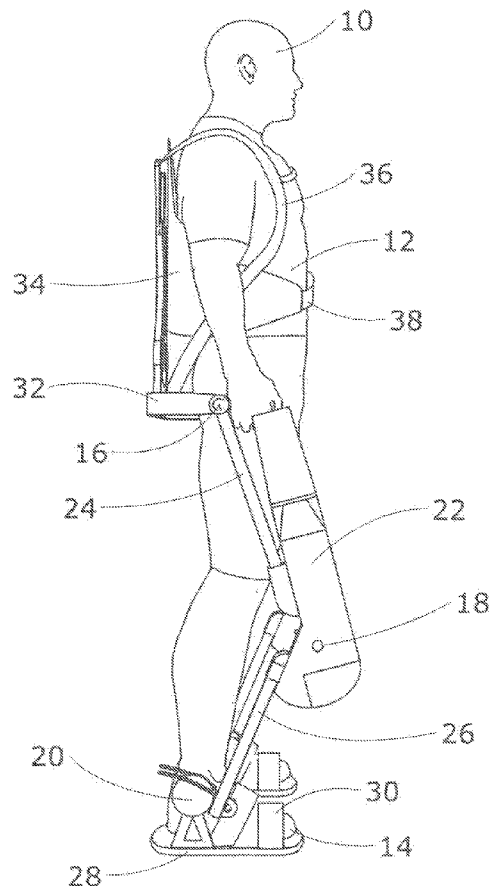




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Craig et al.(10) **Pub. No.: US 2016/0158593 A1**(43) **Pub. Date: Jun. 9, 2016**(54) **EXOSKELETON-BASED EXERCISE AND
TRAINING DEVICE****Publication Classification**(71) Applicants: **Travis Craig**, Pensacola, FL (US);
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Nick Payton, Pensacola, FL (US)(51) **Int. Cl.**
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Machine Cognition**, Pensacola, FL (US)(21) Appl. No.: **14/959,985**(22) Filed: **Dec. 4, 2015****Related U.S. Application Data**(60) Provisional application No. 62/087,389, filed on Dec.
4, 2014.(57) **ABSTRACT**

A wearable robotic device configured to provide exercise for a human user. A primary use of the device is to address muscle and bone density loss for astronauts spending extended periods in microgravity. In one configuration the device applies a compressive force between a users feet and torso. This force acts very generally like gravity—forcing the user to exert a reactive force. The compressive force is precisely controlled using a processor running software so that a virtually endless variety of force applications are possible. For example, the wearable device can be configured to apply a gravity-simulating force throughout the device's range of motion. The robotic device may also be configurable for non-wearable uses. In these cases the robotic device may act as an exercise machine. The programmable nature of the force application allows the device to simulate weight-training devices and other useful exercise devices. The device's functions may be implemented in a microgravity environment or a normal terrestrial environment.



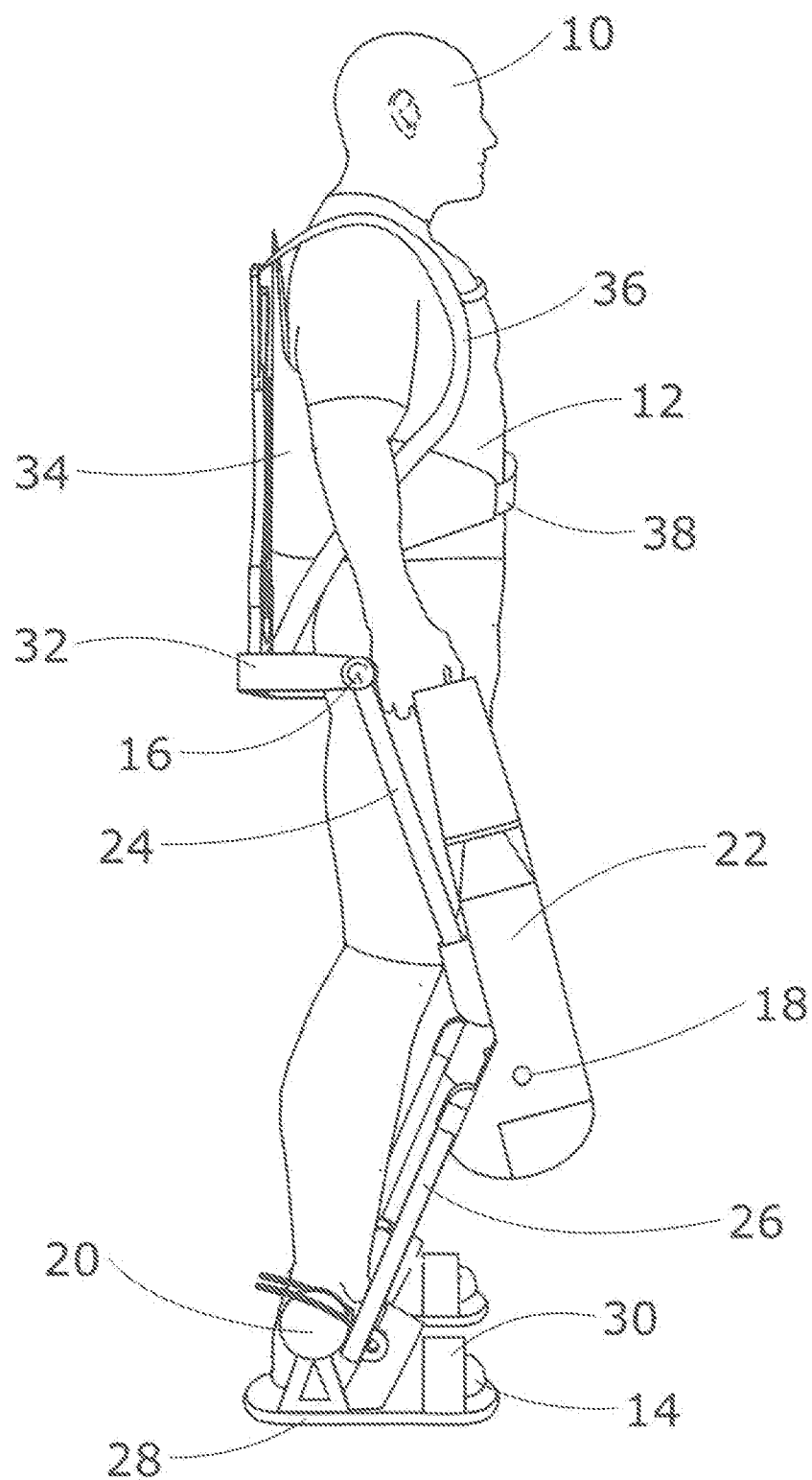


FIG. 1

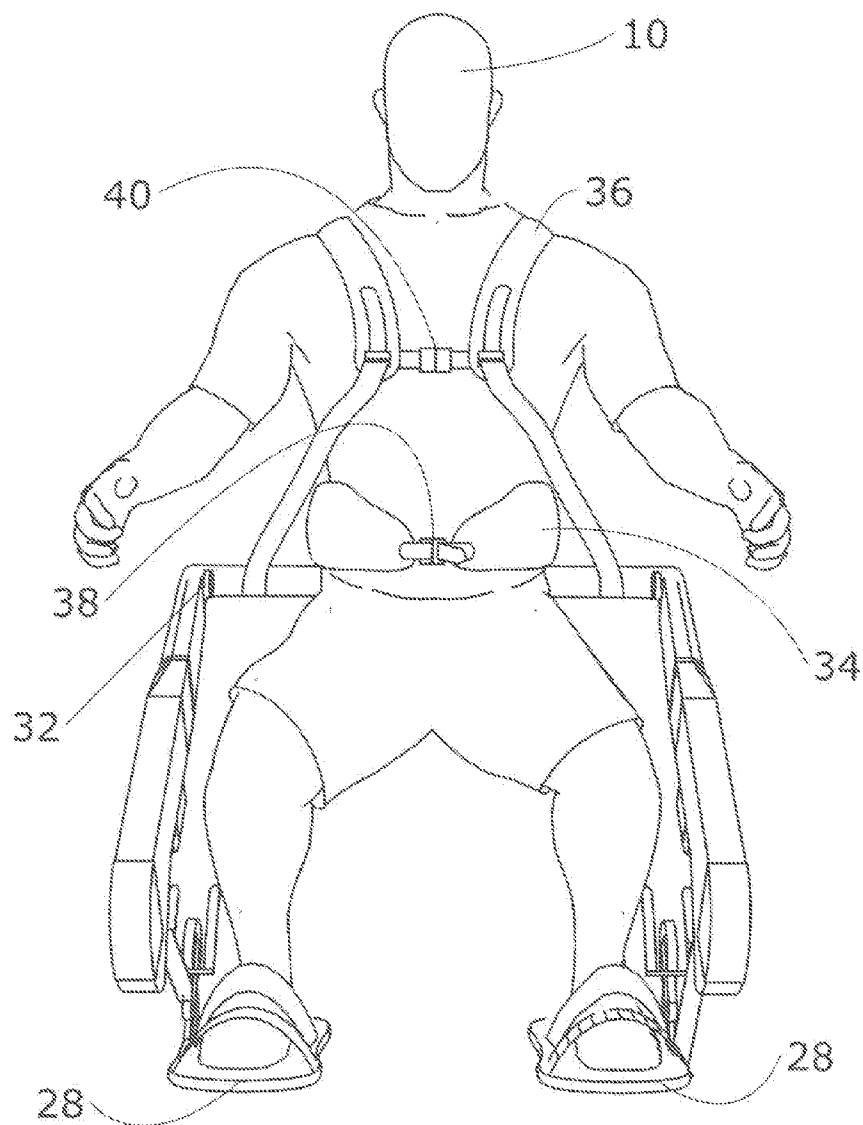


FIG. 2

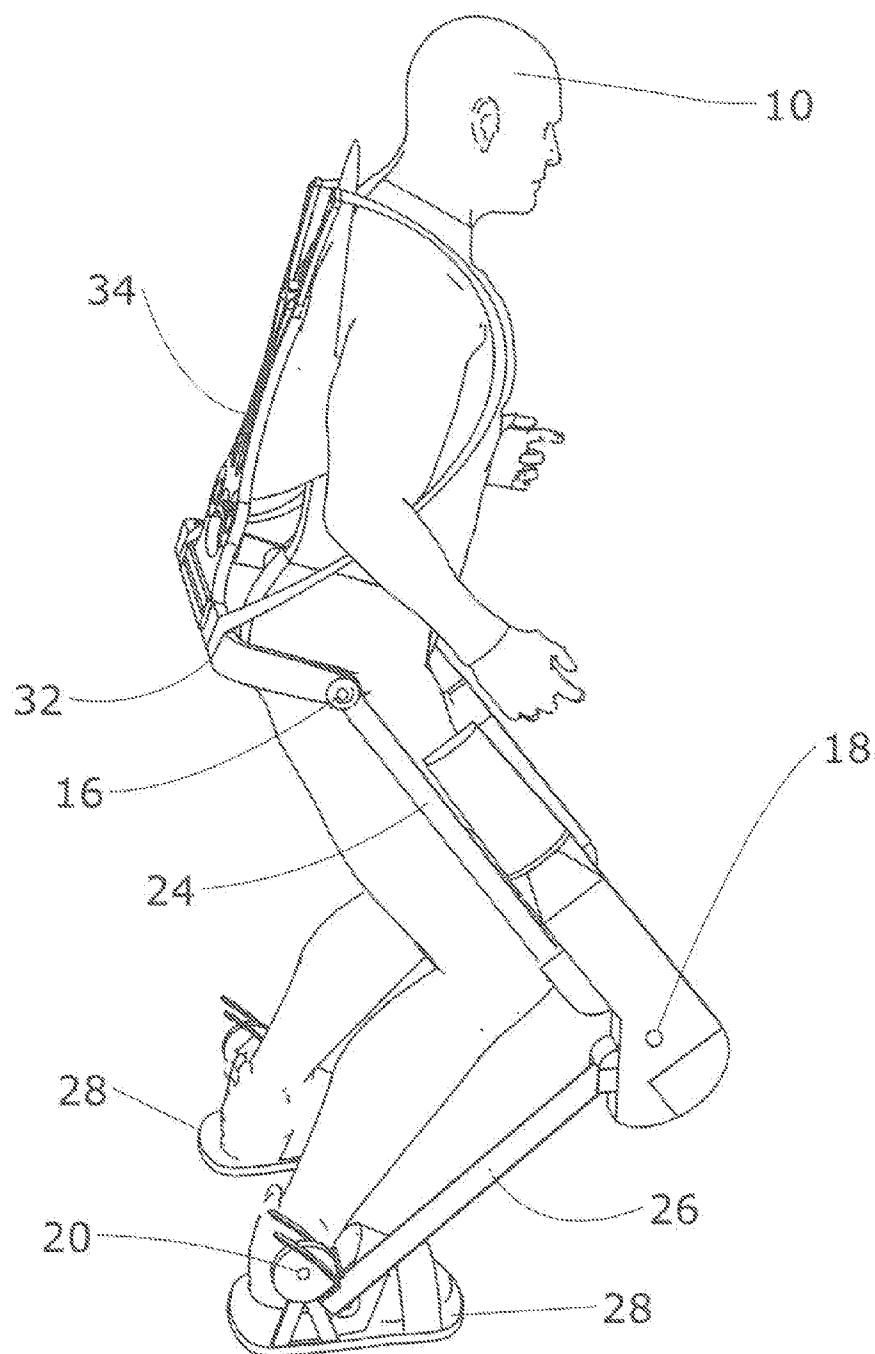


FIG. 3

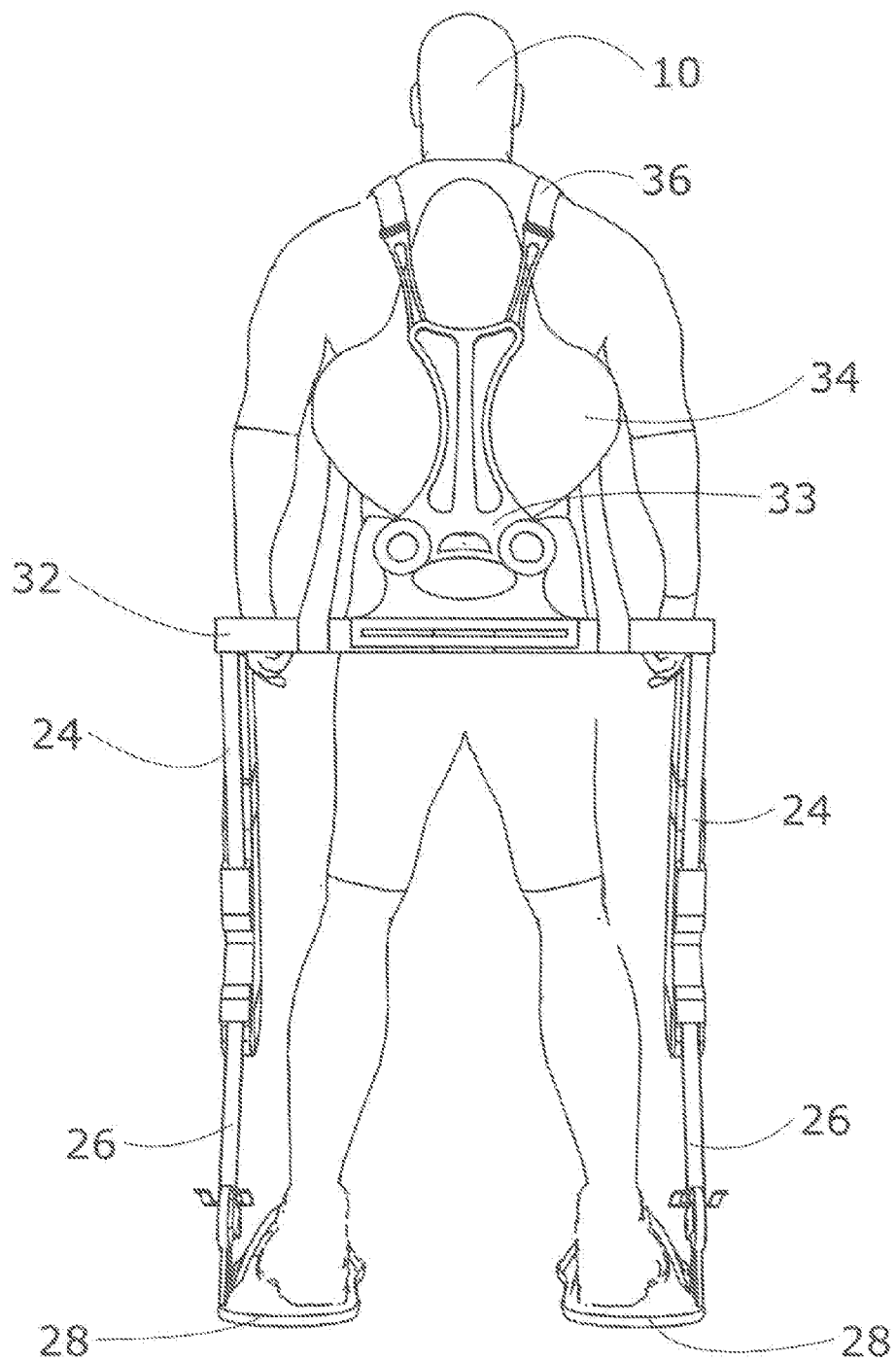


FIG. 4

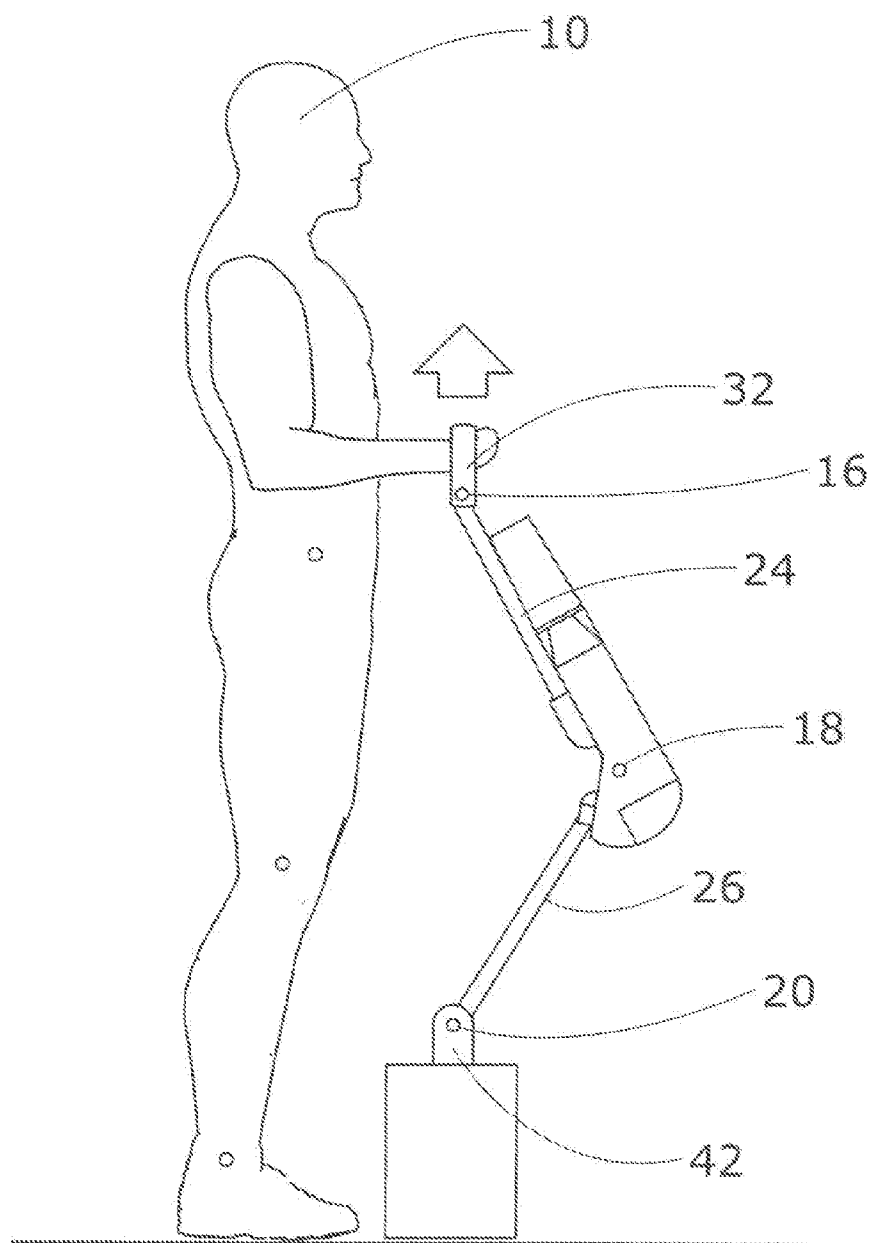


FIG. 5

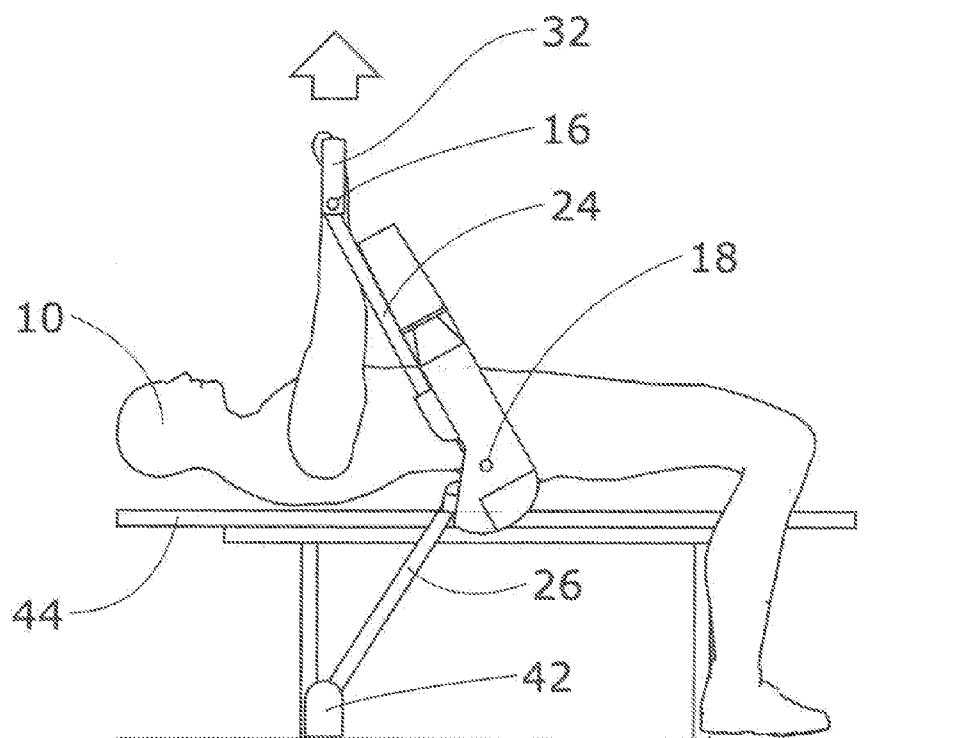


FIG. 6

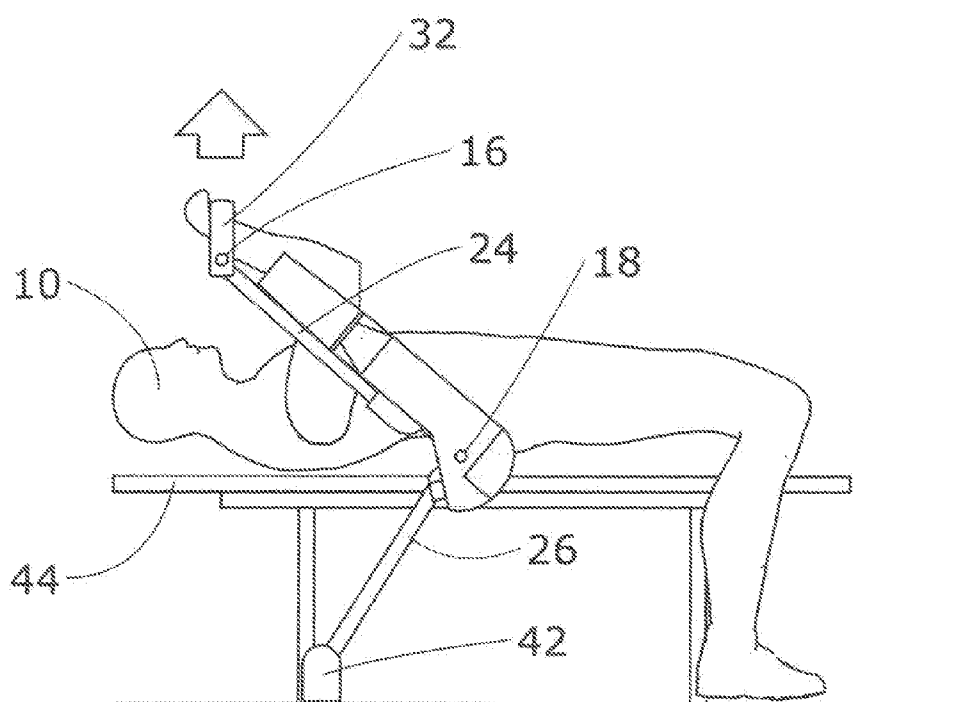


FIG. 7

EXOSKELETON-BASED EXERCISE AND TRAINING DEVICE

CROSS-REFERENCES TO RELATED APPLICATIONS

[0001] This non-provisional patent application claims the benefit of a previously filed provisional application. The provisional application was assigned Ser. No. 62/087,389. It listed the same inventors.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

[0002] Not applicable

MICROFICHE APPENDIX

[0003] Not Applicable

BACKGROUND OF THE INVENTION

[0004] 1. Field of the Invention

[0005] The present invention pertains to the field of physical exercise equipment. More specifically, the invention comprises an exoskeleton-based device that can apply force to the body in a controlled manner. Among other things, the invention is useful for simulating the forces produced by gravity in a weightless environment.

[0006] 2. Description of the Related Art

[0007] Extended weightlessness causes bone loss and other undesirable effects on the human body. Since the body's structures are not used for support and balance, muscle mass tends to be lost over time and the bones tend to become less dense. This problem has been recognized for decades. Mission planners have long realized that human beings staying in space for an extended period need exercise devices. Designing such devices is difficult, since reaction forces must be countered in order to keep the astronaut in one place.

[0008] NASA's Skylab space station included a stationary exercise bicycle. It also included a "treadmill" where bungee cords were attached to a backpack-style harness positioned to urge the astronaut toward a flat walking surface with a force of 80 kg. A TEFLON sheet was placed on the walking surface and the astronaut "walked" on the sheet by sliding his feet in a walking motion.

[0009] Space Shuttle missions employed a bungee treadmill and a cycle exercise device as well. In addition, the Space Shuttle added a zero-g rowing machine to the devices developed for Skylab. The International Space Station has employed similar devices, with a few additional strength-training devices being developed as well.

[0010] Weight is a critical factor in any hardware intended for use in space. Another important factor is the space consumed by the device. Stationary devices were used in Skylab and these were left assembled when not in use. Skylab was relatively roomy, however. Future missions likely will not have the luxury of a dedicated exercise area.

[0011] In addition, it is often difficult for an astronaut to dedicate a large block of time purely to exercise. Human beings on earth are constantly using their muscles and connective structures to move and balance under the pull of gravity. Balance and movement require little conscious thought. Thus, a human being on earth often moves and balances while performing other complex tasks.

[0012] It would be advantageous for an astronaut in zero-g to be able to exercise while performing other functional tasks.

In order to achieve this goal an exercise device should be portable so that the astronaut is free to move around. The exercise device should preferably also be fairly compact so that it does not interfere with other activity. Finally, it is preferable for the exercise device to perform multiple different functions.

BRIEF SUMMARY OF THE INVENTION

[0013] The present invention comprises a wearable robotic device configured to provide exercise for a human user. A primary use of the device is to address muscle and bone density loss for astronauts spending extended periods in microgravity. In one configuration the device applies a compressive force between a user's feet and torso. This force acts very generally like gravity—forcing the user to exert a reactive force. The compressive force is precisely controlled using a processor running software so that a virtually endless variety of force applications are possible. For example, the wearable device can be configured to apply a gravity-simulating force throughout the device's range of motion.

[0014] The robotic device may also be configurable for non-wearable uses. In these cases the robotic device may act as an exercise machine. The programmable nature of the force application allows the device to simulate weight-training devices and other useful exercise devices. The device's functions may be implemented in a microgravity environment or a normal terrestrial environment.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWINGS

[0015] FIG. 1 is a perspective view, showing a user wearing the inventive exoskeleton while in a standing position.

[0016] FIG. 2 is a front perspective view, showing a user wearing the inventive exoskeleton while in a squatting position.

[0017] FIG. 3 is a perspective view, showing a user wearing the inventive exoskeleton while in a squatting position.

[0018] FIG. 4 is a rear perspective view, showing a user wearing the inventive exoskeleton while in a standing position.

[0019] FIG. 5 is a side elevation view, showing the invention being used in a bicep curl exercise.

[0020] FIG. 6 is a side elevation view, showing the invention being used in a bench press exercise.

[0021] FIG. 7 is a side elevation view, showing the invention being used in a tricep curl exercise.

REFERENCE NUMERALS IN THE DRAWINGS

[0022] 10 user
 [0023] 12 torso
 [0024] 14 feet
 [0025] 16 hip joint
 [0026] 18 knee joint
 [0027] 20 ankle joint
 [0028] 22 actuator housing
 [0029] 24 upper link
 [0030] 26 lower link
 [0031] 28 footplate
 [0032] 30 strap
 [0033] 32 lower frame
 [0034] 33 upper frame
 [0035] 34 cradle
 [0036] 36 shoulder strap

[0037] 38 waist strap
 [0038] 40 chest strap
 [0039] 42 anchor
 [0040] 44 bench

DETAILED DESCRIPTION OF THE INVENTION

[0041] FIG. 1 depicts user 10 wearing an embodiment of the robotic device. The moving parts of the device are attached to a static frame that is connected to the user's torso 12. Cradle 34 is connected to torso 12 using a waist strap 38 and a pair of shoulder straps 36. The waist and shoulder straps preferably include conventional snaps and adjustment buckles so that a user may easily connect the straps and adjust them for a desired fit.

[0042] Lower frame 32 is attached to cradle 34 and thereby to user 10. The lower frame mounts a pair of exoskeleton "legs," each of which is connected to a foot plate 28. Each exoskeleton leg includes an upper link 24 and a lower link 26. Upper link 26 is pivotally connected to lower frame 32 at hip joint 16. In this embodiment hip joint 16 is a simple pivot joint. It is not powered in this embodiment and is instead free to rotate with minimal friction. Likewise, in the embodiment shown, ankle joint 20 is a simple, unpowered pivot joint.

[0043] Lower link 26 is pivotally connected to upper link 24 via knee joint 18. Knee joint 18 is contained within actuator housing 22. An actuator or actuators within this housing is configured to control the position of knee joint 18 and the amount of torque applied to the knee joint. The robotic knee joints are capable of high-fidelity torque control. Power for the joints may be provided by an external cable or by energy storage devices mounted on or in the exoskeleton itself.

[0044] The effect of the powered knee joint 18 is that the exoskeleton can apply a wide variety of forces between hip joint 16 and ankle joint 20. The forces applied at ankle joints 20 are transferred to the user's feet 14 through foot plates 28. The forces applied at hip joints 16 are transferred to the user's torso 12 via the "backpack"-type harness the user wears (cradle, waist strap, shoulder straps, etc.).

[0045] The applied forces may be used among other things to (1) simulate the compressive force of gravity in a static position; (2) provide resistance to movement during exercise; and (3) provide a constant load during exercise to simulate the effect of gravity.

[0046] The reader will note that the joints of the inventive exoskeleton are not aligned with the user's corresponding joints. In some rare instances there may in fact be alignment—depending on the user's anatomy—but joint alignment is not necessary or even desirable for the proper use of the inventive exoskeleton. In FIG. 1, for example, the exoskeleton's knee joint 18 is not aligned at all with the user's knee joint.

[0047] The exoskeleton may be worn while performing a wide variety of movements. FIG. 2 shows a front view of a user wearing the exoskeleton while performing a "squat" exercise. The reader will again note that the joints of the exoskeleton are generally not aligned with the user's joints. From this vantage point additional features of the harness may be seen. Chest strap 40 is provided to pull the two shoulder straps 36 inward across the chest. Waist strap 38 links the two sides of cradle 34 together.

[0048] Those skilled in the art will know that many different types of torso harnesses are known. The version shown should properly be viewed as one example among many possibilities. It is preferable to provide snap-fitting attach-

ments between the harness components. It is also preferable to provide easy length-adjustment features on the straps. Many components may be selected to provide this functionality.

[0049] The primary purpose of the harness is to transmit loads from the user's torso to the exoskeleton. The reader will note in FIG. 2 how lower frame 32 is mounted so that the robotic hip joints lie on either side of the user. The robotic "legs" likewise lie outside the normal plane of travel of the user's legs. This geometry allows the user to move his or her legs through a wide range without interfering with the robotic exoskeleton.

[0050] FIG. 3 shows a lateral perspective view of a user assuming a crouching position. The angular relationship between upper link 24 and lower link 26 has been altered to accommodate this position. Again, there is no requirement that the exoskeleton knee joint remain in alignment with the user's knee joint. Thus, depending on the height of the user, the robotic knee joint will move forward a greater or lesser amount as the user enters a crouching position.

[0051] FIG. 4 shows the inventive exoskeleton from the rear with a user in a standing position. The reader will note how the width of lower frame 32 positions the robotic "legs" so that they do not interfere with the motion of the user's legs. A wide lower frame is preferable since it can then accommodate a wider variety of user anatomy. Of course, one may also include width-adjusting features for the lower frame so that the position of the robotic hip joints can be varied laterally.

[0052] FIG. 4 shows more detail of the harness assembly. Cradle 34 encircles the user's abdomen. Upper frame 33 is attached to the cradle. Lower frame 32 is attached to upper frame 33. Shoulder straps 36 are attached to the upper portion of upper frame 33. In this view one may easily see how the links of the robotic legs attach through the ankle joints to the foot plates.

[0053] The ankle joints are preferably only capable of rotation about a single axis. This feature assures that compressive forces are applied evenly to the sole of the foot. If the robotic legs are urging the foot plates 28 upward in the view of FIG. 4, the planar foot plates move upward like the floor of an elevator. In other words, it is not the case that the outer portions of the foot plates (proximate the ankle joints) move toward lower frame 32 while the inner portions do not.

[0054] On the other hand, the presence of the ankle joints allows the user's feet to move in flexion and extension. The user may pivot the foot plates about the ankle joints in order to move the feet in flexion and extension.

[0055] The reader will thereby appreciate the functionality of the inventive exoskeleton. The device is particularly useful in the microgravity environment. The user may employ the device to simulate the effects of gravity while performing a variety of exercises—such as squats. In addition, the device may be used to maintain muscle and bone mass while performing other activities. In a microgravity environment, a user often "floats" while performing tasks. The inventive exoskeleton may be worn while performing these tasks. The exoskeleton may be programmed to apply gravity-simulating loads that the user must counteract. The user will become accustomed to the muscular effort required to counteract these forces and it will become second nature—much as standing in a balanced position is second nature. Thus, the user may continue performing tasks without giving any conscious thought to the function of the exoskeleton. However,

the exoskeleton is forcing the user to employ his or her body to counteract the forces and thereby maintain muscle mass and bone density.

[0056] Some embodiments of the invention may be used as exercise devices while not being worn as an exoskeleton. One approach to this functionality is illustrated in FIG. 4. Upper frame 33 may be selectively detached from lower frame 32 so that the backpack-style harness is removed from the rest of the device. Foot plates 28 may also be selectively removed.

[0057] FIG. 5 shows a side elevation view of the inventive device being used for exercise with the upper frame and foot plates removed. Ankle joint 20 has been pivotally attached to a stationary anchor 42. User 10 grasps lower frame 32. Gripping features may be provided or a separate, specialized lower frame 32 may be provided that is particularly configured for the exercise illustrated. The user then urges the lower frame upward in a traditional “curl” exercise.

[0058] The software controlling the powered knee joints 18 may be configured to do a variety of things in this exercise. A simple approach is for the knee joints to provide a constant gravity-simulating downward force on lower frame 32 to counteract the user’s efforts. For example, if the desired exercise is to curl a 30 kg mass, the software can be configured so that the powered knee joints produce a constant 30 kg downward force on lower frame 32.

[0059] Of course, more complex loads may also be programmed. It is known in sports physiology, for example, that it is desirable to vary the load at different portions of the arc of the “curl.” Some stationary exercise machines use a cam feature to create this effect. The software controlling the powered knee joints may be configured to produce this kind of effect as well.

[0060] FIG. 6 shows another example with the addition of bench 44. The exoskeleton is again attached to a stationary anchor 42. In this example the user is performing a “bench press” exercise. The software controlling the powered knee joints is configured to provide a constant gravity-simulating load, or a more complex load as described previously.

[0061] FIG. 7 shows another possible bench-based exercise. In this configuration the user is performing a “tricep curl.” A gravity-simulating load is again applied by the inventive device. Of course, the device may also be programmed to limit the range of travel and to sense unwanted conditions. If, for example, the user is struggling to move the position of the lower frame the software may be configured to reduce the applied load. The device may also be configured to do one or more of the following:

[0062] 1. Provide a low starting load then increase the load once movement has begun;

[0063] 2. Provide a zero-load “rest” position where the inventive exoskeleton fixes the position of the knee joints;

[0064] 3. Provide a progressively increasing load to simulate “cam” type weight machines; and

[0065] 4. Provide a pulsating load.

[0066] The inventive exoskeleton may provide many different types of load when it is being worn for “passive” muscular and skeleton maintenance (passive meaning that the user is performing other tasks and not concentrating on exercise). In this situation they device may be configured to do one or more of the following:

[0067] 1. Provide a static load simulating gravity;

[0068] 2. Provide a small variation in a static load to simulate muscle enervations needed for normal standing balance; and

[0069] 3. Provide unequal loading of the two foot plates so that the user must apply an asymmetric reaction force.

[0070] Returning now to FIG. 1, some additional optional features of the invention will be explained. First, although the embodiment of FIG. 1 includes passive hip and ankle joints, it is also possible to provide a powered joint for one or more of these. Second, it is possible to vary the position of the hip and/or ankle joints. As an example, the ankle joint may be moved anteriorly and posteriorly along the footplate. If the robotic ankle joint is moved behind the user’s ankle joint, then extension forces applied by the exoskeleton will require the user apply an extension force to the foot. On the other hand, if the robotic ankle is moved forward of the user’s ankle then an extension force applied by the exoskeleton will require the user to apply a flexion force to the foot.

[0071] Position adjustments may also be provided for the hip joints. As an example, the lower frame could include a lateral adjustment so that the lateral spacing between the robotic hip joints could be varied to accommodate differing anatomy.

[0072] The preceding description contains significant detail regarding the novel aspects of the present invention. It is should not be construed, however, as limiting the scope of the invention but rather as providing illustrations of the preferred embodiments of the invention. Many other variations are possible. Thus, the scope of the invention should be fixed by the claims presented, rather than by the examples given.

Having described our invention, we claim:

1. An exoskeleton exercise device for use by a user having a waist, a left leg, a left knee, a left foot, a right leg, a right knee, a right foot, a waist, a back, a torso, a left shoulder, and a right shoulder, comprising:

- a. an upper frame configured to lie behind said user’s back;
- b. a cradle connected to said upper frame, said cradle configured to encircle said user’s torso and thereby connect said torso to said upper frame;
- c. a lower frame connected to said upper frame, said lower frame having a right lateral extreme extending out beyond said user’s right leg and a left lateral extreme extending out beyond said user’s left leg;
- d. a right hip joint located on said right lateral extreme of said lower frame;
- e. a left hip joint located on said left lateral extreme of said lower frame;
- f. a right upper link pivotally connected to said right hip joint;
- g. a left upper link pivotally connected to said left hip joint;
- h. a right lower link pivotally connected to said right upper link by a right knee joint;
- i. a left lower link pivotally connected to said left upper link by a left knee joint;
- j. a right foot plate configured to lie beneath said user’s right foot, said right foot plate being pivotally connected to said right lower link by a right ankle joint;
- k. a left foot plate configured to lie beneath said user’s left foot, said left foot plate being pivotally connected to said left lower link by a left ankle joint;
- l. a right knee joint actuator configured to control a pivotal position of said right lower link with respect to said right upper link and configured to apply a desired torque between said right lower link and said right upper link; and
- m. a left knee joint actuator configured to control a pivotal position of said left lower link with respect to said left

upper link and configured to apply a desired torque between said left lower link and said left upper link.

2. An exoskeleton exercise device as recited in claim 1, wherein:

- a. said right foot plate is configured to be removable;
- b. said left foot plate is configured to be removable;
- c. said right ankle joint is configured to attach to an external anchor; and
- d. said left ankle joint is configured to attach to an external anchor.

3. An exoskeleton exercise device as recited in claim 1, wherein said lower frame includes a U-shaped portion with said left hip joint being located on said left side of said U-shaped portion and said right hip joint being located on said right side of said U-shaped portion.

4. An exoskeleton exercise device as recited in claim 1, wherein said right and left knee joint actuators are electrically powered.

5. An exoskeleton exercise device as recited in claim 1, wherein:

- a. said left knee joint is offset from said user's left knee; and
- b. said right knee joint is offset from said user's right knee.

6. An exoskeleton exercise device for use by a user having a waist, a left leg, a left knee, a left foot, a right leg, a right knee, a right foot, a waist, a back, a torso, a left shoulder, and a right shoulder, comprising:

- a. an upper frame configured to lie behind said user's back;
- b. a cradle connected to said upper frame, said cradle configured to encircle said user's torso and thereby connect said torso to said upper frame;
- c. a lower frame connected to said upper frame, said lower frame having a right lateral extreme extending out beyond said user's right leg and a left lateral extreme extending out beyond said user's left leg;
- d. a right shoulder strap passing from said upper frame, around said user's right shoulder, to said lower frame;
- e. a left shoulder strap passing from said upper frame, around said user's left shoulder to said lower frame;
- f. a right upper link pivotally connected to said right lateral extreme of said lower frame by a right hip joint;
- g. a left upper link pivotally connected to said left lateral extreme of said lower frame by a left hip joint;

h. a right lower link pivotally connected to said right upper link by a right knee joint, said right knee joint including a right actuator;

i. a left lower link pivotally connected to said left upper link by a left knee joint, said left knee joint including a left actuator;

j. a right foot plate configured to lie beneath said user's right foot, said right foot plate being pivotally connected to said right lower link by a right ankle joint;

k. a left foot plate configured to lie beneath said user's left foot, said left foot plate being pivotally connected to said left lower link by a left ankle joint;

l. said right knee joint actuator configured to control a pivotal position of said right lower link with respect to said right upper link and configured to apply a desired torque across said right knee joint; and

m. a left knee joint actuator configured to control a pivotal position of said left lower link with respect to said left upper link and configured to apply a desired torque across said left knee joint.

7. An exoskeleton exercise device as recited in claim 6, wherein:

- a. said right foot plate is configured to be removable;
- b. said left foot plate is configured to be removable;
- c. said right ankle joint is configured to attach to an external anchor; and
- d. said left ankle joint is configured to attach to an external anchor.

8. An exoskeleton exercise device as recited in claim 6, wherein said lower frame includes a U-shaped portion with said left hip joint being located on said left side of said U-shaped portion and said right hip joint being located on said right side of said U-shaped portion.

9. An exoskeleton exercise device as recited in claim 6, wherein said right and left knee joint actuators are electrically powered.

10. An exoskeleton exercise device as recited in claim 6, wherein:

- a. said left knee joint is offset from said user's left knee; and
- b. said right knee joint is offset from said user's right knee.

* * * * *