal break has a third value which is higher than the first value and has a fourth value which is higher than the second value at the medial side of the metatarsal break, when the wearer's speed of motion relative to the ground is greater than a predetermined speed.

2. The shoe of claim 1, wherein the predetermined speed is at least 1.5 ms^{-1}, preferably at least 2 ms^{-1}, more preferably at least 3 ms^{-1}, even more preferably at least 4 ms^{-1}, still more preferably at least 5 ms^{-1}.

3. The shoe of claim 1 or claim 2, wherein the resistance to longitudinal flexing in a direction along or parallel to at least part of the metatarsal break increases linearly as the speed of motion of the wearer increases relative to the ground.

4. The shoe of claim 1 or claim 2, wherein the resistance to longitudinal flexing in a direction along or parallel to at least part of the metatarsal break increases non-linearly as the speed of motion of the wearer increases relative to the ground.

5. The shoe of any preceding claim, wherein the solepiece includes one or more voids extending from the medial to lateral side of the solepiece in a direction along or parallel to at least part of the metatarsal break.

6. The shoe of claim 5, wherein at least one void has varying width from the medial to the lateral side of the solepiece, with a wider portion on the lateral side and a narrower portion on the medial side, optionally wherein the width increases gradually from the medial to the lateral side.

7. The shoe of claim 5 or claim 6, wherein at least one void has varying depth from the medial to the lateral side of the solepiece, with a deeper portion on the lateral side and a shallower portion on the medial side, optionally wherein the depth increases gradually from the medial to the lateral side.

8. The shoe of any of claims 5 to 7, wherein at least one void further comprises baffles that interrupt the void, optionally wherein more than one void further comprises such baffles.

9. The shoe of claim 8, wherein the baffles partially or completely fill the at least one void, so as to sit flush with the bottom surface of the solepiece.

10. The shoe of any of claims 5 to 9, wherein the voids comprise a series of discrete voids located in the region of the metatarso-phalangeal joints (MPJs) of a wearer.

11. The shoe of any of claims 5 to 10, wherein at least one void comprises a primary void in communication with one or more secondary voids, where the secondary voids extend outwards from the primary void.

12. The shoe of any of claims 5 to 11, wherein at least one void comprises one or more enlarged regions, in which the width and/or depth of the void is greater than in the parts of the void in the area immediately surrounding each enlarged region, optionally when the surrounding area includes the parts of the void 2 mm to the lateral side and 2 mm to the medial side of each enlarged region.

13. The shoe of any preceding claim, wherein the solepiece further comprises a midsole comprising one or more flexible resilient elements capable of providing the differential resistance to longitudinal flexing.

14. The shoe of claim 13, wherein the flexible resilient elements comprise one or more strain rate hardening elements.

15. The shoe of claim 13, wherein the flexible resilient elements comprise one or more elastic elements.

16. The shoe of claim 15, wherein the flexible resilient elements comprise a first elastic element on the medial side of the solepiece and a second elastic element on the lateral side of the solepiece, with the first elastic element subject to higher tension than the second elastic element.

17. The shoe of any of claims 13 to 16, wherein the solepiece comprises a void in the midsole to decouple longitudinal flexing between the medial and lateral sides of the metatarsal break.

18. The shoe of claim 13, wherein the flexible resilient elements comprise:

a rear section located at least predominantly behind the medial region of the metatarsal break as defined by metatarsophalangeal joints (MPJs) 1 and 2 of the wearer's foot;

a front section located at least predominantly in front of the medial region of the metatarsal break, and

a hinge joint which serves to connect the front and rear sections and which is located proximate to the medial region of the metatarsal break,

wherein the hinge joint comprises a hollow cylinder filled with a shear thickening fluid and incorporating a paddle adapted to rotate about the axis of the cylinder in response to relative movement of the front and rear sections, and

wherein one of the front and rear section includes the cylinder and the other includes the paddle.

19. The shoe of claim 18, wherein the flexible resilient elements further comprise:

a second rear section located at least predominantly behind the lateral region of the metatarsal break as defined by MPJs 2 to 5 of the wearer's foot;

a second front section located at least predominantly in front of the lateral region of the metatarsal break, and

a second hinge joint which serves to connect the second front and second rear sections and which is located proximate to the lateral region of the metatarsal break,

wherein the second hinge joint comprises a second hollow cylinder filled with a second shear thickening fluid and incorporating a second paddle adapted to rotate about the axis of the second cylinder in response to relative movement of the second front and second rear sections,

wherein one of the second front and second rear section includes the second cylinder and the other includes the second paddle, and

wherein rotation of the paddle through the shear thickening fluid generates a greater resistance than rotation of the second paddle through the second shear thickening fluid.

20. The shoe of claim 19, wherein the shear thickening fluid is more viscous than the second shear thickening fluid.

21. The shoe of any preceding claim, wherein the resistance to flexing is higher along or proximate to the transverse axis defined by MPJs 1 and 2 of the wearer's foot, and lower along or proximate to the oblique axis defined by MPJs 2 to 5 of the wearer's foot.

22. The shoe of any of claims 1 to 17, wherein the resistance to flexing is:

higher in the region proximate to MPJ 1 of the wearer's foot than in the region proximate to MPJ 2 of the wearer's foot, and

higher in the region proximate to MPJ 2 of the wearer's foot than in the region proximate to MPJ 3, MPJ 4 and MPJ 5 of the wearer's foot.

23. The shoe of any of claims 1 to 17, wherein the resistance to flexing is:

higher in the region proximate to MPJ 1 of the wearer's foot than in the region proximate to MPJ 2 of the wearer's foot,

higher in the region proximate to MPJ 2 of the wearer's foot than in the region proximate to MPJ 3 of the wearer's foot, and

higher in the region proximate to MPJ 3 of the wearer's foot than in the region proximate to MPJ 4 and MPJ 5 of the wearer's foot.

24. The shoe of any of claims 1 to 17, wherein the resistance to flexing is:

higher in the region proximate to MPJ 1 of the wearer's foot than in the region proximate to MPJ 2 of the wearer's foot,

higher in the region proximate to MPJ 2 of the wearer's foot than in the region proximate to MPJ 3 of the wearer's foot,

higher in the region proximate to MPJ 3 of the wearer's foot than in the region proximate to MPJ 4 of the wearer's foot, and higher in the region proximate to MPJ 4 of the wearer's foot than in the region proximate to MPJ 5 of the wearer's foot.

25. The shoe of any preceding claim, wherein the shoe is an athletic shoe.

26. The shoe of any preceding claim, wherein the shoe is a shoe for an activity comprising at least one of sprinting, running, or jogging, preferably a shoe for sprinting.

27. The shoe of any preceding claim, wherein the solepiece has differential resistance to longitudinal flexing of at least 50 N, preferably at least 100 N, more preferably at least 200 N.

28. The shoe of any preceding claim, wherein the differential resistance to longitudinal flexing provides a range of resistance to flexing of from 5 N to 300 N, preferably from 50 N to 250 N.

29. The shoe of any preceding claim, wherein the absolute percentage difference in the resistance to longitudinal flexing along the transverse axis compared to the oblique axis, as measured in accordance with the Alternative Test Procedure described herein, is at least 25%, preferably at least 50%, more preferably at least 100%, even more preferably at least 150%, still more preferably at least 200%, wherein the resistance to longitudinal flexing along the transverse axis is higher than the resistance to longitudinal flexing along the oblique axis.

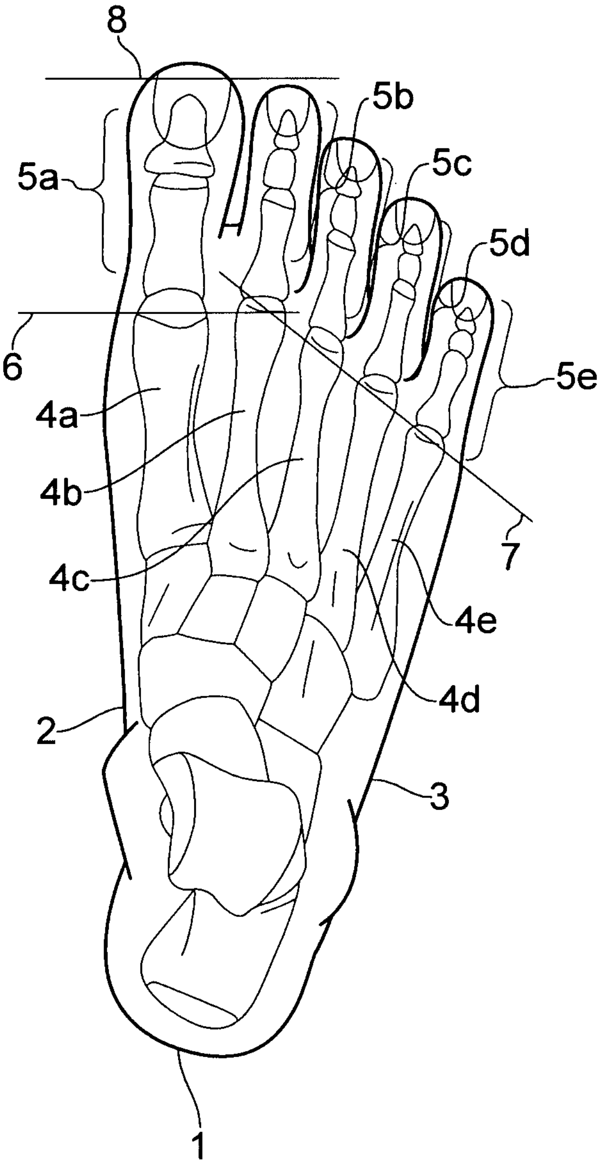

FIG. 1

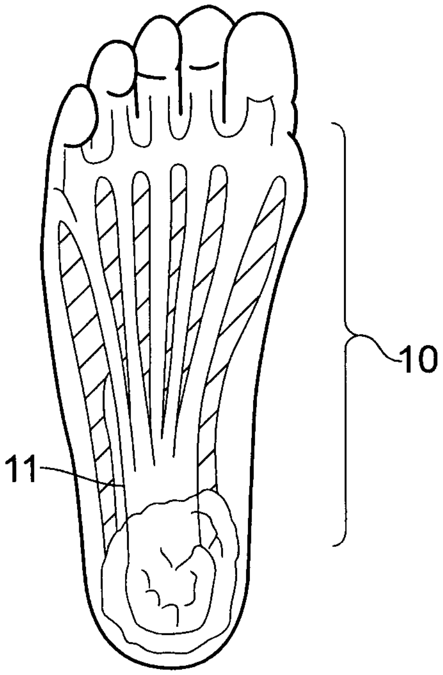

FIG. 2

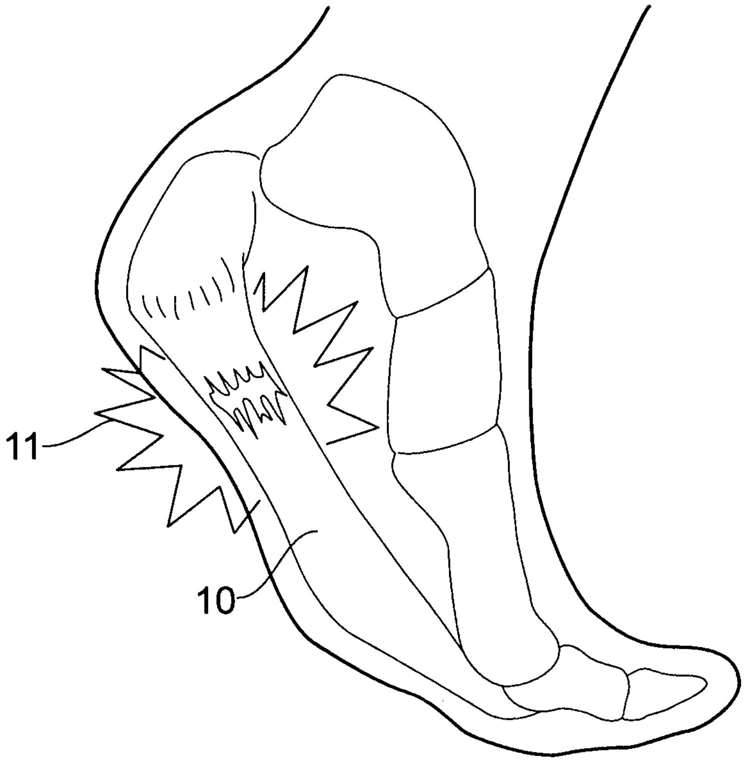

FIG. 3

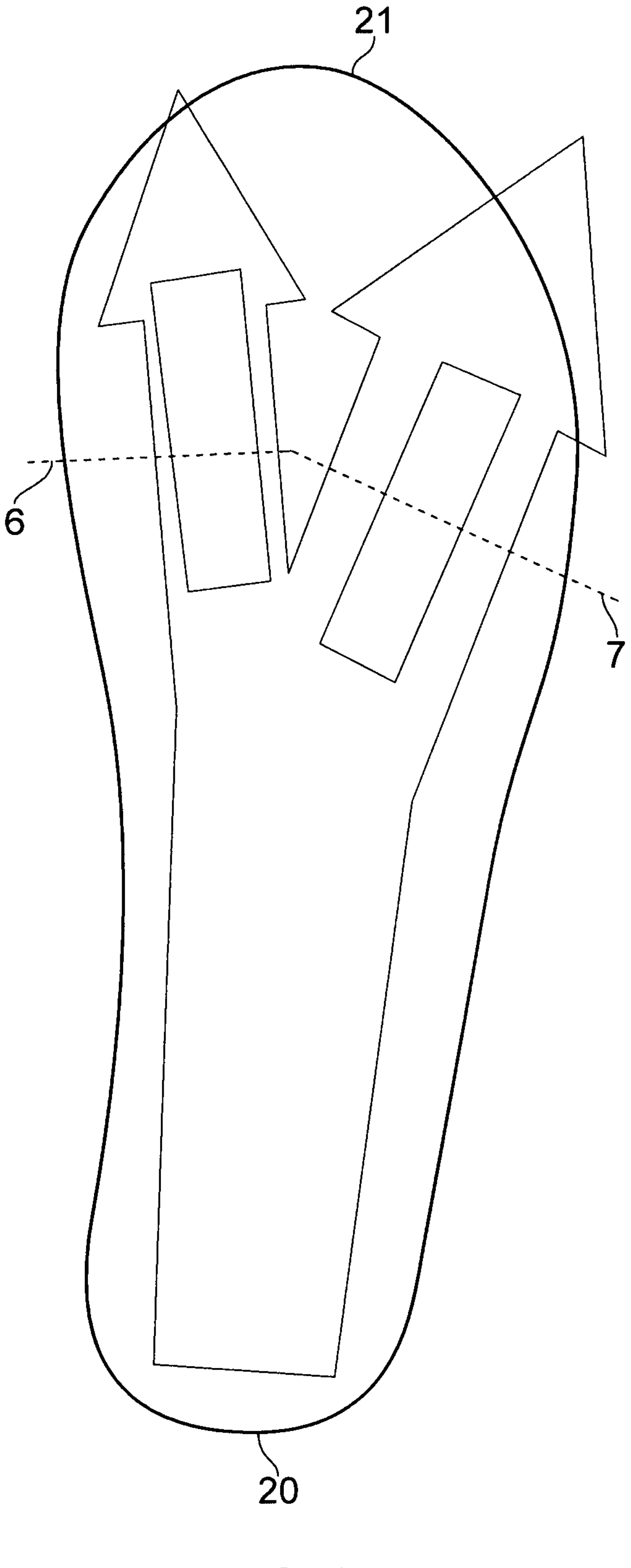

FIG. 4

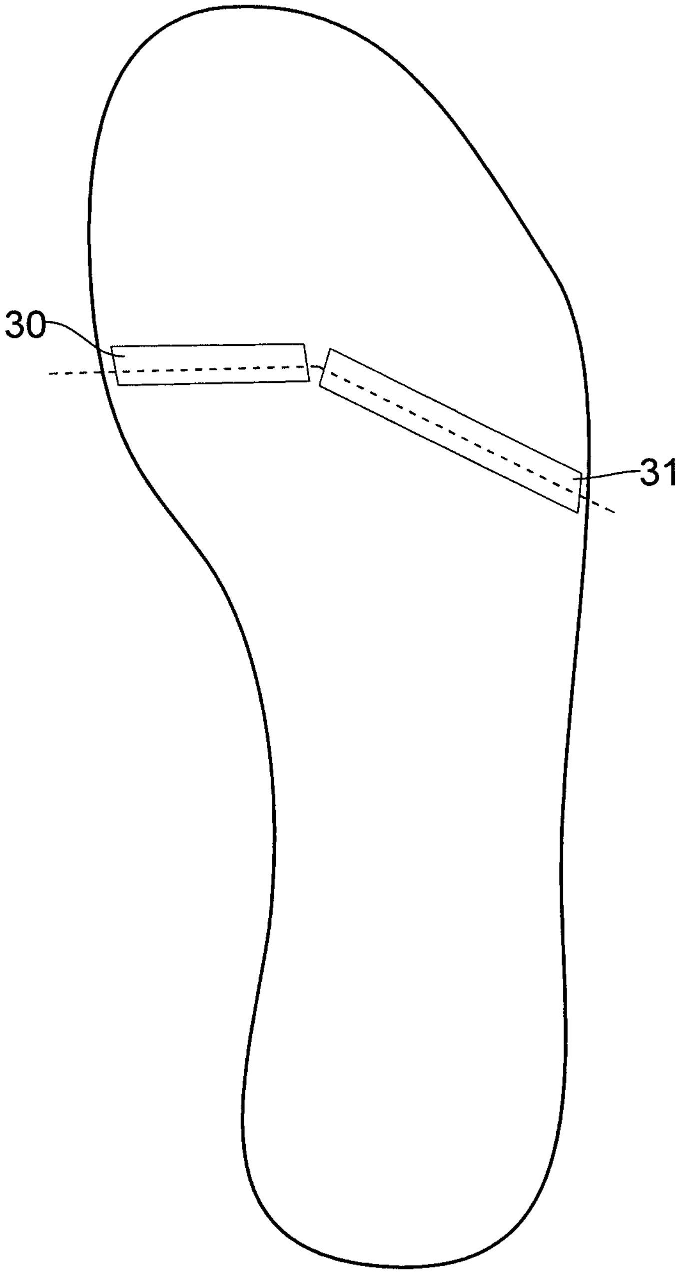

FIG. 5

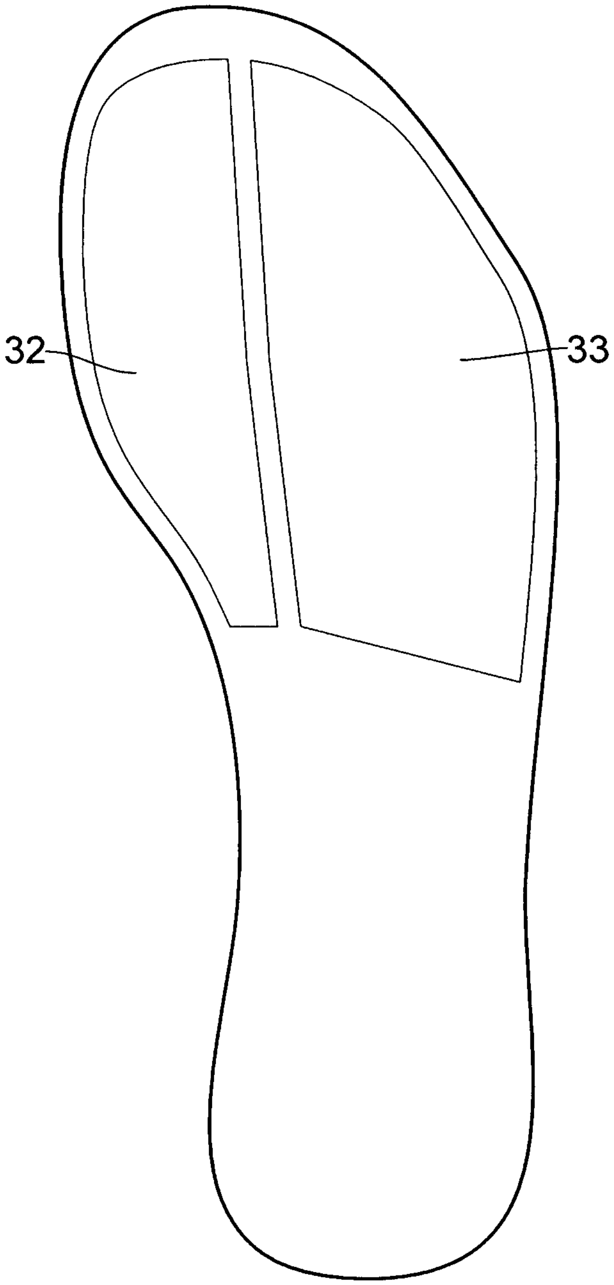

FIG. 6

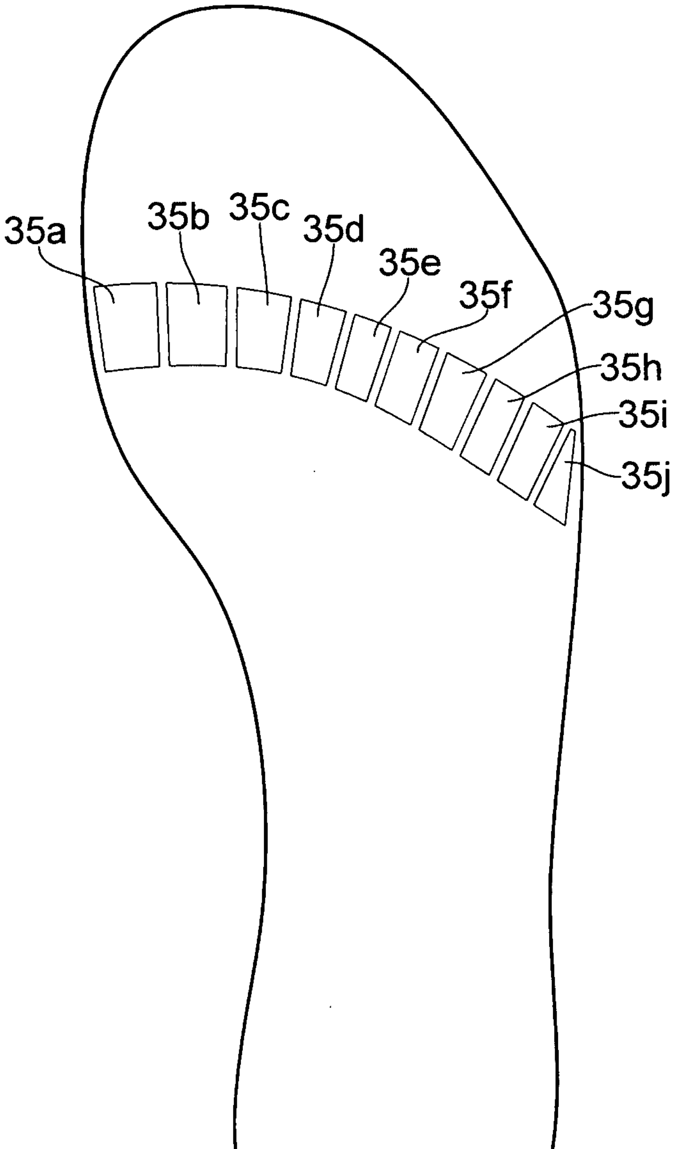

FIG. 7

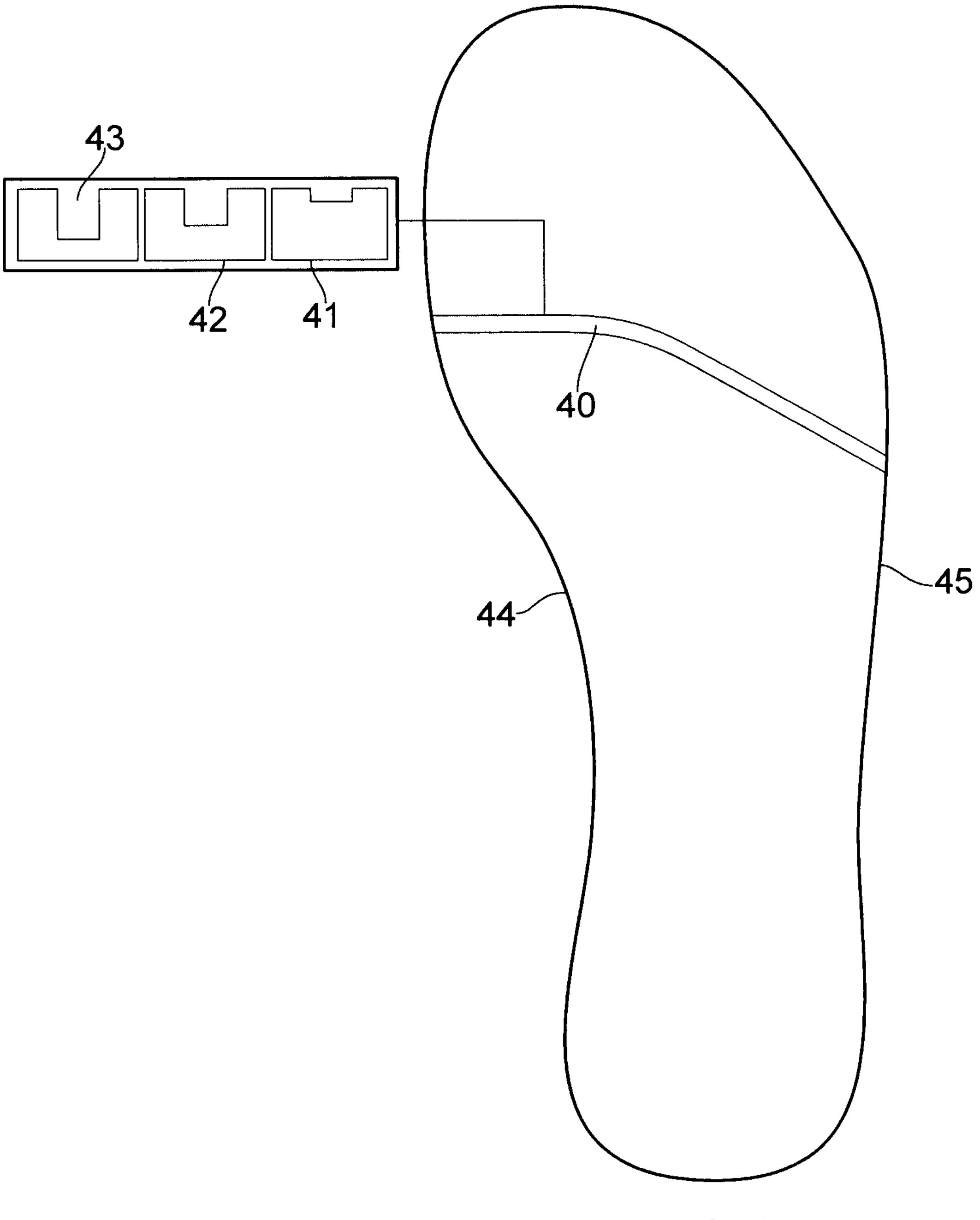

FIG. 8

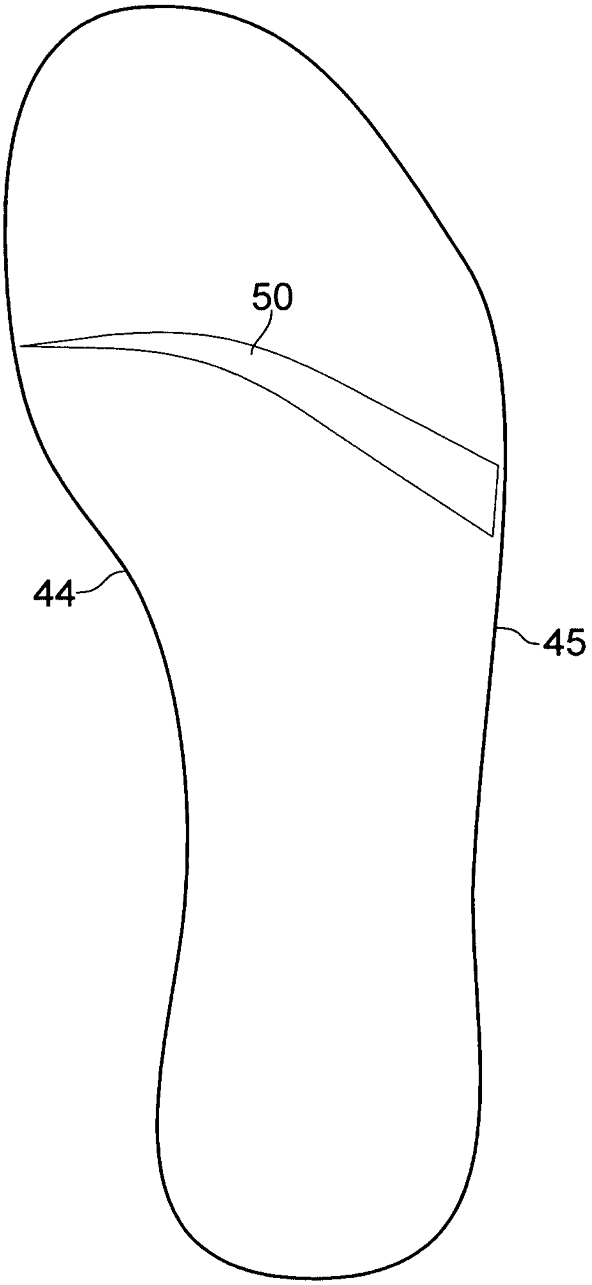

FIG. 9

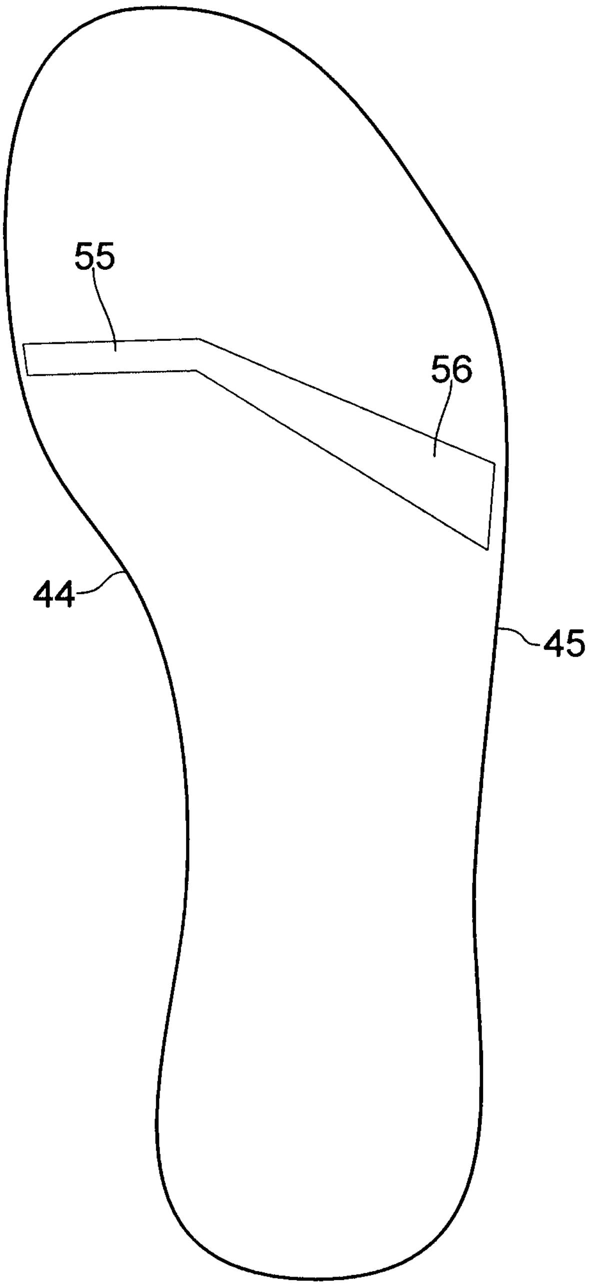

FIG. 10

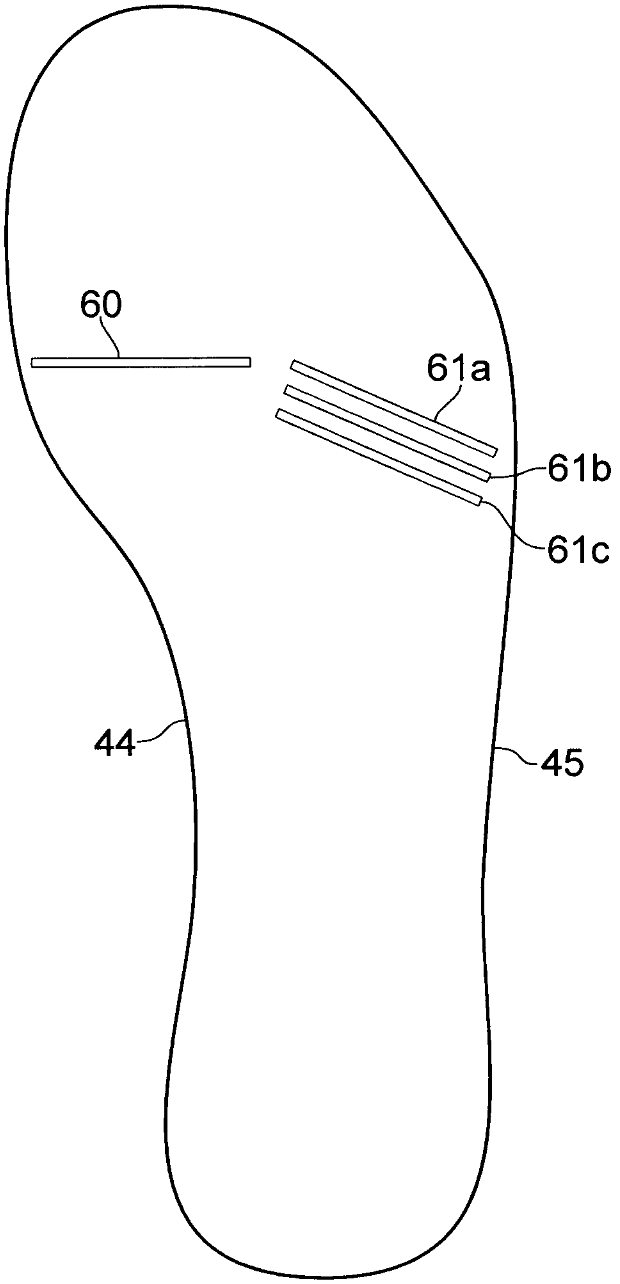

FIG. 11

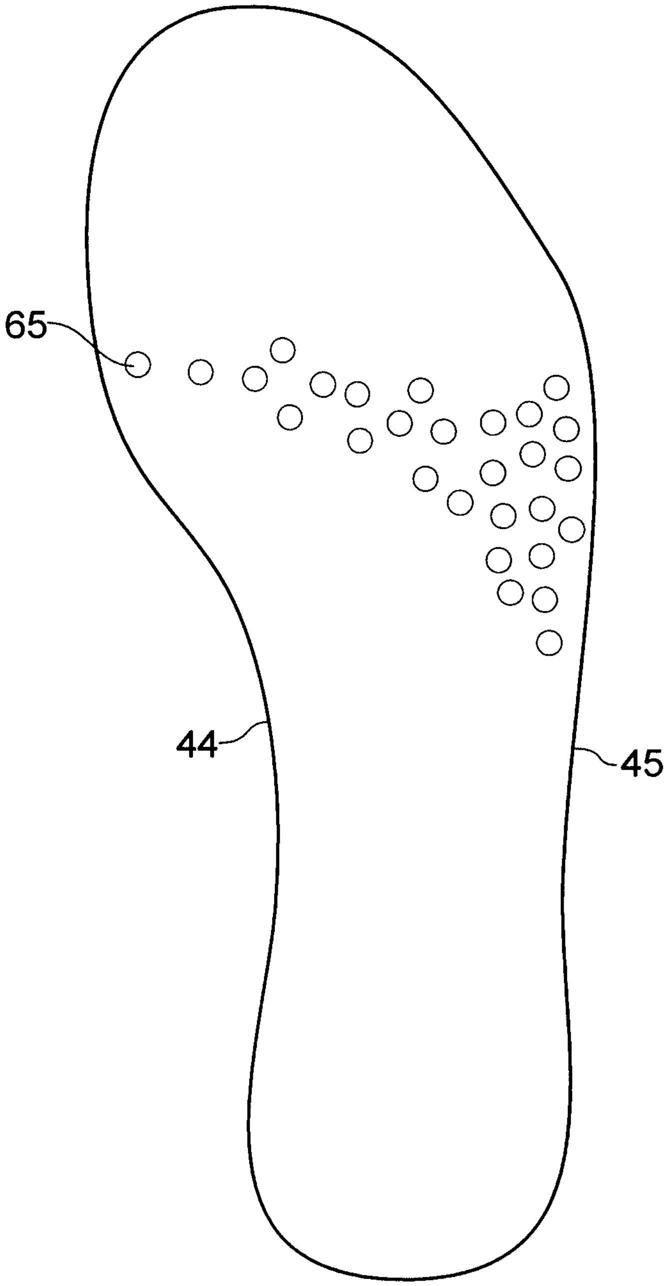

FIG. 12

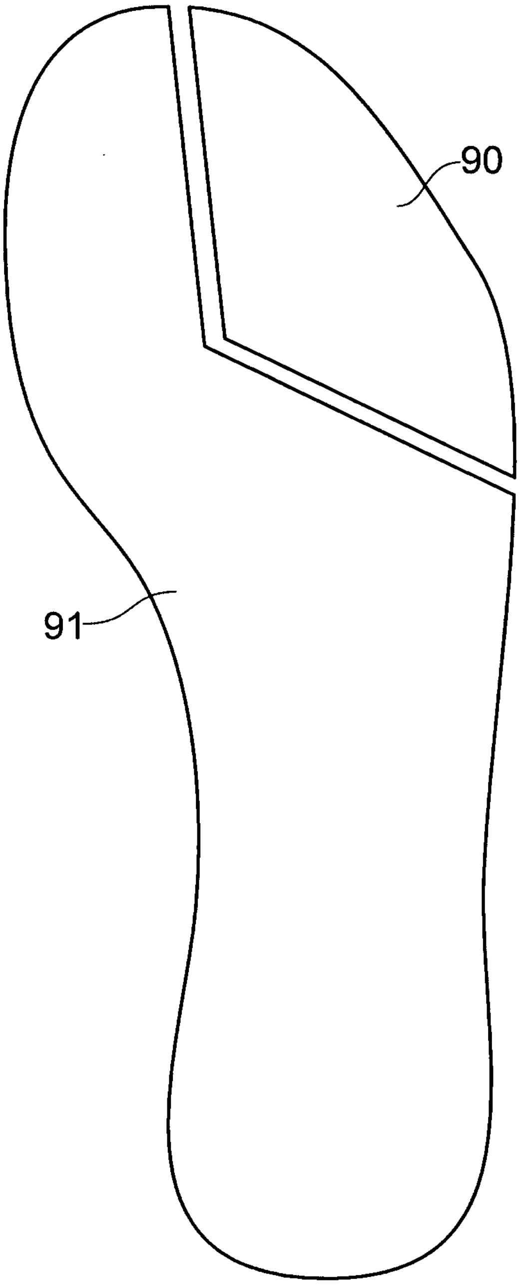

FIG. 13

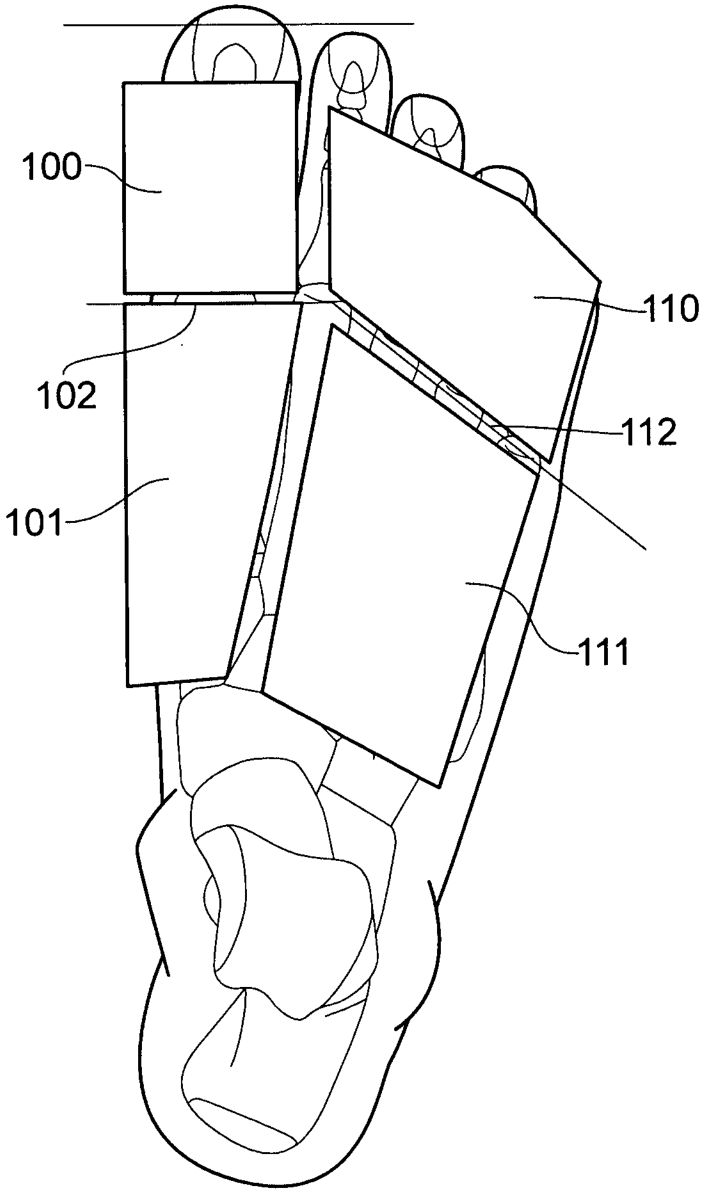

FIG. 14

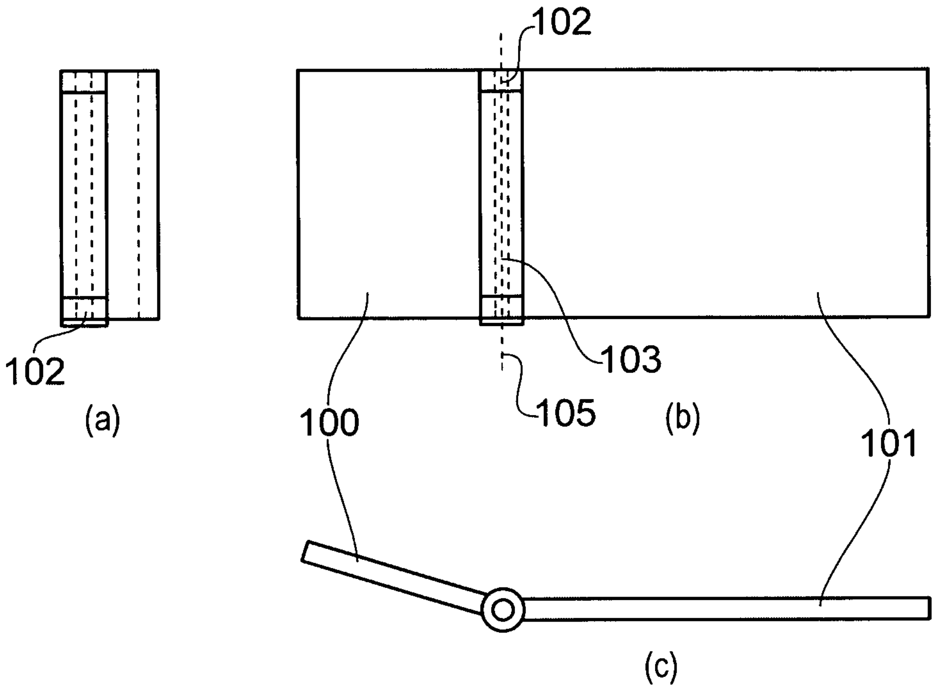

FIG. 15

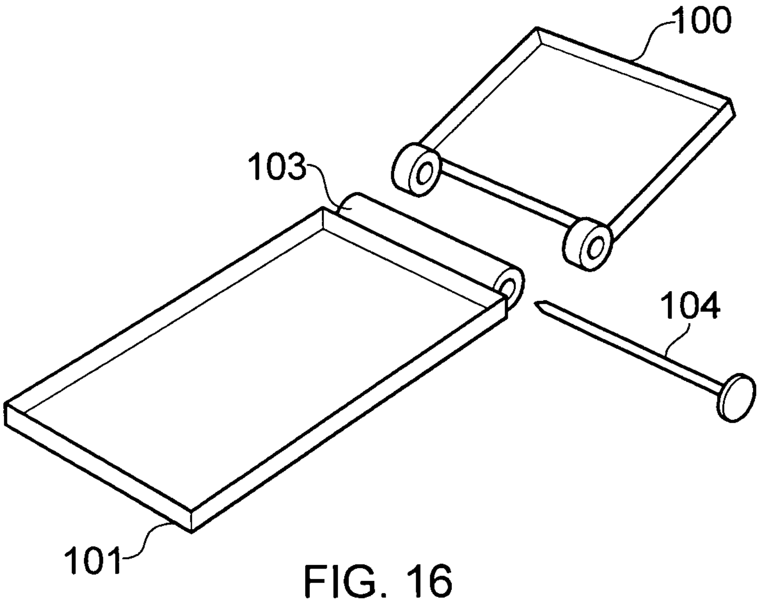

FIG. 16

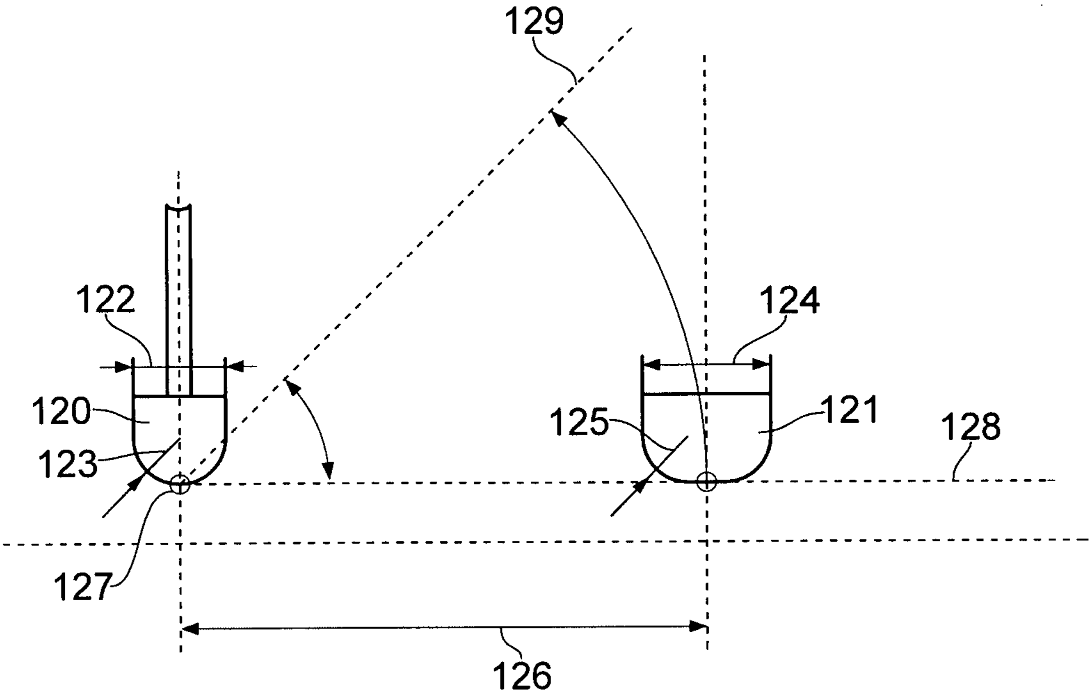
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FIG. 17

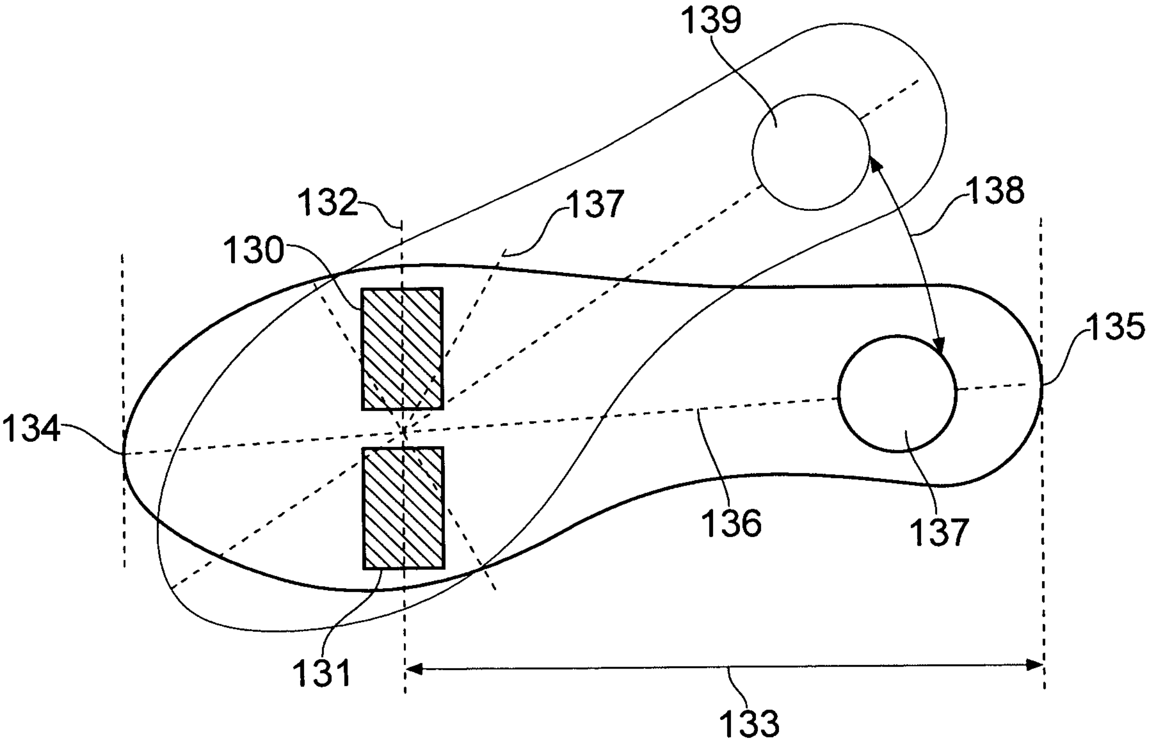
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FIG. 18

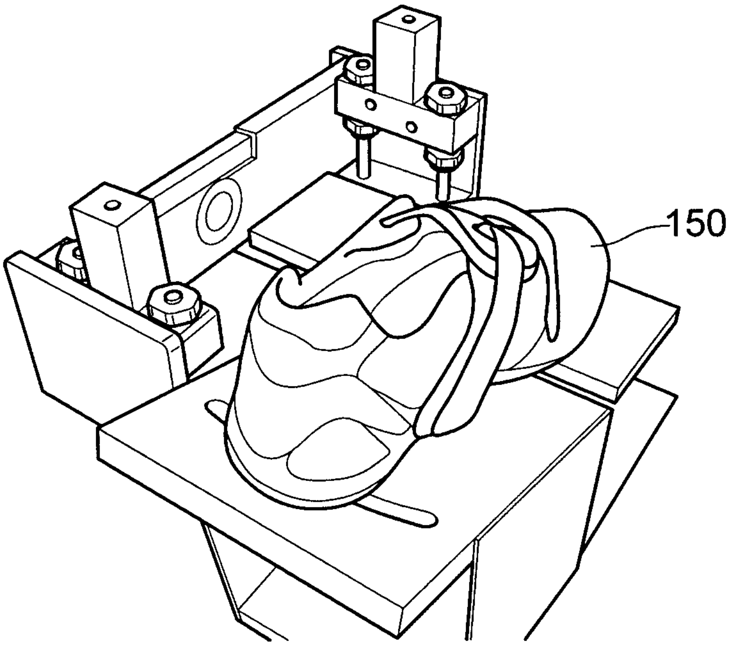

FIG. 19a

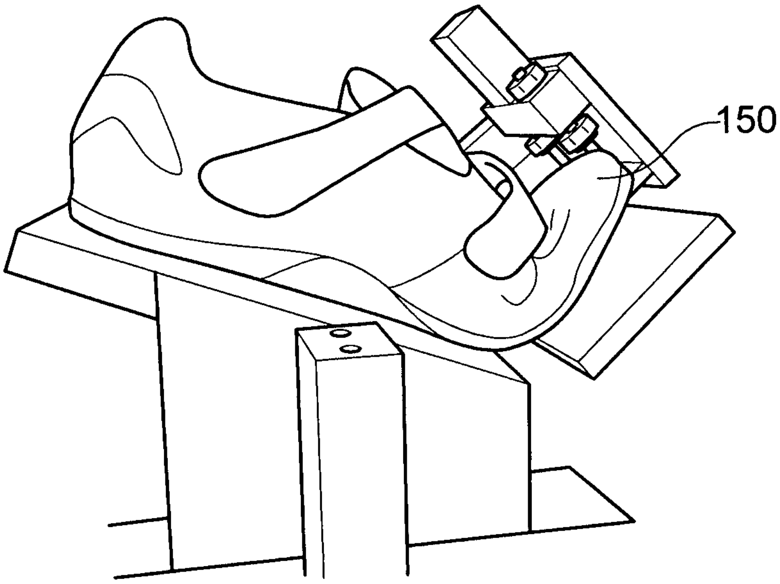

FIG. 19b

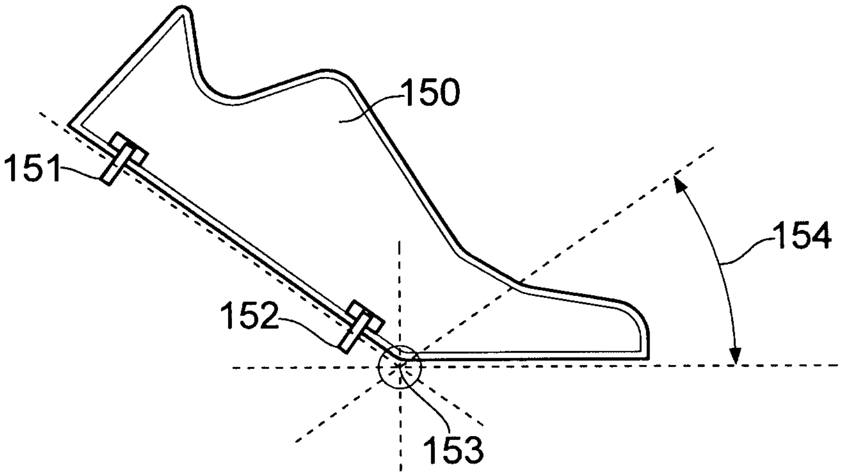

FIG. 20

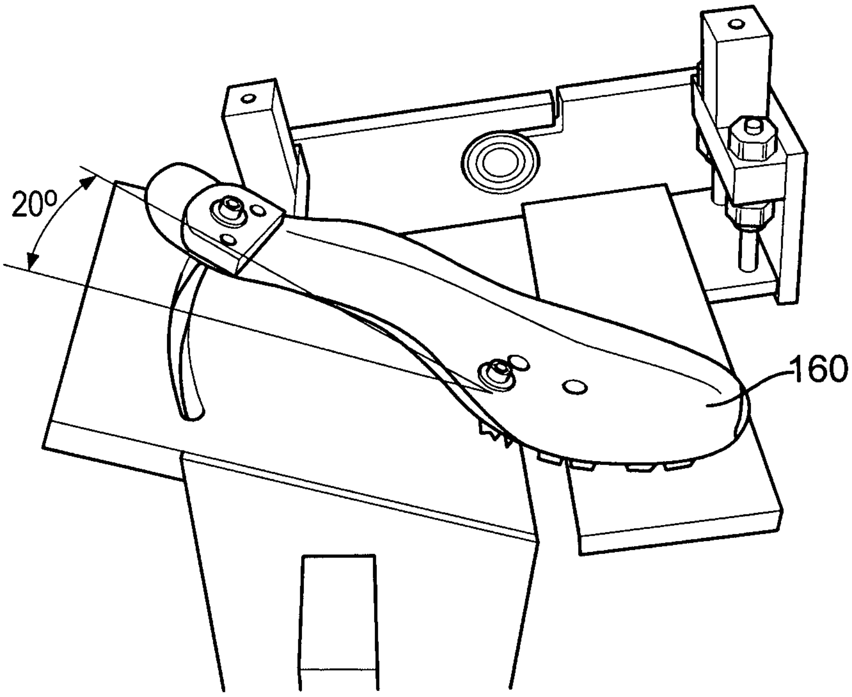

FIG. 21