3-29-2016

Gait-altering shoes

Kyle B. Reed

Ismet Handzic

US009295302B1

(12) **United States Patent**
Reed et al.

(10) **Patent No.: US 9,295,302 B1**
(45) **Date of Patent: Mar. 29, 2016**

(54) **GAIT-ALTERING SHOES**

(71) Applicants: **Kyle B. Reed**, Tampa, FL (US); **Ismet Handzic**, Lutz, FL (US)

(72) Inventors: **Kyle B. Reed**, Tampa, FL (US); **Ismet Handzic**, Lutz, FL (US)

(73) Assignee: **University of South Florida**, Tampa, FL (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 563 days.

(21) Appl. No.: **13/769,632**

(22) Filed: **Feb. 18, 2013**

Related U.S. Application Data

(60) Provisional application No. 61/600,267, filed on Feb. 17, 2012.

(51) **Int. Cl.**
A43B 7/14 (2006.01)

(52) **U.S. Cl.**
CPC *A43B 7/14* (2013.01)

(58) **Field of Classification Search**
CPC A47B 7/14; A47B 7/141; A47B 3/00; A47B 3/0005
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

942,333	A *	12/1909	Lennox	A63C 17/12	280/11.115
4,416,293	A *	11/1983	Anderson	A63B 22/02	348/77
4,600,016	A *	7/1986	Boyd	A61B 5/1038	600/592
4,631,676	A *	12/1986	Pugh	A61B 5/1038	348/77
4,745,930	A *	5/1988	Confer	A43B 3/0005	600/592
4,813,436	A *	3/1989	Au	A61B 5/1038	356/620
5,299,454	A *	4/1994	Fuglewicz	A63B 22/02	600/592
5,382,052	A *	1/1995	Tarng	A63C 1/306	280/11.27
5,474,087	A *	12/1995	Nashner	A61B 5/1036	482/54
5,607,376	A *	3/1997	Magid	A47D 13/04	482/54
5,613,690	A *	3/1997	McShane	A63B 22/18	273/449
5,831,937	A *	11/1998	Weir	A61B 5/1038	367/128
5,899,963	A *	5/1999	Hutchings	A43B 3/0005	700/14
5,947,486	A *	9/1999	Zell	A43B 5/1641	280/11.201
5,955,667	A *	9/1999	Fyfe	A43B 3/0005	702/160
6,059,062	A *	5/2000	Staelin	A43B 5/16	180/181
6,162,151	A *	12/2000	Tani	A63B 21/4009	482/54
6,237,923	B1 *	5/2001	Fowle	A63C 17/06	280/11.115

(Continued)

OTHER PUBLICATIONS

Ismet Handiz, "Design and Testing of a Motion Controlled Gati Enhancing Mobile Shoe (GEMS) for Rehabilitation", pp. 1-110, Mar. 22, 2011.

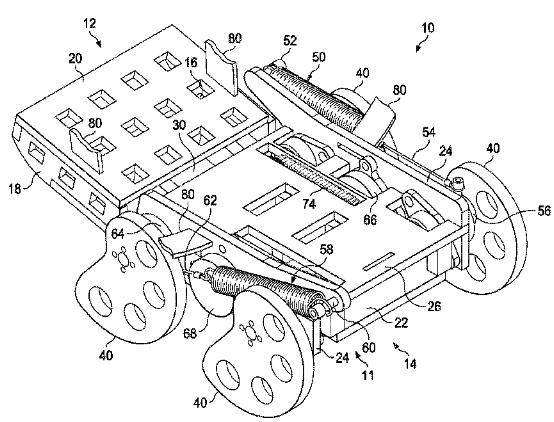
(Continued)

Primary Examiner — Brodie Follman
Assistant Examiner — Brian Cassidy
(74) *Attorney, Agent, or Firm* — Thomas | Horstemeyer, LLP

(57) **ABSTRACT**

In one embodiment, a gait-altering shoe includes a frame adapted to support a user's foot and at least one wheel that supports the frame above a walking surface, the wheel having a radius that varies as a function of angular position of the wheel.

25 Claims, 9 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

6,689,075	B2 *	2/2004	West	A61F 5/0102 482/69
6,811,523	B1 *	11/2004	Timmer	A63B 21/0004 482/146
6,836,744	B1 *	12/2004	Asphahani	A43D 1/02 377/24.2
6,882,955	B1 *	4/2005	Ohlenbusch	A43B 3/0005 324/160
7,150,722	B1	12/2006	Tyrrell	
7,153,242	B2	12/2006	Goffer	
7,367,569	B2 *	5/2008	Viitamaki	A63C 17/12 280/11.115
7,383,908	B2 *	6/2008	Tuli	A43B 3/0005 180/181
7,422,550	B1 *	9/2008	Pinero	A61H 3/008 135/65
7,552,021	B2 *	6/2009	Bar-Haim	A61B 5/1038 602/36
7,632,239	B2 *	12/2009	Dar	A61B 5/6807 600/587
7,648,472	B2 *	1/2010	McCarthy	A61F 5/0111 128/882
7,938,756	B2	5/2011	Rodetsky et al.	
7,988,647	B2 *	8/2011	Bunn	A61B 5/1038 600/587
8,006,795	B2 *	8/2011	Manor	A43B 3/0005 180/181
8,052,629	B2	11/2011	Smith et al.	
8,142,381	B1 *	3/2012	Birnbaum	A43B 7/141 128/882
8,209,147	B2 *	6/2012	Solinsky	G01C 21/005 235/105
8,413,998	B2 *	4/2013	Sano	A63C 17/0066 280/11.222
8,613,691	B2 *	12/2013	Bosecker	A61H 1/005 482/54
9,027,690	B2 *	5/2015	Chavand	A63C 17/12 180/181
9,180,025	B2 *	11/2015	Goldfarb	A61F 2/60
2004/0154192	A1 *	8/2004	Bengtsson	A43B 7/1415 36/30 R
2005/0261609	A1	11/2005	Collings	
2011/0257764	A1	11/2005	Collings	
2006/0247104	A1 *	11/2006	Grabiner	A63B 22/0292 482/54
2006/0249315	A1 *	11/2006	Herr	A61F 2/60 180/8.1
2007/0130804	A1 *	6/2007	Levy	A43B 1/0027 36/136
2007/0275830	A1 *	11/2007	Lee	A61B 5/1038 482/54
2008/0134541	A1 *	6/2008	Bar-Haim	A61B 5/1038 36/27
2008/0146968	A1 *	6/2008	Hanawaka	A61B 5/1038 600/595
2010/0038983	A1 *	2/2010	Bhugra	A61F 2/68 310/83
2010/0076360	A1	3/2010	Shimada	
2010/0268129	A1 *	10/2010	Park	A61H 1/0237 601/35
2010/0298102	A1 *	11/2010	Bosecker	A61H 1/005 482/54
2011/0208444	A1 *	8/2011	Solinsky	A61B 5/112 702/41
2013/0197407	A1 *	8/2013	Flythe, Jr.	A61H 1/0262 601/34
2014/0162858	A1 *	6/2014	Dalebout	A63B 23/02 482/142
2014/0262576	A1 *	9/2014	Tuli	A43B 3/0005 180/167

OTHER PUBLICATIONS

Groot, et al. "Gait Enhancing Mobile Shoe (GEMS) for Rehabilitation", Third Joint Eurohaptics Conference and Symposium on Haptic Interfaces for Virtual Environment and Teleoperator Systems, Mar. 18-20, 2009.

II. Handzic, E. Vasudevan, and K B. Reed, "Motion Controlled Gait Enhancing Mobile Shoe for Rehabilitation," Proc. of the 12th Intl. Conf. on Rehabilitation Robotics (ICORR), Zurich, Switzerland, Jun. 2011.

Handzic, et al., Design and Pilot Study of a Gait Enhancing Mobile Shoe, SpringerLink, Dec. 2011, vol. 2, Issue 4, pp. 193-201.

* cited by examiner

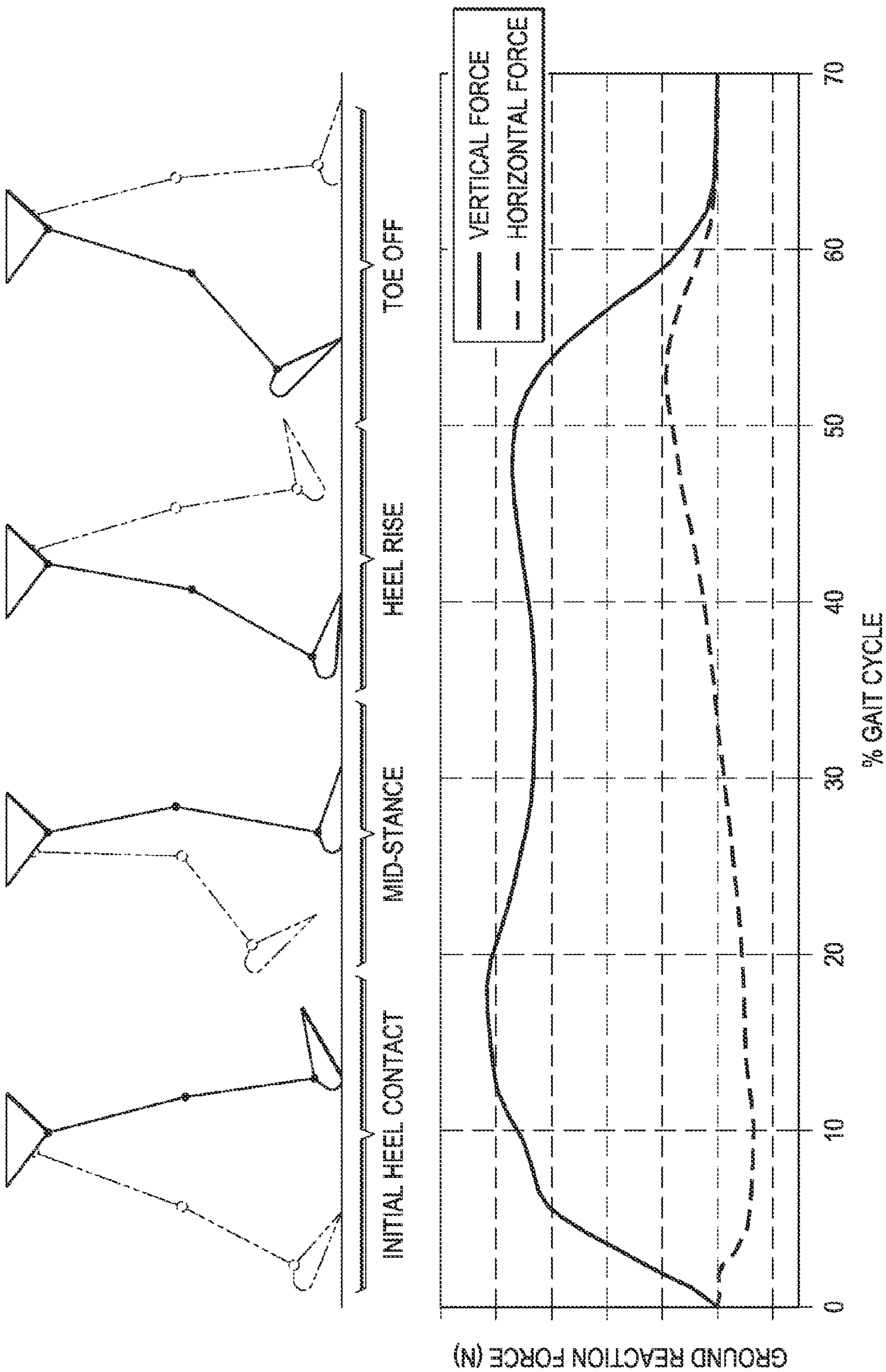


FIG. 1
(PRIOR ART)

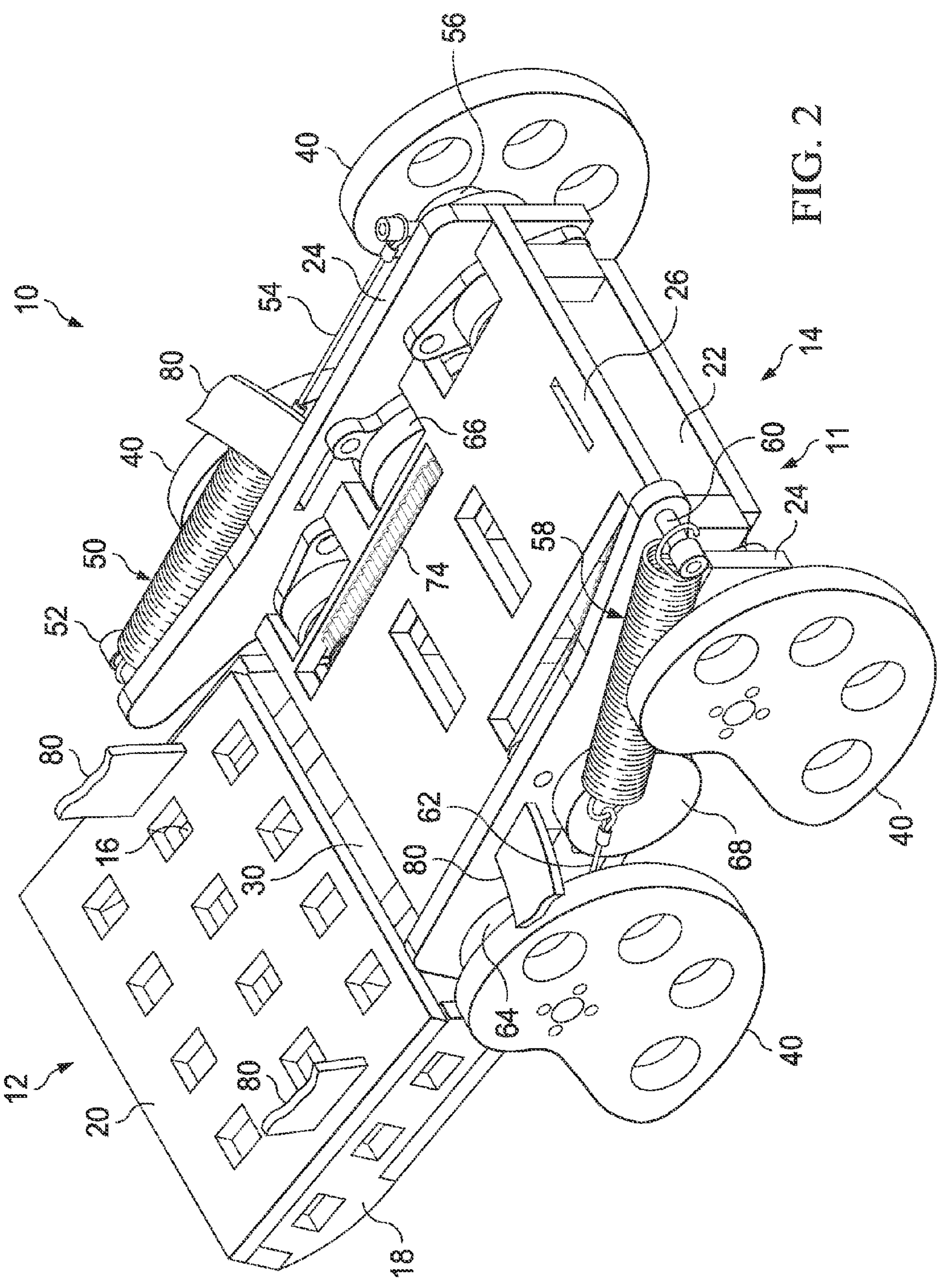


FIG. 2

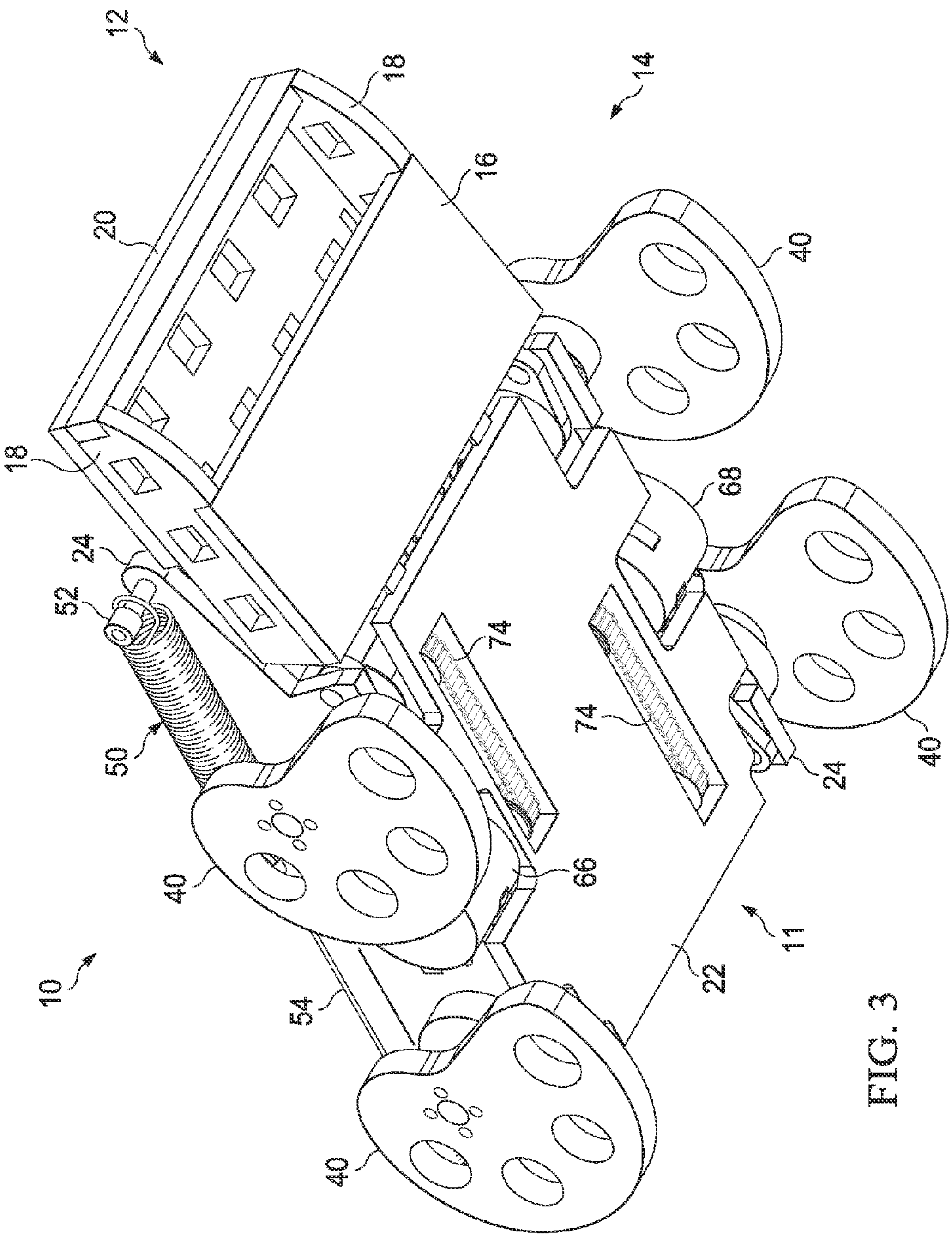


FIG. 3

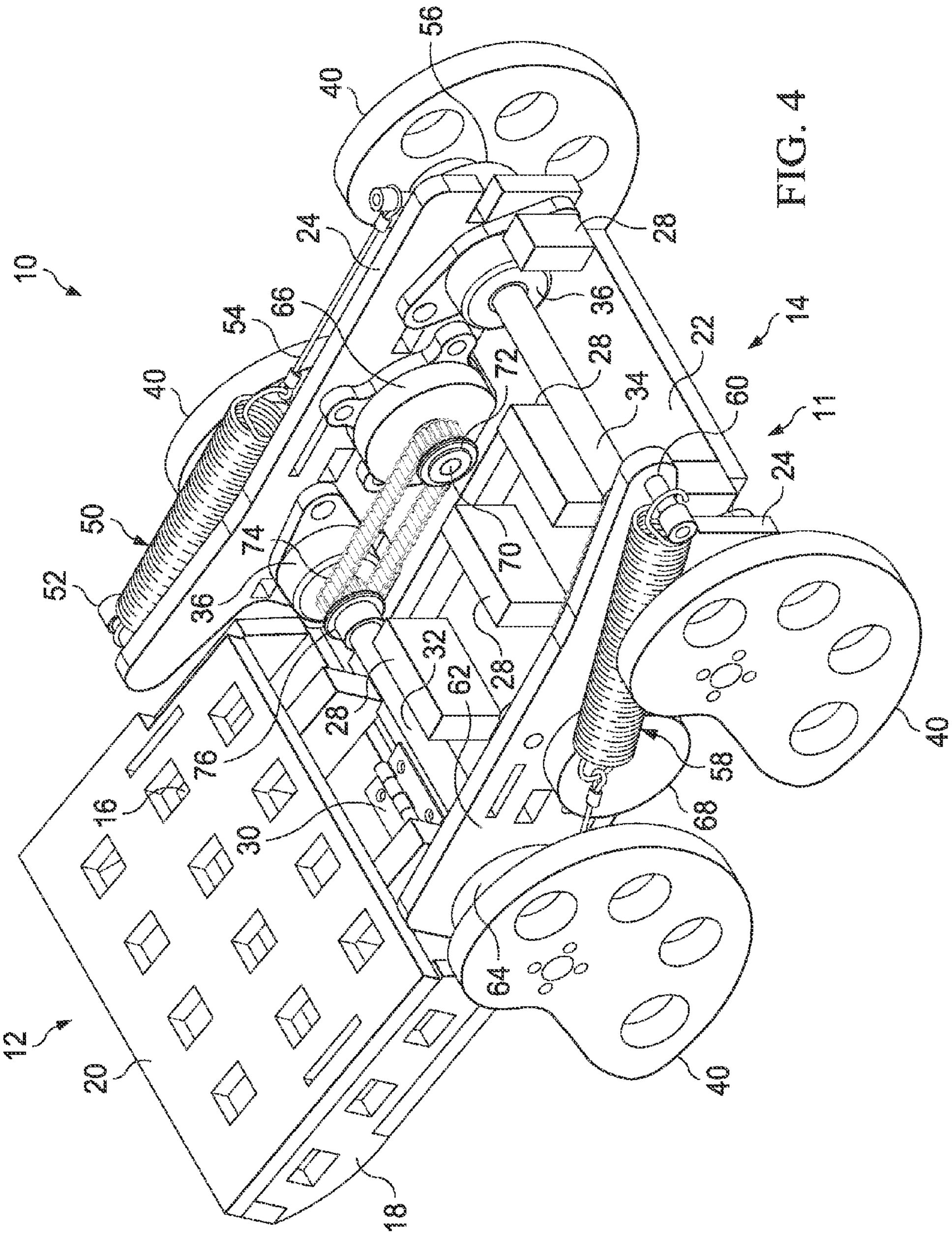

10
12
14
11
16
18
20
22
24
28
30
32
34
36
40
50
52
54
56
58
60
62
64
66
68
70
72
74
76

FIG. 4

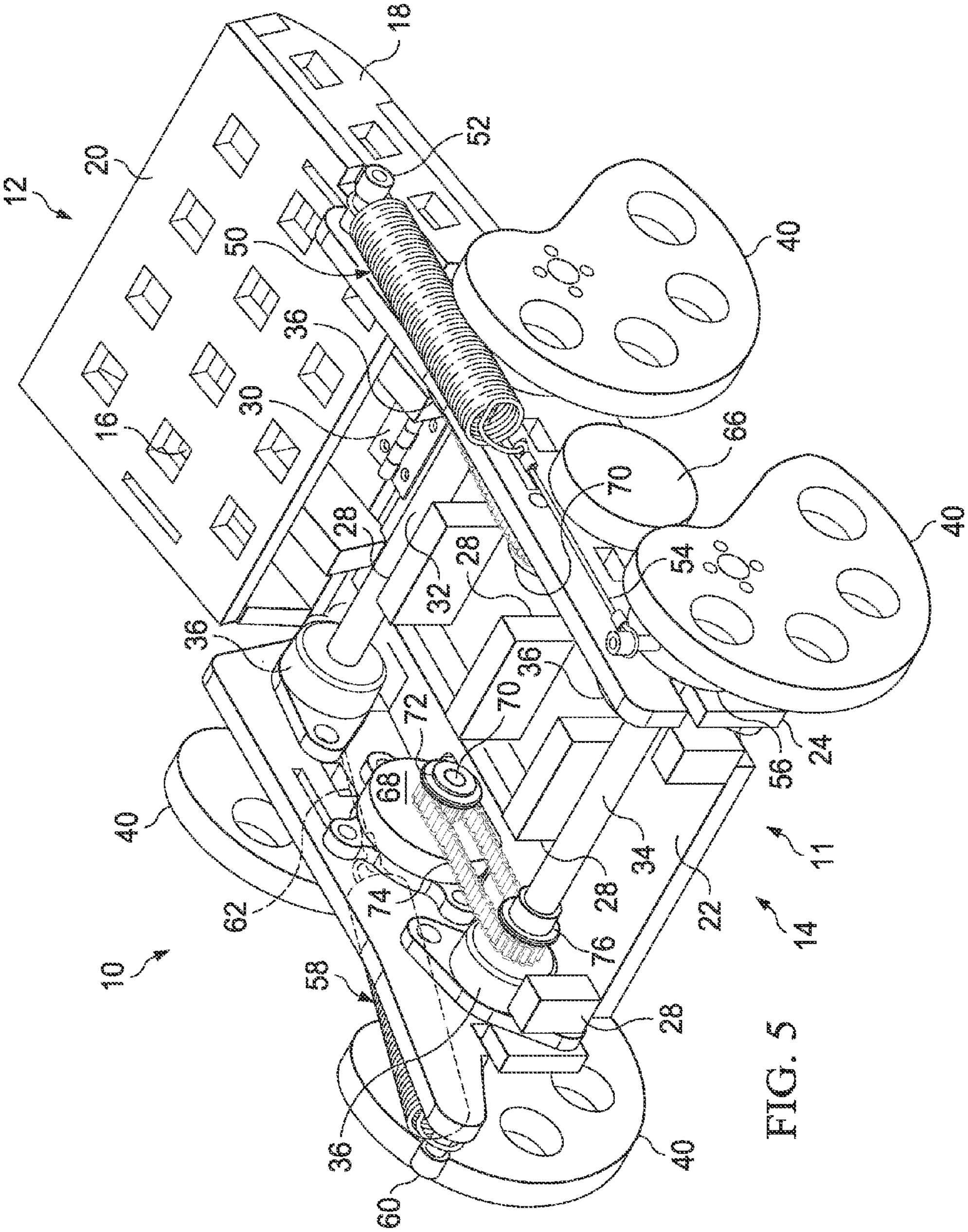

12
20
18
52
50
40
36
16
30
66
70
40
28
32
28
54
36
70
36
72
68
40
62
74
34
28
22
11
56
24
10
58
76
14
28
36
40
60

FIG. 5

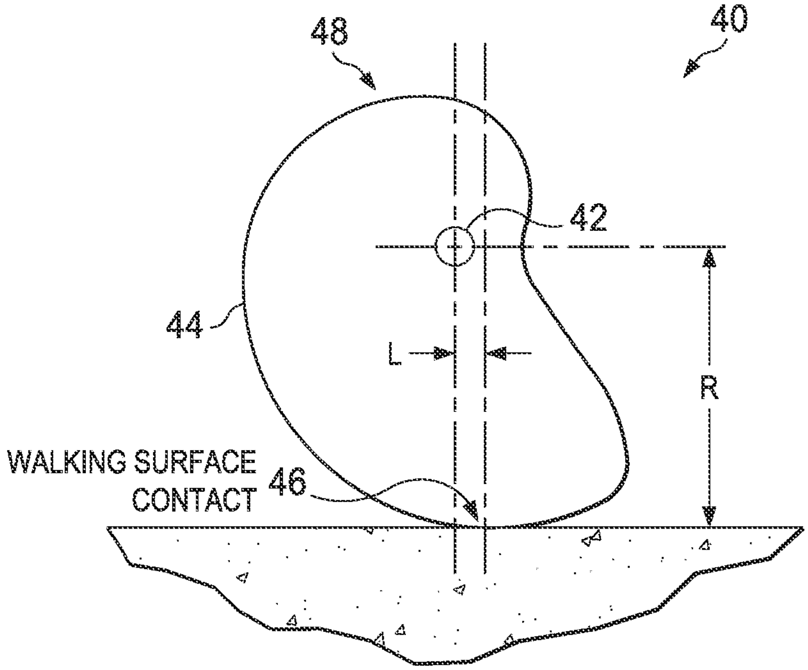

48
40
42
44
L
R
WALKING SURFACE
CONTACT
46

FIG. 6

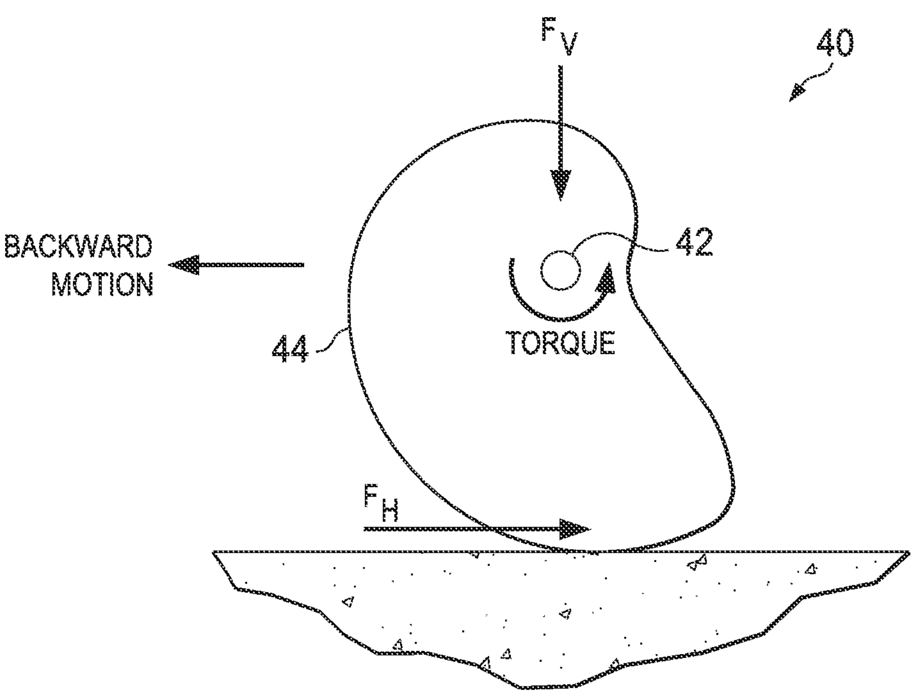

F
V
40
BACKWARD
MOTION
42
TORQUE
44
F
H

FIG. 7

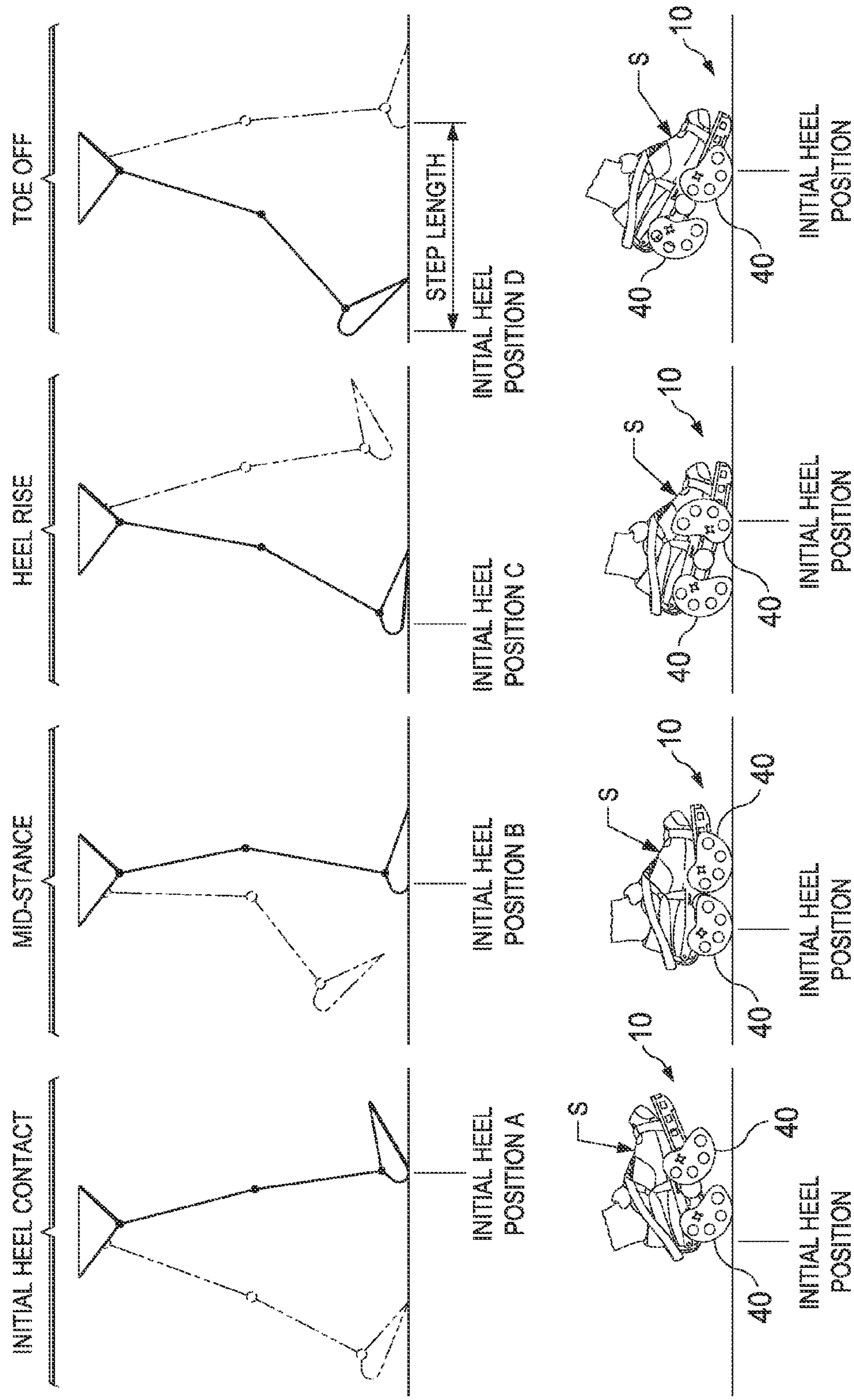

INITIAL HEEL CONTACT
MID-STANCE
HEEL RISE
TOE OFF
INITIAL HEEL POSITION A
INITIAL HEEL POSITION B
INITIAL HEEL POSITION C
INITIAL HEEL POSITION D
STEP LENGTH
S
10
40
INITIAL HEEL POSITION

FIG. 8

FIG. 9

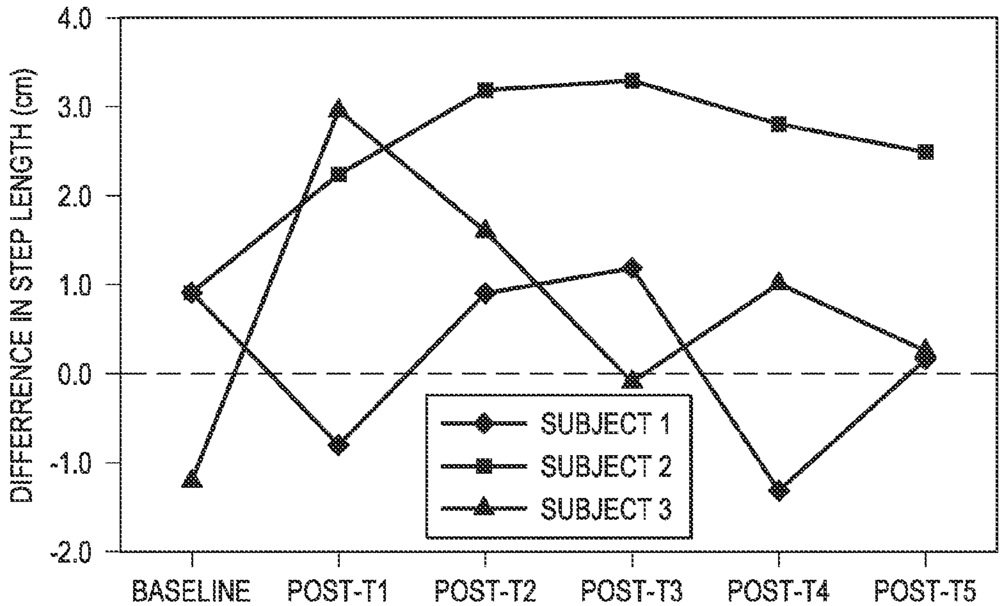
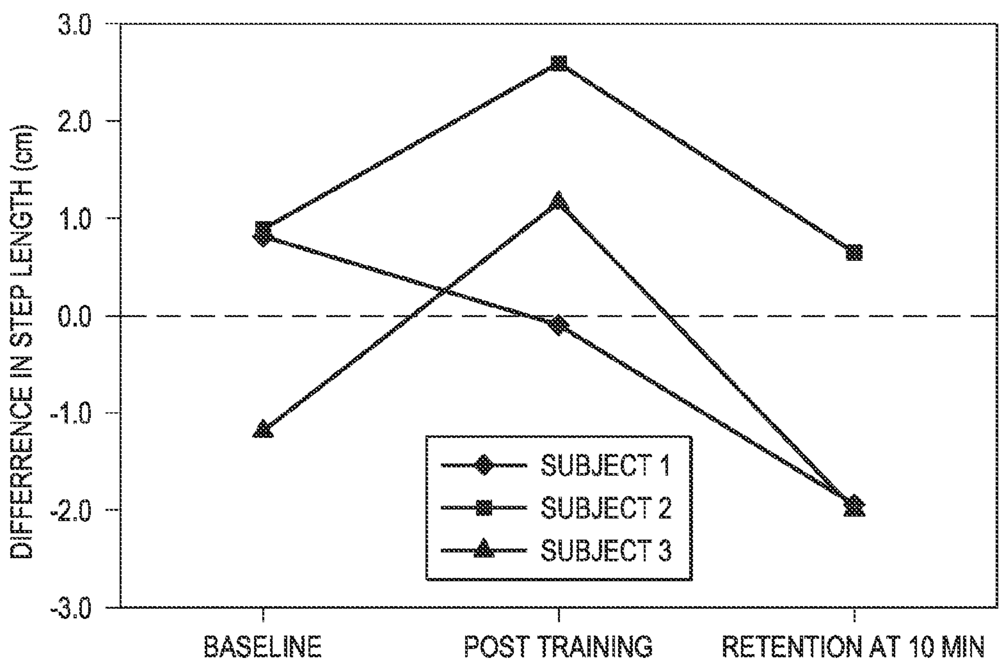

4.0
3.0
2.0
1.0
0.0
-1.0
-2.0
DIFFERENCE IN STEP LENGTH (cm)
SUBJECT 1
SUBJECT 2
SUBJECT 3
BASELINE
POST-T1
POST-T2
POST-T3
POST-T4
POST-T5

FIG. 10


3.0
2.0
1.0
0.0
-1.0
-2.0
-3.0
DIFFERENCE IN STEP LENGTH (cm)
SUBJECT 1
SUBJECT 2
SUBJECT 3
BASELINE
POST TRAINING
RETENTION AT 10 MIN

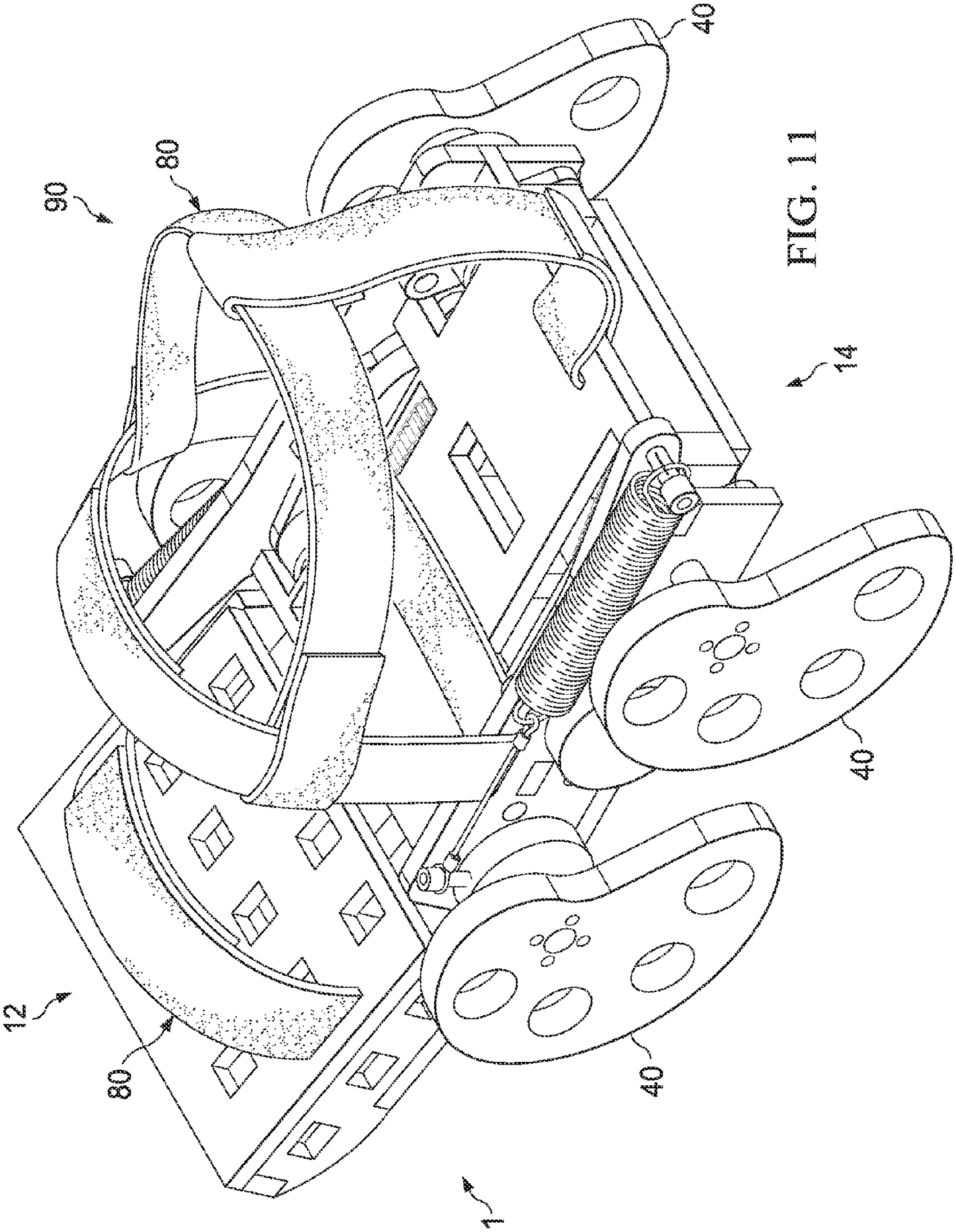


FIG. 11

GAIT-ALTERING SHOES

CROSS-REFERENCE TO RELATED APPLICATION

This application claims priority to U.S. Provisional Application Ser. No. 61/600,267, filed Feb. 17, 2012, which is hereby incorporated by reference herein in its entirety.

NOTICE OF GOVERNMENT-SPONSORED RESEARCH

This invention was made with Government support under grant 1 R21 HD066200-01, awarded by the National Institutes of Health. The Government has certain rights in the invention.

BACKGROUND

Asymmetric gait is sometimes developed in individuals with central nervous system damage, such as stroke, or in persons who have suffered damage to the spinal cord, brainstem, cerebellum, or motor cortex. In such cases, a limp is developed and the person does not fully extend his foot far enough backward, which can prevent him from effectively pushing off into the swing phase of his gait.

In such cases, rehabilitation is often provided using a split-belt treadmill having two independent belts that can be operated at different speeds to exaggerate the asymmetry of the person's gait. In particular, the belt associated with the weak leg can be driven faster than the belt associated with the strong leg. An adaptation process occurs during such rehabilitation such that, once the belts are operated at the same speed, an altered walking pattern is retained as an after-effect.

Continuous and repeated split-belt gait training has been found to temporarily restore a normal walking pattern. However, individuals with such corrected walking patterns typically only retain them for a short period of time and the gait pattern often does not transfer to walking over a normal walking surface, such as the floor or ground. Because the adaptation effects only last for a short period of time, the effects of long-term training are still unknown.

In view of the above discussion, it can be appreciated that it would be desirable to have a way to provide rehabilitation to persons with asymmetric gait other than using split-belt treadmill therapy.

BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure may be better understood with reference to the following figures. Matching reference numerals designate corresponding parts throughout the figures, which are not necessarily drawn to scale.

FIG. **1** is a schematic of the normal human gait cycle matched with a graph that identifies vertical and horizontal forces applied to a walking surface throughout the gait cycle.

FIG. **2** is a top perspective view of an embodiment of a gait-altering shoe.

FIG. **3** is a bottom perspective view of the gait-altering shoe of FIG. **2**.

FIG. **4** is a top perspective view of the gait-altering shoe of FIG. **2** illustrating internal components of the shoe.

FIG. **5** is a further top perspective view of the gait-altering shoe of FIG. **2** illustrating internal components of the shoe.

FIG. **6** is a schematic view of an embodiment of a wheel that can be used on a gait-altering shoe.

FIG. **7** is a schematic view of the wheel of FIG. **6** illustrating movement of the wheel as well as forces that are applied to the wheel during such movement.

FIG. **8** is a schematic of the normal human gait cycle matched with sequential views of the gait-altering shoe of FIG. **2** during the various phases of the gait cycle.

FIG. **9** is a graph that plots differences in step length between the left and right feet for test subjects walking without a gait-altering shoe after having walked with a gait-altering shoe.

FIG. **10** is a graph that plots the average and retention differences in step length between the left and right feet for test subjects after training with a gait-altering shoe.

FIG. **11** is a top perspective view of a further embodiment of a gait-altering shoe.

DETAILED DESCRIPTION

As described above, it would be desirable to have a way to provide rehabilitation to persons with asymmetric gait other than using split-belt treadmill therapy. Disclosed herein are gait-altering shoes that, at least in some cases, provide similar rehabilitation to the person but without limiting him or her to walking on a treadmill. In some embodiments, the shoes transform the downward force of a user's weight into a force that shifts the user's foot backward to exaggerate the user's asymmetric gait. As with a split-belt treadmill, this forces the user to put forth greater effort with his or her weak leg and helps restore normal function. In some embodiments, the gait-altering shoe includes wheels having a varying radius that automatically rotate backward under the weight of the user. In some embodiments, one or more springs are used to return the wheels to their original positions when the user lifts his or her foot and one or more dampers are used to control the backward rotation of the wheels.

Because this disclosure pertains to altering a user's gait, it is worthwhile to review the basics of a normal human gait pattern. The gait cycle can be divided into two distinct phases: the stance phase, in which the user applies weight to the walking surface, and the swing phase, in which the user swings the leg forward to take the next step. As is shown in FIG. **1**, the stance phase is preceded by initial heel contact at which time the heel first contacts the walking surface. By mid-stance, all of the user's weight is transferred to the foot. The end of the stance phase begins with the user lifting the heel of the foot (i.e., heel rise) to prepare for weight transfer to the other foot, which has been swung forward. Heel rise is then followed by toe off at which point the user pushes off with his or her foot. Stroke victims often have similar gaits but can exhibit slightly different gait patterns. The forward propulsive force is typically smaller in such persons. In addition, many stroke victims place their feet in plantar flexion, which causes a toe first step pattern and supination such that more weight is applied to the lateral side of the foot.

FIG. **1** further includes a graph that illustrates the horizontal and vertical forces that are applied by the foot during phases of the gate cycle described above. As is apparent from the graph, a slightly variable vertical force is applied during the stance phase. At a point that equates to 33% of the full gait cycle, the horizontal reaction force switches from accelerating the body backward to accelerating the body forward.

The concept of context awareness is an important consideration when altering a user's gait. Context awareness is the user's ability to unconsciously anticipate the environment while preparing for disturbances. This can be witnessed in

situations in which a person relies upon visual cues, such as stepping onto a non-operating escalator. In particular, as an individual approaches the escalator, the individual will automatically prepare to engage the escalator by leaning forward. If the escalator is not moving, however, the person may become unbalanced. This occurs because the body's internal model expects that forward lean is necessary when getting on the escalator because of the individual's many previous interactions with it, but the person stumbles because there is no acceleration from the non-moving escalator. Context awareness provides evidence of visual exteroception and the role it plays in the conditioning of the human gait and gait adaptation process in hemiplegic patients.

It is this context awareness that is hypothesized to be an integrating factor in the inability to store the previously-described feed-forward motion learned in split-belt gait manipulation research. While after-effects can be achieved, the learned gait motion disappears quickly once subjects adapt to the asymmetric treadmill speed and subsequently walk over a normal walking surface, such as the floor or ground. This may occur because the visual cues perceived while walking on a treadmill are very different from those perceived while walking over the floor or ground.

If the person's gait could be adjusted in the natural context of walking (as opposed to the context of walking on a treadmill), the problem of context awareness during the gait adaptation process would be removed. In such a case, there would be no disconnect between the visual cues perceived during the conditioning process and the visual cues perceived during the adaptation process. This suggests that gait should be adjusted with an apparatus that can be used in the natural walking context. One such apparatus is a gait-altering shoe. As is described below, a gait-altering shoe can be used to passively convert the vertical force of the user during the stance phase and redirect it into a backward motion as would a moving belt of a treadmill. Unlike when a treadmill is used, however, the backward motion is provided in the natural walking context.

FIGS. **2-5** illustrate an example embodiment of a gait-altering shoe **10**. As shown in those figures, the shoe **10** generally comprises a frame **11** that includes a front portion **12** that can be associated with the front part of a user's foot and a rear portion **14** that can be associated with a rear part of the user's foot. More particularly, the front portion **12** is adapted to span from the ball of the foot to the toes while the rear portion **14** is adapted to span from the ball of the foot to the heel.

In the illustrated embodiment, the front portion **12** of the frame **11** is defined by a base **16**, lateral sides **18**, and a top platform **20**. Although the base **16**, sides **18**, and platform **20** are shown in the figures as being separate components, it is noted that one or more of these components can be unitarily formed from the same piece of material. In some embodiments, the components are made of a polymeric or lightweight metal material. Irrespective of the construction of the front portion **12**, the platform **20** is sized and configured so as to extend across an area that is slightly greater than that of the front part of the user's foot. In some embodiments, the platform **20** can have a width of approximately 2.5 to 5 inches and a length of approximately 2 to 6 inches.

The rear portion **14** of the frame **11** is defined by a base **22**, lateral sides **24**, and a top platform **26**. Although the base **22**, sides **24**, and platform **26** are shown in the figures as being separate components, it is noted that one or more of these components can also be unitarily formed from the same piece of material. In some embodiments, the components are made of a polymeric or lightweight metal material. Irrespective of the construction of the rear portion **14**, the platform **26** is sized so as to span an area that is slightly greater than that of the rear part of the user's foot. In some embodiments, the platform **26** can have a width of approximately 2.5 to 5 inches and a length of approximately 6 to 10 inches.

FIGS. **4** and **5** illustrate the gait-altering shoe **10** with the top platform **26** of the rear portion **14** of the frame **11** removed. As is apparent from those figures, the rear portion **14** further includes spacers **28** that are positioned between the base **22** and the platform **26** to provide support to the platform to which the user's weight is applied. In some embodiments, the spacers **28** are unitarily formed with the base **22**.

As is further apparent from FIGS. **4** and **5**, the front portion **12** of the frame **11** is pivotally mounted to the rear portion **14** of the frame. More particularly, the base **16** of the front portion **12** is pivotally mounted to the base **22** of the rear portion **14** with the hinge **30**. With such a configuration, the front portion **12** can pivot relative to the rear portion **14** in a similar manner to the way in which the front part of the foot pivots relative to the rear part of the foot during the push-off phase of the gait cycle.

With further reference to FIGS. **4** and **5**, the rear portion **14** of the frame **11** supports a front axle **32** and a rear axle **34** that are perpendicular to the length direction of the frame. By way of example, the axles **32**, **34** are made of a metal material, such as steel. In the illustrated embodiment, the axles **32**, **34** are mounted to the rear portion **14** with bearings **36** that are attached to the inner surfaces of the lateral sides **24**. As is further shown in FIGS. **4** and **5**, the axles **32**, **34** extend through the bearings **36** and the lateral sides **24** of the rear portion **14** so as to extend out from opposite sides of the rear portion.

Fixedly mounted to each end of the axles **32**, **34** is a wheel **40**. Together, the four wheels **40** support the gait-altering shoe **10** above a walking surface, such as the floor or ground. FIG. **6** shows an example embodiment for the wheels **40**. As shown in that figure, the wheels **40** comprise a mounting opening **42** through which an associated axle can pass and a curved outer surface **44** that can make contact with the walking surface. As is apparent from FIG. **6**, the distance between the center of the opening **42** and the outer surface **44** (i.e., the radius, R, of the wheel **40**) varies as a function of the angular position along the wheel. In some embodiments, the outer surface **44** follows the Archimedean spiral such that the slope of the surface in polar coordinates is constant. With such a shape, the distance between the opening **42** and the outer surface **44** is much greater at a bottom **46** of the wheel **40**, where the wheel initially contacts the walking surface, than at a top **48** of the wheel, which later comes into contact with the walking surface once the user applies his or her weight to the shoe **10**. As is further shown in FIG. **6**, the opening **42** can be offset from the point at which the wheel **40** initially contacts the walking surface by a distance, L.

The above-described wheel shape is an important aspect of the gait-altering shoe design. When the wheel **40** is attached to an axle, its spiral shape redirects the wearer's downward force F_V during the stance phase into a horizontal backward motion, as shown in FIG. **7**. This resulting motion is similar to a circular wheel rolling down a hill except that the slope is attached to the foot. The shape of the wheel and the generated horizontal force F_H are determined by the following equations. The equations can also be used to determine the shape of the wheel needed to generate a specific horizontal force:

$$R(\theta) = b\theta_{\frac{1}{n}} \quad (1)$$

$$F_{H,avg} = \frac{1}{R_2 - R_1} \int_{R_1}^{R_2} F_H(R)\,dr \quad (2)$$

$$F_H = F_V * \left(\frac{L}{R}\right) \quad (3)$$

Assuming a linear increase in the size of the wheel (n=1), changing the slope at different points along the outer surface of the wheel enables optimization of the force generated at each instant of the stance phase because the relationship is based on the slope of the wheel in polar coordinates. In some embodiments, the largest radius of the wheel is approximately 2.75 inches (7.0 cm), the shortest radius is approximately 1.0 inches (2.54 cm), and n=1 so that the wheels generate an average horizontal backward force of 36 pounds (160 N) assuming an 800 pound (180 N) vertical downward force from the user.

In some embodiments, the outer surfaces **44** of the wheels **40** can be coated with a high-friction coating, such as a rubber or polymeric coating, to ensure that the wheel does not slip on the walking surface to which it is applied. Such a coating can further absorb some of the initial force transmitted to the shoe **10** when the wheel **40** first comes into contact with the walking surface.

With reference again to FIGS. **2**-**5**, the rear portion **14** of the gait-altering shoe **10** further includes biasing elements that return the wheels **40** to their original positions after they have rotated during use. In the illustrated embodiment, the biasing elements comprise a right-side spring **50** that affects the rear axle **34** and a left-side spring **58** that affects the front axle **32**. As is shown in the figures, the right-side spring **50** is connected at one end to a mounting peg **52** located at a front, right end of the rear portion **14** of the frame **11**. The other end of the spring **50** is connected to a cable **54** that extends rearward from the spring and attaches to a pulley **56** that is fixedly mounted to the rear axle **34**. The left-side spring **58** is connected at one end to a mounting peg **60** located at a rear, left end of the rear portion **14** of the frame **11**. The other end of the spring **58** is connected to a further cable **62** that extends forward from the spring and attaches to a pulley **64** that is fixedly mounted to the front axle **32**. Although the springs **50**, **58** are shown positioned outside of the rear portion **14** of the frame **11**, it is noted that they can, in some embodiments, be positioned inside the rear portion. Moreover, while a particular configuration of the springs, cables, and pulleys is shown in the figures, it is noted that other configurations are possible. The particular nature of the configuration is less important than the functionality that is provided (i.e., returning the wheels **40** to their original positions).

When the rear wheels **40** rotate backward, for example, during the stance phase of the gait cycle, the rear axle **34** and pulley **56** likewise rotate backward. When this occurs, the cable **54** is pulled toward the rear of the rear portion **14** and the spring **50** is stretched. As the heel is lifted and the force of the user's weight is removed, however, the spring **50** pulls on the cable **54** causing the pulley **56** to rotate forward, thereby returning the rear wheels **40** to their initial positions. When the front wheels **40** rotate backward, for example, during the stance phase of the gait cycle, the front axle **32** and pulley **64** likewise rotate backward. When this occurs, the cable **62** is pulled forward and the spring **58** is stretched. As the foot is lifted and the force of the user's weight is removed, however, the spring **58** pulls on the cable **62**, causing the pulley **64** to rotate forward, thereby returning the front wheels **40** to their initial positions.

With particular reference to FIGS. **4** and **5**, the rear portion **14** of the gait-altering shoe **10** can further comprise damping elements that control rotation of the wheels **40** when force is applied to them. In the illustrated embodiment, the damping elements comprise unidirectional dampers **66** and **68** that are mounted to the lateral sides **24** of the rear portion **14** of the frame **11**. Each damper **66**, **68** includes an inwardly extending shaft **70** on which is mounted a sprocket **72**. The sprockets **72** engage chains **74** that are respectively coupled to the front and rear axles **32**, **34**. Specifically, the chain **74** coupled to the right-side damper **66** is coupled to the front axle **32** with a sprocket **76** and the left-side damper **68** is coupled to the rear axle **34** with another sprocket **76**. Although chains and sprockets are illustrated in the figures and have been described, it is noted that other linkage components that provide the same function can be used. For example, rubber or polymeric belts can be used in lieu of chains.

During use, the dampers **66**, **68** limit the rotation speed of the wheels **40** and prevent a jerky motion when the user steps on the gait-altering shoe **10**. Because the dampers **66**, **68** are unidirectional, they do not limit the speed of forward rotation of the wheels **40** and therefore enable the wheels to quickly return to their initial positions. In some embodiments, the dampers **66**, **68** provide approximately 17 lb-in (1.9 N-m) of torque per axle. That amount of torque is adequate for a 180 pound (82 kg) user, but works for a range of 150 pounds (68 kg) to 190 pounds (86 kg) and can be adjusted as needed for other wearers.

As is further shown in FIG. **2**, the gait-altering shoe **10** can further comprise multiple securing straps **80** that can be used to secure the shoe to a user's foot or a normal shoe that is present on the user's foot (see FIG. **8**). In some embodiments, the straps **80** include a toe strap, a mid-foot strap, and a heel strap.

FIG. **8** comprises sequential images of the gait-altering shoe **10** during the various phases of the gait cycle. As is shown in FIG. **8**, the shoe **10** has been attached to an exercise shoe S worn by a user. In some embodiments, the gait-altering shoe **10** can be worn on the foot of the weak leg and an equivalent height and weight shoe or walking platform (not shown) can be worn on the other foot.

In image A of FIG. **8**, which illustrates initial heel contact, the rear wheels **40** of the gait-altering shoe **10** have made contact with the floor after the user has taken a step. By way of example, the bottom of the user's shoe S is approximately 3.5 inches above the floor surface when the user first initiates heel contact. The point on the floor at which initial contact was made by the rear wheels **40** is indicated in image A, as well as in images B-D. Because the user has begun to apply his weight to the shoe **10**, the rear wheels **40** have rotated about the rear axle **34**.

In image B, which illustrates the mid-stance phase, the user has placed all of his weight on the gait-altering shoe **10**. As a result, all of the wheels **40** have rotated about their axles. By way of example, the bottom of the user's shoe S is approximately 1.5 inches above the floor surface at this point. Because of the variable radiuses of the wheels **40**, this rotation has caused the shoe **10** and the user's foot to move backward from the initial contact point.

In image C, the user has begun to raise his heel and the rear wheels **40** have rotated forward under the force of the spring **50** (see FIG. **2**). Because the user's weight has transferred to the ball of the user's foot, however, the front wheels **40** have continued to rotate backward. As can be appreciated from

image C, this has resulted in even further backward motion of the shoe **10**. By way of example, the shoe **10** can have moved the foot up to approximately 12 inches backward at this point in the gait cycle.

In image D, which shows the toe-off phase, the user is about to lift his foot off of the floor. As is apparent from that image, the rear wheels **40** no longer touch the floor and have moved closer toward their original positions because of the spring **50**. In addition, the front wheels **40** have begun to return to their original positions under the force of the spring **58** (see FIG. **2**).

The therapy that the above-described gait-altering shoe provides differs significantly from that of split-belt treadmills. While the body's velocity relative to the walking surface is zero on a split-belt treadmill, the relative velocity of the gait-altering shoe is non-zero and forward. The gait-altering shoe forces the wearer's foot backward whereas the stationary foot has a zero velocity relative to the walking surface. It is anticipated that prolonged use of the gait-altering shoe will yield positive after-effects in individuals with asymmetric gait and enable those individuals to develop a more persistent symmetric gait. Training an individual with the gait-altering shoe may also strengthen muscles due to the different walking pattern that is developed, which in turn could alter the individual's gait.

Testing was performed to evaluate the effectiveness of a gait-altering shoe having a construction similar to that described above. The testing involved three subjects who were all university student males, ages 20-25, with normal walking patterns. All three subjects were measured on their baseline walking pattern before walking on the gait-altering shoe. Temporal and spatial variables of gait were evaluated using the GAITRite Walkway System (CIR Systems, Inc., PA), which is a 2-foot (0.6 m) by 16-foot (4.9 m) walkway comprising pressure sensors that are able to accurately monitor each step position. The testing emphasized the change in step length between the baseline and immediately post-training.

For the baseline measurement, each subject walked on the GAITRite Walkway System five separate times. The average step length of all five trials was recorded and later compared to post-training step length. The baseline readings were analyzed for any initial asymmetry of the subject's gait before the gait-altering shoe was strapped to the foot with the shorter step length (if present). This was done because an individual with an asymmetric gait, such as a stroke patient, would have a shorter step length on the hemiplegic side. Accordingly, the gait-altering shoe was attached to the "hemiplegic" leg of the healthy subject in order to increase the step length although the asymmetry was very small or nonexistent. In order to compensate for the height and weight of the gait-altering shoe, the subjects wore an adjustable platform on the other foot.

Each of the subjects walked back and forth on a 48-foot (14.6 m) thin carpet walkway for approximately 20 minutes. The thin carpet was used in order to increase the friction between the smooth wheels and the floor. The subjects were observed during the training and were encouraged to take normal heel-to-toe steps in order to keep a consistent gait. After 20 minutes of gait training on the gait-altering shoe, the subject was seated in a rolling chair and the gait-altering shoe and support platform were removed. The subject was then rolled to the GAITRite Walkway System in order to capture the initial steps. The subject proceeded to walk five separate times on the walkway system and each trial was recorded for later comparison to the average baseline step length.

A retention test was also performed in order to determine if any after-effects persisted over a longer time period. This was achieved by enabling the subject to walk around for 10 additional minutes at a comfortable pace without stopping. After the subject walked 10 minutes, the subject walked on the GAITRite mat five more times and an average retention step length was recorded for later analysis.

In pretesting, the gait-altering shoe pushed the user's foot back an average of 7 inches (17.8 cm) in a continuous, steady, and smooth motion. Because of its deformability, the shoe enabled the user to toe off correctly for a smooth transition into the swing phase. Every step was consistent and there was little variation, much like a split-belt treadmill. This low variation from step to step was important because it was a goal of the study to mimic the motion of a split-belt treadmill.

As mentioned above, the gait-altering shoe closely mimics a split-belt treadmill. However, unlike the split-belt treadmill, which has a tread speed ratio of 2:1, the tested gait-altering shoe had a foot speed ratio of 4:3.

The differences in step length between the foot with the gait-altering shoe and the other foot are shown in FIG. **9** for the baseline average, post-training five trials of walking 16 feet (4.9 m), and retention average. Two out of the three subjects (Subjects **2** and **3**) showed an increase in the asymmetry in the expected direction. Specifically, the leg that wore the shoe developed a longer step length in the post-training trials. This implies that adaptation was created in the gait patterns. The subject who had the opposite pattern also had the highest variability in step symmetry during baseline and retention testing, so there may be other effects affecting this subject's adaptation. The post-training average step length difference for Subjects **2** and **3** increased by 0.67 inches (1.72 cm) and 0.94 inches (2.38 cm), respectively. For both Subjects **2** and **3**, the retention after a 10-minute walking period was negligible, which can be expected in healthy subjects.

Test Subject **1** showed no average difference in step length increase, but rather a slight decrease of 0.36 inches (0.92 cm) in the reverse direction. It is apparent from FIG. **10** that the post-training step length difference fluctuated around zero. The results for Subject **1** are interesting because they show that the average retention difference in step length has a magnitude of 1.10 inches (2.77 cm) from baseline average in the reverse direction from the other two subjects. This deviation can possibly be explained by the walking style of Subject **1**. While Subjects **2** and **3** comfortably walked in a correct gait when wearing the gait-altering shoe, Subject **1** swung the leg with the gait-altering shoe around the side to compensate for the loss in step length, thus conditioning separate leg muscles. This indicates that training may be dependent upon the user walking with his or her typical gait.

The baseline average and all five post-training trials are shown in FIG. **10**. Again, test Subjects **2** and **3** show post training after-effects. Compared to their baseline difference in step length, these after-effects are very strong in Subjects **2** and **3**, although with slight differences. Subject **2** kept the after-effect over all five post-training trials, whereas Subject **3** diminishes some of the after-effect at trial **3**, regains some at trial **4**, and then diminishes again at trial **5**.

Various modifications can be made to the disclosed gait-altering shoe without materially changing its underlying functionality. For example, although the front and rear axles have been illustrated and described as being independent of each other, they can be coupled together with a linkage (e.g., a chain or belt) so that they rotate in unison. In such a case, a single spring can be used to return all of the wheels to their original positions and/or a single damper can be used to control rotation of all wheels during the stance phase of the

gait cycle. In other embodiments, the direction in which the wheels rotate can be reversed so that the shoe propels the foot forward instead of moving it backward. FIG. **11** provides an example of such an embodiment.

FIG. **11** illustrates an embodiment of a gait-altering shoe **90** that provides forward propulsion. As is apparent from FIG. **11**, the shoe **90** is similar in many ways to the shoe **10**. Accordingly, the shoe **90** comprises a frame **11** having a front portion **12** adapted to span from the ball of the foot to the toes and a rear portion **14** adapted to span from the ball of the foot to the heel. The rear portion **14** of the frame **11** supports a front axle **32** and a rear axle **34** to which are mounted wheels **40**. However, in the embodiment of FIG. **11**, the wheels **40** are reversed from the orientations shown in FIGS. **2**-**5** such that the wheels tend to rotate forward instead of backward when weight is applied to the shoe **90**. The remainder of the shoe **90** can be substantially identical to that of the shoe **10**, although the springs and dampers operate in opposite directions to return the wheels **40** to their original positions and control forward rotation of the wheels.

In some cases, a gait-altering shoe **10** can be worn on one foot and a gait-altering shoe **90** can worn on the other foot to further exaggerate the gait asymmetry and generate the greatest motion differential between the feet. In other cases, a gait-altering shoe **90** can be worn on each foot to propel both feet forward during ambulation. In still further cases, a gait-altering shoe **10** can be worn on each foot to displace each foot backward to provide exercise.

The invention claimed is:

1. A gait-altering shoe comprising:

a frame adapted to support a user's foot; and

at least one wheel that supports the frame above a walking surface, the wheel having a radius that varies as a function of angular position of the wheel such that the wheel automatically rotates when weight is applied to the shoe.

2. The shoe of claim **1**, wherein the frame comprises a front portion adapted to support a front part of the foot and a rear portion adapted to support a rear part of the foot.

3. The shoe of claim **2**, wherein the front portion is pivotally mounted to the rear portion.

4. The shoe of claim **1**, wherein the wheel comprises an outer surface that generally follows an Archimedean spiral.

5. The shoe of claim **1**, wherein the wheel is configured to automatically rotate backward as the user's weight is applied to the shoe.

6. The shoe of claim **1**, wherein the wheel is configured to automatically rotate forward as the user's weight is applied to the shoe.

7. The shoe of claim **1**, wherein the shoe comprises front wheels and rear wheels.

8. The shoe of claim **7**, wherein the front wheels are fixedly mounted to a front axle supported by the frame and the rear wheels are fixedly mounted to a rear axle supported by the frame.

9. The shoe of claim **1**, further comprising a spring associated with the wheel that returns the wheel to an initial position after the user's weight is removed from the shoe.

10. The shoe of claim **1**, further comprising a damper associated with the wheel that slows rotation of the wheel when the user applies weight to the shoe.

11. A gait-altering shoe comprising:

a frame adapted to support a user's foot, the frame including a rear portion and a front portion that is pivotally mounted to the rear portion; and

wheels mounted to the rear portion of the frame that support the frame above a walking surface, each wheel having a radius that varies as a function of angular position of the wheel such that the wheel automatically rotates when weight is applied to the shoe.

12. The shoe of claim **11**, wherein the wheels comprise an outer surface that generally follows an Archimedean spiral.

13. The shoe of claim **11**, wherein the wheels are configured to automatically rotate backward as the user's weight is applied to the shoe.

14. The shoe of claim **11**, wherein the wheels are configured to automatically rotate forward as the user's weight is applied to the shoe.

15. The shoe of claim **11**, wherein the wheels include front wheels that are fixedly mounted to a front axle supported by the frame and rear wheels that are fixedly mounted to a rear axle supported by the frame.

16. The shoe of claim **15**, further comprising a first spring that acts upon the front axle to return it and the front wheels to an initial position after the user's weight is removed from the front wheels and a second spring that acts upon the rear axle to return it and the rear wheels to an initial position after the user's weight is removed from the rear wheels.

17. The shoe of claim **16**, further comprising a first pulley mounted to the front axle to which the first spring is coupled and a second pulley mounted to the rear axle to which the second spring is coupled.

18. The shoe of claim **15**, further comprising a first damper that acts upon the front axle to slow rotation of the front wheels when the user's weight is applied to the front wheels and a second damper that acts upon the rear axle to slow rotation of the rear wheels when the user's weight is applied to the rear wheels.

19. The shoe of claim **18**, further comprising a first chain or belt that couples the first damper to the front axle and a second chain or belt that couples the second damper to the rear axle.

20. The shoe of claim **11**, further comprising straps attached to the frame that are adapted to secure the shoe to the user's foot.

21. A method for altering a gait cycle of a user, the method comprising:

attaching a gait-altering shoe to a foot of the user, the shoe including at least one wheel having a radius that varies as a function of angular position of the wheel and that automatically rotates when weight is applied to the wheel; and

displacing the user's foot with the wheel of the shoe during a stance phase of the gait cycle.

22. The method of claim **21**, wherein displacing the user's foot comprises displacing the user's foot backward in a direction opposite a direction in which the user is walking.

23. The method of claim **21**, wherein displacing the user's foot comprises displacing the user's foot forward in a same direction in which the user is walking.

24. The method of claim **21**, further comprising slowing rotation of the wheel using a damper of the shoe.

25. The method of claim **21**, further comprising returning the wheel to an initial position using a spring of the shoe.

* * * * *