

(19)



(11)

EP 2 134 427 B1

(12)

EUROPEAN PATENT SPECIFICATION

(45) Date of publication and mention of the grant of the patent:

19.12.2018 Bulletin 2018/51

(51) Int Cl.:

A61B 5/00 (2006.01)

(21) Application number: **08732785.4**

(86) International application number:

PCT/US2008/058078

(22) Date of filing: **24.03.2008**

(87) International publication number:

WO 2008/116228 (25.09.2008 Gazette 2008/39)

(54) SYSTEM AND METHOD FOR TRAINING HUMAN SUBJECTS TO IMPROVE OFF-AXIS NEUROMUSCULAR CONTROL OF THE LOWER LIMBS

SYSTEM UND VERFAHREN ZUM TRAINIEREN VON PROBANDEN ZUR VERBESSERTEN AUSSERAXIALEN NEUROMUSKULÄREN STEUERUNG DER UNTEREN GLIEDMASSEN

SYSTÈME ET PROCÉDÉ DESTINÉS À ENTRAÎNER DES SUJETS HUMAINS AFIN D'AMÉLIORER LE CONTRÔLE NEUROMUSCULAIRE HORS-AXE DES MEMBRES INFÉRIEURS

(84) Designated Contracting States:

AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR

• **PARK, Hyung-Soon**

**North Potomac
MD 20878 (US)**

(30) Priority: **22.03.2007 US 919401 P**

(74) Representative: **Adamson Jones**

**BioCity Nottingham
Pennyfoot Street
Nottingham NG1 1GF (GB)**

(43) Date of publication of application:

23.12.2009 Bulletin 2009/52

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(73) Proprietor: **Rehabtek LLC**

Wilmette, IL 60091 (US)

(72) Inventors:

- **ZHANG, Li-Qun**
Wilmette, IL 60091 (US)
- **REN, Yupeng**
Chicago, IL 60611 (US)

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Description

FIELD OF INVENTION

[0001] The present invention relates to the field of exercise training and injury prevention and rehabilitation.

BACKGROUND OF INVENTION

[0002] Musculoskeletal injuries of the lower limbs are associated with the strenuous sports and recreational activities. The knee was the most often injured body area, with the anterior cruciate ligament (ACL) as the most frequently injured body part overall (Lauder et al., Am J Prev. Med., 18: 118-128, 2000). Approximately 80,000 to 250,000 ACL tears occur annually in the U.S. with an estimated cost for the injuries of almost one billion dollars per year (Griffin et al. Am J Sports Med. 34, 1512-32). The highest incidence is in individuals 15 to 25 years old who participate in pivoting sports (Griffin et al., J Am Acad Orthop Surg. 8, 141-150, 2000). Considering that the lower limbs are free to move in the sagittal plane (e.g., knee flexion/extension, ankle dorsi-/plantar flexion), musculoskeletal injuries generally do not occur in sagittal plane movements. On the other hand, joint motion about the minor axes (e.g., knee valgus/varus (synonymous with abduction/adduction), tibial rotation, ankle inversion/eversion and internal/external rotation) is much more limited and musculoskeletal injuries are usually associated with excessive loading/movement about the minor axes (or called off-axes). The ACL is most commonly injured in pivoting and valgus activities that are inherent to sports and high demanding activities, for example. It is therefore critical to improve neuromuscular control of off-axis motions (e.g., tibial rotation / valgus at the knee) in order to reduce/prevent musculoskeletal injuries. However, existing exercise equipment (e.g., elliptical machine, treadmill, and stair climber) focuses on the sagittal plane movement. There is a lack of convenient and effective equipment and methods to train people for strenuous and high-risk activities involving off-axis loading. Training off-axis motions such as tibial rotation or valgus in isolation is unlikely to be practical and effective. A training program that addresses the specific issue of off-axis movement control during sagittal plane stepping/running functional movements will be helpful in preventing musculoskeletal injuries of the lower limbs during strenuous and training and in real sports activities.

[0003] US 6,514,180 discloses apparatus and methods for exercising using skating motion. The apparatus includes a frame having left and right pedal guides, left and right pedals moveably coupled to the left and right pedal guides, and a pedal control device. The pedal control device is coupled to the left and right pedals such that as one of the left or right pedals is moved along its pedal guide, the other pedal is moved in an opposite direction along its pedal guide, and both the left and right pedals rotate in a first rotational direction. As the pedals

are moved back along their respective pedal guides in opposite directions, the pedal control device simultaneously rotates the pedals in a second rotational direction. The apparatus may thereby provide an improved simulation of skating, and may increase the user's enjoyment of the exercise.

[0004] SU 1533710 discloses a device for training skiers, specifically cross country skiers, which serves to increase the effectiveness of training by approximating the real conditions of hand and feet movements. A frame is provided with sliders and footplates connected by belts and pulleys so as to simulate actual skiing conditions.

SUMMARY OF INVENTION

[0005] According to the present invention there is provided an off-axis training and evaluation mechanism as defined in the appended claim 1. Further beneficial features of the invention are recited in the associated dependent claims. Claims 12-17 define beneficial uses of the mechanism of claim 1 and its dependent claims.

[0006] The off-axis training and evaluation mechanism of the invention is designed to help human subjects improve neuromuscular control about the off-axes including external/internal tibial rotation, valgus/varus, inversion/eversion, and sliding in mediolateral, anteroposterior directions, and their combined motions (change the "modifiable" factors and reduce the risk of ACL and other lower limb injuries). Practically, an isolated tibial pivoting or frontal plane valgus/varus exercise against resistance in a seated posture, for example, is not closely related to functional weight-bearing activities and may not provide effective training. Therefore, off-axis training is combined with sagittal plane movements to make the training more practical and potentially more effective. In practical implantations, the off-axis training (e.g., pivoting/sliding) mechanism can be combined with various sagittal plane exercise/training machines including the elliptical machines, stair climbers, stair steppers, and exercise bicycles. Furthermore, the off-axis training (e.g., pivoting/sliding) mechanism can be implemented for an individual off-axis such as pivoting mechanism only or the sliding mechanism only, or it can be implemented in the combined axes such as pivoting-sliding mechanism.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007]

Fig. 1. (A) A pivoting-sliding mechanism combined with controlled tibial rotation (pivoting) and mediolateral sliding, which can be combined with any sagittal plane exercise machine for off-axis as well as sagittal plane training and evaluations. The footplate rotation and mediolateral sliding are controlled by two servomotors and various combinations of perturbations can be applied flexibly. (B) Top view of the pair of pivoting-sliding mechanisms. (C) The piv-

oting-sliding mechanism combined with an elliptical machine with controlled tibial rotation (pivoting) and mediolateral sliding (knee valgus/varus) during sagittal plane stepping/running movement.

Fig. 2. Real-time feedback used for the pivoting-sliding elliptical training. The subject is asked to follow the virtual reality (VR) cues and keep the feet pointing forward as indicated by the target shoe positions during the sagittal stepping movement. A web camera is used to capture and display the lower limb posture in real time, which helps the subject align the lower limbs properly in the frontal plane. Target lower limbs and shoe positions are indicated by the arrows to help the subject reach desired target limb/foot positions.

Figs 3A and B do not form part of the claimed invention: Fig. 3. (A) A pivoting elliptical machine with controlled pivoting (tibial rotation) during sagittal plane elliptical stepping movement, with the pivoting driven by the sagittal plane movement through cables. Movement of the sliding wheel on the ramp causes coupled rotation of pivoting disk. (B) . A stair climber with added movement and training in tibial rotation, for training and exercises in pivoting. Through the cable arrangement, the stepping movement of the stair climber causes coupled rotation of the footplate. A turn-buckle can be used to adjust the tension of the cable and the coupling between the sagittal stair climbing and pivoting movements.

Fig. 4. A pivoting mechanism with controlled tibial rotation (pivoting), which can be combined with sagittal movement using various exercise machines. The footplate rotation is controlled by a servomotor and various perturbations can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to rotate.

FIG. 5. A sliding mechanism with controlled mediolateral sliding, which can be combined with sagittal movement. The footplate sliding is controlled by a linear motor and various perturbations can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to slide.

Fig. 6. The pivoting-sliding mechanism **2010** combined with a stair climber with controlled tibial rotation (pivoting) and mediolateral sliding (knee valgus/varus) during sagittal plane stair-climbing movement. The footplate pivoting and sliding are controlled by a rotary motor through cable and a linear motor, respectively. Various perturbations in pivoting and/or in sliding can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to rotate/slide.

Fig. 7. Not forming part of the claimed invention: A sliding mechanism with controlled anteroposterior sliding, which can be combined with sagittal movement. The footplate sliding is controlled by a linear motor and various perturbations can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to slide.

Fig. 8. A X-Y sliding mechanism with controlled anteroposterior and mediolateral slidings, which can be further combined with sagittal stepping/running movement. The footplate sliding is controlled by a pair of linear motors and various perturbations can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to slide in the anteroposterior and mediolateral directions.

Fig. 9. The pivoting mechanism can be combined with a tilting mechanism with controlled inversion/eversion and/or dorsiflexion/plantar flexion to form a pivoting-tilting mechanism. With rear end of the footplate resting on a ball-socket joint **700**, the two linear actuators **720** (also anchored on ball-socket joints at both ends **730** and **740**) can perturb the footplate and move it into target positions in inversion/eversion and/or in dorsiflexion/plantar flexion. The pivoting-tilting mechanism can be combined with a sagittal plane training machine such as an elliptical machine or stair climber to perform pivoting/tilting training during sagittal plane movement. The footplate pivoting and tilting are controlled by a rotary motor through a cable mechanism and a linear motor, respectively. Various perturbations in pivoting and/or in tilting can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to rotate/tilt.

Fig. 10. Integrated training with pre-training diagnosis, off-axis training, followed by post-training evaluations.

Fig. 11. The subject performed the pivoting elliptical exercise using the novel pivoting elliptical machine. (a) The footplates were locked in the elliptical movement. (b) The footplates were perturbed by a series of torque pulses which rotate the footplates back and forth. The subject was asked to perform the elliptical movement while maintaining the foot pointing forward. Notice that the enhanced muscle activities when the subject performed the elliptical movement with rotation perturbations. From top to bottom, the plots show the footplate external rotation torque (tibial internal rotator muscle generated torque was positive), sliding wheel position (a measurement of elliptical cycle), footplate rotation angle (external rotation is positive), and EMG signals from the rectus femoris, vastus lateralis, semitendinosus, biceps femoris, medial gastrocnemius, and lateral gastroc-

nemius.

Fig. 12. (a) Stability in tibial rotation during the pivoting elliptical exercise before and after 5 sessions of training using the pivoting elliptical machine. The data are from the same female subject. Notice the considerable reduction in rotation angle variation and thus improvement in rotation stability. (b) Rotation instability of a female subject before and after 5 sessions of training during forward elliptical exercise with foot free to rotate. Similar results were observed in backward pivoting elliptical movements. (c) Rotation instability of multiple subjects before and after 5 sessions of training during forward pivoting elliptical exercise with footplate perturbed in rotation by the motor.

Fig. 13. (a) Proprioception of the female subjects before and after 5 sessions of training, and the males (before training only). (b) Reaction time of the female subjects before and after 5 sessions of training, and between females and males (before training only). The subject stood on the left leg (100% body load) on the pivoting elliptical machine with the right knee flexed and unloaded (0% body load). From left to right, the 4 groups of bars correspond to the reaction time for external rotating (ER) the loaded left leg, the reaction time for internal rotating (IR) the loaded left leg; the reaction time for external rotating the unloaded right leg; and the reaction time for internal rotating the unloaded right leg.

LIST OF REFERENCE NUMERALS

[0008]

100. Servo motor for the pivoting function
 110. Gear head
 120. Torque sensor
 130. Small cable pulley for transferring the pivoting movement
 140. Supporting beams
 150. Big cable pulley for driving the pivoting movement
 160. Cable for the torque and rotation transmission
 200. Shoe holding plate
 210. Shoe side blocks
 220. Toe clip
 230. Shoe side clips
 300. Supporting plate for holding the whole setup
 310. Back linear bearing guide
 311. Front linear bearing guide
 320. Small supporting plate for holding the pivoting setup
 330. Safety block for the pivoting exercise
 400. Servo motor for the sliding function
 410. Medial safety block for the sliding exercise
 411. Lateral safety block for the sliding exercise

420. L-shape link for transferring the sliding force and movement
 430. Linear guide driven by the servo motor
 440. Force sensor
 450. Small L-shape link
 500. Servo motor
 501. Gear head
 510. Sliding block
 520. Linear guide driven by the servo motor
 530. Setup for inversion and eversion of the foot movement
 600. Big cable pulley for driving the pivoting movement
 610. Cable pulley
 620. Cable
 630. Cable pulley
 640. Cable pulley
 650. Cable holder
 700. Back ball-socket joint
 710. Mounting plate
 720. Right Linear actuator
 730. Support ball-socket joint
 740. Top ball-socket joint
 750. Left Linear actuator
 1000. Popular exercise device (Elliptical Machine)
 1010. Mounting space on the popular exercise device
 1020. Potentiometer cable
 1030. Potentiometer for measuring the moving cycle
 2010. Pivoting and sliding mechanism mounting on the left side
 2020. Pivoting and sliding mechanism mounting on the right side
 3000. Mounting base
 3010. Rotating beam
 3020. Big pulley disk for transferring the pivoting movement
 3030. Cable pulley
 3040. Cable pulley
 3050. Cable
 3060. Passive damping mechanism

DETAILED DESCRIPTION OF THE INVENTION

[0009] The invention is about off-axis training and evaluation in general including multiple off-axes and applicable to multiple sagittal plane exercise machines. In the following, application of the combined pivoting and sliding mechanism to an elliptical machine is focused on and used as an example for simplicity.

A Novel Pivoting/Sliding Elliptical Machine

[0010] The traditional footplates of an elliptical machine are replaced with a pair of custom pivoting-sliding mechanism (Fig. 1). The subject stands on each of the pivoting-sliding mechanism through a rotating disk, which is free to rotate about the tibial rotation axis. The

subject's shoes are mounted to the rotating disks through a toe strap and medial and lateral shoe blockers (or use a mechanism like a snowboard binding mounted on the rotating disk), which makes the shoe rotate together with the rotating disk while allows the subject to get off the machine easily (Fig. 1A and Fig. 1B). Each rotating disk is controlled by a servomotor through a cable-driven mechanism (Fig. 1A). An encoder and a torque sensor mounted on the servomotor measure the pivoting angle and torque, respectively (Fig. 1).

[0011] The pivoting mechanism including the rotating disk and controlling motor (Fig. 1) will be mounted on a pair of linear guides (with mechanical limits/stops at both ends) and controlled by a linear motor in the mediolateral direction (Fig. 1A and Fig. 1B). The mediolateral movement causes perturbation in knee valgus/varus. The foot rotation and the mediolateral movements can be controlled individually for isolated pivoting or valgus training, or they can be controlled simultaneously for combined pivoting and valgus movements. Combined with the sagittal movement, the machine can potentially be programmed to generate 3-D movement synchronized with the stepping cycle (Fig. 1C).

[0012] A linear position sensor is used to measure the linear movement of the sliding wheel on the ramp and thus determine the stride cycle of the elliptical movement (Fig. 1C). 0% corresponds to the highest position of the sliding wheel on the ramp and a full cycle corresponds to a stride (Fig. 1C). If needed, surface EMG can be used to evaluate the activation patterns of muscles in the lower limb to investigate which muscles are activated at what phase of the elliptical movements and to study the influence of tibial rotation/valgus movements, elliptical movement direction (forward and backward), and slope of the sliding ramp on muscle activities (Fig. 1).

[0013] Training in pivoting/sliding control can be done under the motor control in two modes:

1. The footplate is perturbed back and forth by tibial rotation (pivoting) torque and/or frontal plane mediolateral sliding force during the sagittal plane stepping/running movement. The subject is asked to resist the foot/tibial rotation torque and/or mediolateral foot-sliding force, and keep the foot pointing forward and lower limb aligned properly while doing the sagittal movements. Perturbations are applied to both footplates simultaneously during the pivoting/sliding elliptical training. The perturbations will be random in timing so the subject can not predict and reaction to the individual perturbation pulses. The tibial rotation/mediolateral perturbation torque/position amplitude, direction, frequency, and waveform can be adjusted conveniently. The perturbations will be applied throughout the exercise but can also be turned on only for selected time if needed.

2. The footplate is made free to rotate/slide and the subject needs to maintain stability and keep the foot straight and lower limb properly aligned during the

elliptical stepping/running exercise.

[0014] Both modes are used to improve neuromuscular control in tibial rotation and/or valgus/varus.

Training Off-axis Neuromuscular Control Using the Pivoting/Sliding Elliptical Machine

[0015] Real-time feedback of the footplate position is used to update a virtual reality display of the feet, which is used to help the subject achieve proper foot positioning (Fig. 2A). A web camera is used to capture the lower limb posture, which is played in real-time to provide qualitative feedback to the subject to help keep the lower limbs aligned properly (Fig. 2B).

[0016] The measured footplate rotation/slide is closely related to the pivoting/sliding movements. However, if tibial rotation/valgus angles need to be monitored more accurately, a knee goniometer can be used to measure 6-DOF knee kinematics (Zhang et al., Gait & Posture, 2003).

[0017] Among the muscles crossing the knee, the hamstrings and gastrocnemius muscles have strong off-axis actions in controlling tibial rotation and valgus/varus. Therefore, they are expected to get strengthened through the pivoting elliptical training. Furthermore, lateral hamstring and medial gastrocnemius muscles have significant off-axis action in external tibial rotation. So if control in external tibial rotation needs to be improved based on the subject-specific diagnosis, these muscles are targeted for strengthening. If needed, real-time feedback from the EMG signals of these muscles can be used. On the other hand, the medial hamstring and lateral gastrocnemius muscles are targeted in particular if control in internal tibial rotation needs to be improved. Of note is that for more precise control, both agonist and antagonist muscles may be involved. Therefore, both medial and lateral hamstrings and both medial and lateral gastrocnemius muscles need to be trained but with the medial and lateral sides strengthened differentially (to different degrees).

[0018] The pre-training diagnosis/evaluation of off-axis neuromechanical properties in tibial rotation/valgus and the ACL-notch geometries and likelihood of ACL impingement during external tibial rotation and valgus are used to guide the subject-specific training on the pivoting/sliding elliptical machine for the study group. The rotation/sliding direction that should be stronger and the specific amplitude for the internal and external rotation directions and for the valgus/varus are tailored according to the pre-training diagnosis. If the training needs to be focused on a certain direction, the servomotors are controlled accordingly and apply stronger perturbations in the desired direction. For example, if a subject has specific deficits in external tibial rotation such as high laxity/instability, low muscle strength, less sensitive proprioception, and/or slow reaction, training on the pivoting/sliding elliptical machine are focused on the external

tibial rotation. The perturbations to the footplate are set stronger/quicker and more time is spent in external tibial rotation. Overall, the subjects are trained in both external and internal tibial rotations during the back-and-forth movement, which likely improve neuromuscular control in tibial rotation in general but emphasis is placed on the direction identified as the risk factors. Similar principles are used to guide training in valgus/varus with the training tailored according to the diagnosis. Furthermore, training may focus on combined off-axis loadings. For example, if a female subject is identified as having high susceptibility of ACL impingement against the lateral notch wall due to her 'narrow' notch geometry and high tibial external rotation/valgus laxity, training emphasis will be placed in the combined external tibial rotation and valgus direction. The pivoting/sliding elliptical machine will be programmed to apply more intense combined loading and with more training time in the external tibial rotation and valgus direction.

[0019] Overall, the amplitude of perturbation applied to the footplate rotation/sliding during the elliptical movement starts from moderate level and increase to a higher level of perturbations, within the subject's comfort limit. The subjects are encouraged to exercise at the level of strong tibial rotation/valgus perturbations. The perturbations can be adjusted within pre-specified ranges to insure safe and proper training. If needed, a shoulder-chest harness can be used to insure subject safety.

[0020] In an embodiment not forming part of the claimed invention, the tibial rotation training can be done with a low-cost modified elliptical machine operating passively without a motor with such an example shown in Fig. 3A. A leather cable couples the linear movement of the sliding wheel with the rotation of the pivoting disk, and as the subject performs the elliptical movement, the footplate is rotated back and forth in tibial rotation. The rotating torque level can be adjusted by adjusting the tension of the cable-pulley system. The subject is asked to resist the rotation and keep the foot straight during the elliptical movement (Fig. 3A). As another exercise mode, the leather cable can be made loose and the pivoting disk is thus free to rotate. The subject needs to keep the legs stable in tibial rotation during the elliptical movement (Fig. 3A). Motors will not be needed in either the coupled tibial rotation mode or the free tibial rotation mode using the leather cables.

[0021] The off-axis training can be similarly done with other exercise machines. For example, an alternative, also not forming part of the claimed invention, is a modified stair climber with the same principle of coupled tibial rotation during stepping movement: through a leather cable, the stepping movement of the stair climber is coupled with the rotation of the footplate/shoe (Fig. 3B) and can be used to train neuromuscular control in tibial rotation.

[0022] Combined pivoting and sliding perturbations to the foot plate may be rather challenging for the subject to deal with. Considering that external tibial rotation may be coupled with valgus in various functional movements,

training in tibial rotation alone will likely help improve valgus control as well. Furthermore, it is more practical to rotate the foot and tibia, while it is difficult to abduct the knee voluntarily (Zhang et al., Med Sci Sports Exerc, 2001). Therefore, for simplified/easier training, a pivoting elliptical machine can be developed for focused training in tibial rotation (Fig. 4A). Similarly, if the training/evaluation needs to be focused on the frontal plane, a mediolateral sliding only mechanism can be used (Fig. 4B). Alternatively, the sliding (pivoting) mechanism in the pivoting/sliding mechanism in Fig. 1 can be locked for pivoting-only (sliding only) training.

[0023] The pivoting (or pivoting/sliding) training using the pivoting/sliding device may involve ankle and hip as well as the knee. However, considering the trunk and entire lower extremities are involved in an injury scenario in pivoting sports, it is more appropriate to train the whole lower limb together instead of training the knee in isolation. Therefore, the pivot/sliding training is useful for the purpose of lower limb injury prevention and/or rehabilitation with the multiple joints involved.

[0024] In general, the off-axis training can be combined with many sagittal plane training machines. The pivoting-sliding assembly 2010, for example, can be combined with a stair climber with controlled tibial rotation (pivoting) and mediolateral sliding (knee valgus/varus) during sagittal plane stair-climbing movement (Fig. 6).

[0025] Other perturbations and free movements can be similarly implemented. For example, in an embodiment not according to the invention, a sliding mechanism with controlled anteroposterior sliding can be combined with a sagittal training machine (Fig. 7). The footplate sliding is controlled by a linear motor and various perturbations and "backdrivable" free to sliding can be implemented flexibly (Fig. 7). Slippery during the sagittal stepping/running, for example, can be simulated and potentially used for fall-prevention training.

[0026] Furthermore, an X-Y sliding mechanism can be used for more general sliding movement control in both mediolateral and anteroposterior directions during sagittal plane stepping/running movement (Fig. 8). Two-dimensional X-Y slippery, for example, can be simulated during sagittal stepping/running movement for fall-prevention training.

[0027] The pivoting mechanism can also be combined with a tilting mechanism with controlled inversion/eversion and/or dorsiflexion/plantar flexion to form a pivoting-tilting mechanism (Fig. 9). With the rear end of the footplate resting on a ball-socket joint **700**, two linear actuators **720** (anchored on ball-socket joints at both ends **730** and **740**) can perturb the footplate and move it into target positions in inversion/eversion and/or in dorsiflexion/plantar flexion. The pivoting-tilting mechanism can be combined with a sagittal plane training machine such as an elliptical machine or stair climber to perform pivoting/tilting training during sagittal plane movement. The footplate pivoting and tilting are controlled by a rotary motor through a cable mechanism and a linear motor,

respectively. Various perturbations in pivoting and/or in tilting can be applied flexibly. The footplate can also be controlled as "backdrivable" and free to rotate/tilt.

Determine training-induced neuromechanical changes using the Pivoting/Sliding elliptical machine Neuromechanical diagnosis/evaluations using the pivoting/sliding elliptical machine

[0028] The pivoting-sliding elliptical machine described for the off-axis training can also be used for pre-training diagnosis of off-axis risk factors and for post-training outcome evaluations, forming an integrated subject-specific training program (Fig. 10). The subject stands on the machine with the shoes held to the pivoting disks (Fig. 1). The diagnosis/evaluations can be done at various lower limb postures. The following postures can be used, for example. First, the subject stands on one leg with the knee at full extension and the contralateral knee flexed at about 45°. Measurements will be done at both legs, one side after the other. The flexed knee posture is helpful in separating the tibial rotation from femoral rotation, while the extended side provides measurements of the whole lower limb. The second posture will be the reverse of the first one. The sequence of testing is randomized to minimize the learning effect. Several measures of neuromuscular control in tibial rotation (pivoting) are taken at each of the postures as follows:

1. Stiffness: With the subject standing at a selected posture on the pivoting/sliding elliptical machine, the servomotor will apply a perturbation with controlled velocity and angle to the footplate, and the resulting pivoting rotation and torque will be measured. Pivoting stiffness will be determined from the slope of the torque-angle relationship at the common positions for both external and internal tibial rotations (Chung et al., Arch Phys Med Rehab, 2004).

2. Energy loss: For joint viscoelasticity, energy loss will be measured as the area enclosed by the hysteresis loop (Chung et al., Arch Phys Med Rehab, 2004).

3. Proprioception: The footplate will be rotated by the servomotor slowly (e.g., 1°/sec) and the subject will be asked to press a handheld switch as soon as she/he feels the movement. The proprioception evaluates sensing of the foot as well as tibia rotations. The perturbations will be applied randomly to the left or right leg and in the direction of either internal or external rotation. The subject will be asked to tell the side and direction of the slow movement at the time she/he presses the switch. The subject can be blindfolded to eliminate visual cues, if needed.

4. Reaction time to sudden twisting perturbation in tibial rotation: Starting with a relaxed condition, the subject's leg will be rotated at a controlled velocity and at a random time. The subject will be asked to react and resist the tibial rotation as soon as she

feels the movement. Reaction time will be measured as the interval from the onset of the perturbation to the onset of the torque response generated by the subject. Several trials will be conducted, including both left and right legs and both internal and external rotation directions.

5. Stability (or instability) in tibial rotation is determined as the variation of foot rotation (in degrees) during the sagittal stepping movement.

6. Muscle strength in pivoting is measured using the pivoting elliptical machine. With the pivoting disk locked at a position of neutral foot rotation, the subject performs maximal voluntary contraction (MVC) in tibial external rotation and then in tibial internal rotation. The MVC measurements are repeated a couple of times for each direction.

[0029] The frontal plane neuromechanical properties can be evaluated using the pivoting-sliding elliptical machine, similar to the evaluations in pivoting. For example, instability in the frontal plane of the knee can be determined as the variation of foot mediolateral sliding during the sagittal stepping movement.

[0030] For pre-training diagnosis, measures from the pivoting/sliding elliptical machine can be used to identify the off-axis risk factors, which can be used to guide subsequent subject-specific off-axis training using the pivoting/sliding mechanism. Similarly, post-training outcome evaluations can be done similarly with focus on the specific risky/weak axes/DOFs for the individual subjects. Although measures obtained on the pivoting/sliding elliptical machine are not focused on the knee only, evaluations on the pivoting/sliding elliptical machine are done under close-chain condition with the whole lower limb involved, which better match the actual injury scenarios.

[0031] The pivoting/sliding elliptical machine shown in Fig. 1 can also be used to evaluate training outcomes. The subject stands on the machine with the shoes attached to the pivoting disks (Fig. 1C). The evaluations can potentially be done at various postures. For example, the subject can stand on the left leg with the left knee at full extension and right knee flexes at about 45°. Measurements can be done at both legs, one side after the other. The flexed knee posture is helpful in separating the tibial rotation from femoral rotation, while the extended side provides measurements of the whole lower limb. The second posture is the reverse of the first one. Several measures of neuromuscular control in tibial rotation can be taken at the selected posture as follows:

1. Stiffness: At a selected posture during the elliptical stepping movement, the motor applies a perturbation with controlled velocity and angle to the footplate, and the resulting pivoting rotation and torque are measured. Pivoting stiffness is determined from the slope of the torque-angle relationship at the common positions and at controlled torque levels.

2. Energy loss: For joint viscoelasticity, energy loss

is measured as the area enclosed by the hysteresis loop.

3. Proprioception: The footplate is rotated by the motor at a standardized slow velocity and the subject is asked to press a handheld switch as soon as he/she feels the movement. The perturbations are applied randomly to the left or right leg and internal or external rotation. The subject is asked to tell the side and direction of the slow movement at the time she presses the switch. The subject is asked to close the eyes to eliminate visual cues.

4. Reaction time to sudden twisting perturbation in tibial rotation: Starting with a relaxed condition, the subject's leg is rotated at a controlled velocity and at a random time. The subject is asked to react and resist the tibial rotation as soon as she feels the movement. Several trials are conducted, including both left and right legs and both internal and external rotation directions.

5. Stability (or instability) in tibial rotation is determined as the variation of foot rotation (in degrees) during the elliptical stepping movement.

6. Muscle strength in pivoting is measured using the pivoting elliptical machine. With the pivoting disk locked at a position of neutral foot rotation, the subject performs maximal voluntary contraction (MVC) in tibial external rotation and then in tibial internal rotation. The MVC measurements are repeated twice for each direction.

Improvements through off-axis pivoting training using the pivoting elliptical machine

[0032] Human subject can easily get used to the elliptical movement with rotational pivoting perturbations at both feet and perform the pivoting elliptical movement naturally. The rotational perturbations result in stronger muscle activities in the targeted lower limb muscles. The hamstrings and gastrocnemius activities are increased considerably during forward elliptical movement with the perturbation, for example, as shown in Fig. 11.

[0033] Improvement in sensory-motor performance through the pivoting elliptical training is observed. Over five 30-minute training sessions, the subjects showed marked improvement in controlling tibial rotation, as shown in the reduced rotation instability (variation in rotation) (Fig. 12A). The pivoting disks were made free to rotate and the subject was asked to keep the feet stable and pointing forward during the elliptical movements. Standard deviation of the rotating angle during the pivoting elliptical exercise was used to measure the rotating instability, which was reduced markedly after the training (Fig. 12A), and the instability reduction was obvious for both left and right legs (Fig. 12B). Similar results were seen for both forward and backward elliptical movements. Interestingly, the instability of the dominant right side was generally lower than the non-dominant left side, considering that the subjects involved were all right-

handed. Similar improvement was observed for rotation instability measured under external perturbation of the footplate by the motor, as shown in Fig. 12C, which also showed higher rotation instability of females as compared with males. The increased stability following the training may be related to improvement in tibial rotation muscle strength, which was increased after the training of multiple sessions.

[0034] Proprioception in tibial rotation also showed improvement with the training, as shown in Fig. 13A. In addition, reaction time tends to be shorter for the loaded leg as compared to the unloaded one and tendency of training-induced improvement was observed (Fig. 13B).

Claims

1. An off-axis training and evaluation mechanism designed to help human subjects improve neuromuscular control about the off-axes, the mechanism comprising a footplate (200) for holding the shoe or foot of a user and means for applying perturbations to the footplate, said means comprising at least one of:

- a. A pivoting mechanism (100,130,150,160); and
- b. A sliding mechanism (400,430);

and characterised in that

the pivoting mechanism (100,130,150,160) applies random perturbations in pivoting about the tibial rotation axis, making the subject fight the perturbations during the major sagittal plane movement and improve their neuromuscular control in the off-axis control in pivoting; and/or the sliding mechanism (400,430) applies random perturbations in mediolateral sliding or makes the footplate (200) free to slide mediolaterally, challenging the subject to improve their neuromuscular control in the off-axis control in the frontal plane; and **in that** mounting means are provided for mounting the mechanism to a sagittal plane exercise or training machine such that off axis training can be combined with sagittal plane movements.

2. An off-axis training and evaluation mechanism according to claim 1, further comprising an encoder and a torque sensor (120) mounted on a servomotor (100) to measure the pivoting angle and torque, respectively

3. An off-axis training and evaluation mechanism according to claim 1 or 2, wherein the footplate pivoting is controlled by a rotary motor (100) through a cable (160) and/or the footplate sliding is controlled by a

linear motor (400).

4. An off-axis training and evaluation mechanism according to claim 3, further comprising a motor controller for applying sinusoidal torques and/or sinusoidal force to perturb the footplate. 5
5. A training and evaluation mechanism according to claim 1, wherein the means for applying perturbations comprises said pivoting mechanism (100, 130, 150, 160) and further comprises a tilting mechanism (700, 720, 730, 740, 750) with controlled inversion/eversion and/or dorsiflexion/plantar flexion. 10
6. A training and evaluation mechanism according to claim 1, wherein the means for applying perturbations comprises said sliding mechanism (400, 430) and further comprises controlled anteroposterior sliding. 15
7. A training and evaluation mechanism according to claim 1, further comprising a toe clip (220) arranged to be tightened to accommodate shoes of different sizes and/or a side clip (230) to prevent a shoe from sliding laterally. 20
8. A training and evaluation mechanism according to claim 1, further comprising a virtual reality display, wherein target lower limbs and shoe positions are indicated by arrows to help the subject reach desired target limb/foot positions. 25
9. A training and evaluation mechanism according to claim 1, wherein a web camera is used to capture and display the lower limb posture in real time to help the subject align the lower limbs properly in the frontal plane. 30
10. A training and evaluation mechanism according to claim 1, wherein the means for applying perturbations comprises said pivoting mechanism (100, 130, 150, 160) and the pivoting mechanism comprises a cable (160). 35
11. A sagittal plane exercise/training machine comprising a first off-axis training and evaluation mechanism mounted on the left side of the machine, and a second off-axis training and evaluation mechanism mounted on the right side of the machine, wherein said first and second mechanisms are as claimed in any of the preceding claims. 40
12. Use of the off-axis training and evaluation mechanism according to claim 2 to measure joint stiffness, wherein a perturbation is applied with controlled velocity and angle to the footplate (200), the resulting pivoting rotation and torque is measured, and pivoting stiffness is determined from the slope of the 45

torque-angle relationship.

13. Use of the off-axis training and evaluation mechanism according to claim 2 to measure joint viscoelasticity, wherein a perturbation is applied with controlled velocity and angle to the footplate (200), the resulting pivoting rotation and torque is measured, and energy loss is determined from the area enclosed by the hysteresis loop in the angle-torque curve. 5
14. Use of the off-axis training and evaluation mechanism according to any of claims 1 to 10 to measure proprioception, wherein the footplate (200) is randomly perturbed at a standardized slow velocity and a subject is deprived of visual cues and asked to press a handheld switch as soon as movement is felt and define the side and direction of the slow movement at the time of pressing the switch, and wherein the proprioception is measured by the rotation angle or linear translation from the time of the cue to the time when the switch is pressed. 10
15. Use of the off-axis training and evaluation mechanism according to any of claims 1 to 10 to measure reaction time, wherein a subject is asked to react to and resist a controlled velocity rotation randomly applied to the footplate (200) as soon as movement is felt, and wherein the time delay is measured to determine the reaction time. 15
16. Use of the off-axis training and evaluation mechanism according to any of claims 1 to 10 to measure joint instability, wherein said instability is determined as the variation of foot rotation or foot mediolateral sliding during a sagittal stepping movement. 20
17. Use of the off-axis training and evaluation mechanism according to any of claims 1 to 10 to measure muscle strength, wherein the mechanism is locked at a position of neutral foot rotation or translation and a user performs maximal voluntary contraction (MVC). 25

Patentansprüche

1. Außeraxialer Trainings- und Bewertungsmechanismus, der dazu gestaltet ist, menschlichen Probanden zu helfen, eine außeraxiale neuromuskuläre Steuerung zu verbessern, wobei der Mechanismus eine Fußplatte (200) zum Halten des Schuhs oder des Fußes eines Benutzers und ein Mittel zum Anwenden von Störungen auf die Fußplatte umfasst, wobei das Mittel wenigstens eines der Folgenden umfasst: 30

a. einen Schwenkmechanismus (100, 130, 150,

160); und
b. einen Gleitmechanismus (400, 430); und **dadurch gekennzeichnet, dass**

- der Schwenkmechanismus (100, 130, 150, 160) zufällige Störungen anwendet, indem er um eine tibiale Drehachse schwenkt, wodurch er den Probanden veranlasst, während der Hauptbewegung in der Sagittalebene gegen die Störungen anzugehen und seine außeraxiale neuromuskuläre Steuerung beim Schwenken zu verbessern; und/oder dadurch, dass der Gleitmechanismus (400, 430) zufällige Störungen durch ein mediolaterales Gleiten anwendet oder der Fußplatte (200) ein freies mediolaterales Gleiten ermöglicht, wodurch der Proband dazu aufgefordert wird, seine außeraxiale neuromuskuläre Steuerung in der Frontalebene zu verbessern, und dadurch, dass Befestigungsmittel zum Befestigen des Mechanismus an einer Sagittalebene-Übungs- oder Trainingsmaschine bereitgestellt werden, sodass ein außeraxiales Training mit Sagittalebene-Bewegungen kombiniert werden kann.
2. Außeraxialer Trainings- und Bewertungsmechanismus nach Anspruch 1, ferner umfassend einen Codierer und einen Drehmomentsensor (120), die an einem Servomotor (100) befestigt sind, um jeweils den Schwenkwinkel und das Drehmoment zu messen.
 3. Außeraxialer Trainings- und Bewertungsmechanismus nach Anspruch 1 oder 2, wobei die Fußplattenschwenkung durch einen Drehmotor (100) über ein Kabel (160) gesteuert wird und/oder das Fußplattengleiten durch einen Linearmotor (400) gesteuert wird.
 4. Außeraxialer Trainings- und Bewertungsmechanismus nach Anspruch 3, ferner umfassend eine Motorsteuerung zum Anwenden von sinusförmigen Drehmomenten und/oder einer sinusförmigen Kraft zum Stören der Fußplatte.
 5. Trainings- und Bewertungsmechanismus nach Anspruch 1, wobei das Mittel zum Anwenden von Störungen den Schwenkmechanismus (100, 130, 150, 160) umfasst, und ferner einen Neigemechanismus (700, 720, 730, 740, 750) mit einer gesteuerten Inversion/Ausstülpung und/oder einer gesteuerten Dorsiflexion/Plantarflexion umfasst.
 6. Trainings- und Bewertungsmechanismus nach Anspruch 1, wobei das Mittel zum Anwenden von Störungen den Gleitmechanismus (400, 430) umfasst, und ferner ein gesteuertes antero-posteriore Gleiten umfasst.
 7. Trainings- und Bewertungsmechanismus nach An-
- spruch 1, ferner umfassend eine Fußsperre (220), die dazu angeordnet ist, angezogen zu werden, um Schuhe von verschiedenen Größen unterzubringen und/oder eine Seitensperre (230), um zu verhindern, dass ein Schuh seitlich gleitet.
8. Trainings- und Bewertungsmechanismus nach Anspruch 1, ferner umfassend eine Virtual-Reality-Anzeige, wobei die Zielunterschenkel- und -schuhpositionen durch Pfeile angezeigt werden, um dem Probanden zu helfen, die gewünschten Schenkel/Schuh-Positionen zu erreichen.
 9. Trainings- und Bewertungsmechanismus nach Anspruch 1, wobei eine Webkamera verwendet wird, um die Unterschenkelhaltung in Echtzeit zu erfassen und anzuzeigen, um dem Probanden zu helfen, die Unterschenkel ordnungsgemäß in der Frontalebene auszurichten.
 10. Trainings- und Bewertungsmechanismus nach Anspruch 1, wobei das Mittel zum Anwenden von Störungen den Schwenkmechanismus (100, 130, 150, 160) umfasst, und wobei der Schwenkmechanismus ein Kabel (160) umfasst.
 11. Sagittalebene-Übungs-/Trainingsmaschine, die einen ersten außeraxialen Trainings- und Bewertungsmechanismus, der auf der linken Seite der Maschine befestigt ist, und einen zweiten außeraxialen Trainings- und Bewertungsmechanismus, der auf der rechten Seite der Maschine befestigt ist, umfasst, wobei der erste und zweite Mechanismus nach einem der vorhergehenden Ansprüche sind.
 12. Verwendung des außeraxialen Trainings- und Bewertungsmechanismus nach Anspruch 2 zum Messen von Gelenksteifigkeit, wobei eine Störung mit einer gesteuerten Geschwindigkeit und einem gesteuerten Winkel auf die Fußplatte (200) angewendet wird, wobei die Schwenkdrehung und das Drehmoment, die daraus resultieren, gemessen werden, und wobei eine Schwenksteifigkeit durch den Abfall der Drehmoment-Winkel-Beziehung bestimmt wird.
 13. Verwendung des außeraxialen Trainings- und Bewertungsmechanismus nach Anspruch 2 zum Messen von Gelenkviskoelastizität, wobei eine Störung mit einer gesteuerten Geschwindigkeit und einem gesteuerten Winkel auf die Fußplatte (200) angewendet wird, wobei die Schwenkrotation und das Drehmoment, die daraus resultieren, gemessen werden, und wobei ein Energieverlust von dem Bereich bestimmt wird, der in der Winkel-Drehmoment-Kurve von einer Hystereseschleife eingeschlossen ist.
 14. Verwendung des außeraxialen Trainings- und Be-

wertungsmechanismus nach einem der Ansprüche 1 bis 10 zum Messen von Propriozeption, wobei die Fußplatte (200) zufällig bei einer standardisierten langsamen Geschwindigkeit gestört wird und einem Probanden visuelle Reize vorenthalten werden und er gebeten wird, einen Handschalter zu drücken, sobald er eine Bewegung spürt, und die Seite und die Richtung der langsamen Bewegung zum Zeitpunkt des Drückens des Schalters zu definieren, und wobei die Propriozeption durch den Rotationswinkel oder die lineare Übersetzung von dem Zeitpunkt des Reizes bis zu dem Zeitpunkt des Drückens des Schalters gemessen wird.

- 15 15. Verwendung des außeraxialen Trainings- und Bewertungsmechanismus nach einem der Ansprüche 1 bis 10 zum Messen einer Reaktionszeit, wobei ein Proband gebeten wird, auf eine kontrollierte zufällige auf die Fußplatte (200) angewendete Geschwindigkeitsrotation zu reagieren und dieser zu widerstehen, sobald er eine Bewegung spürt, und wobei die Zeitverzögerung gemessen wird, um die Reaktionszeit zu bestimmen.
- 20 16. Verwendung des außeraxialen Trainings- und Bewertungsmechanismus nach einem der Ansprüche 1 bis 10 zum Messen von Gelenkinstabilität, wobei die Instabilität als die Schwankung einer Fußrotation oder ein mediolaterales Gleiten des Fußes während einer sagittalen Schrittbewegung bestimmt wird.
- 25 17. Verwendung des außeraxialen Trainings- und Bewertungsmechanismus nach einem der Ansprüche 1 bis 10 zum Messen von Muskelstärke, wobei der Mechanismus in einer Position einer neutralen Fußrotation oder -Übersetzung verriegelt wird und der Benutzer eine maximale freiwillige Kontraktion (MFK) durchführt.

Revendications

- 30 1. Mécanisme d'entraînement et d'évaluation hors axes conçu pour aider des sujets humains à améliorer le contrôle neuromusculaire hors des axes, le mécanisme comprend un repose-pied (200) pour maintenir la chaussure ou le pied d'un utilisateur et un moyen d'application de perturbations au repose-pied, ledit moyen comprenant au moins un élément parmi :
- 35 a. un mécanisme de pivotement (100, 130, 150, 160) ; et
- 40 b. un mécanisme de coulissement (400, 430) ;

et caractérisé en ce que

le mécanisme de pivotement (100, 130, 150, 160) applique des perturbations aléatoires en pivotant

autour de l'axe de rotation tibial, amenant le sujet à combattre les perturbations pendant le mouvement en plan sagittal principal et à améliorer son contrôle neuromusculaire dans le contrôle hors axes dans le pivotement ; et/ou le mécanisme de coulissement (400, 430) applique des perturbations aléatoires dans le coulissement médiolatéral ou libère le repose-pied (200) pour qu'il coulisse de manière médiolatérale, poussant le sujet à améliorer son contrôle neuromusculaire dans le contrôle hors axe dans le plan frontal ; et **en ce que**

un moyen de montage est fourni pour monter le mécanisme sur une machine d'exercice ou d'entraînement en plan sagittal de sorte qu'un entraînement hors axes peut être combiné avec des mouvements en plan sagittal.

- 45 2. Mécanisme d'entraînement et d'évaluation hors axes selon la revendication 1, comprenant en outre un codeur et un capteur de couple (120) monté sur un servomoteur (100) pour mesurer l'angle et le couple de pivotement, respectivement.
- 50 3. Mécanisme d'entraînement et d'évaluation hors axes selon la revendication 1 ou 2, dans lequel le pivotement du repose-pied est commandé par un moteur rotatif (100) par le biais d'un câble (160) et/ou le coulissement du repose-pied est commandé par un moteur linéaire (400).
- 55 4. Mécanisme d'entraînement et d'évaluation hors axes selon la revendication 3, comprenant en outre un dispositif de commande de moteur pour appliquer des couples sinusoïdaux et/ou une force sinusoïdale pour perturber le repose-pied.
- 60 5. Mécanisme d'entraînement et d'évaluation selon la revendication 1, dans lequel le moyen d'application de perturbations comprend ledit mécanisme de pivotement (100, 130, 150, 160) et comprend en outre un mécanisme de basculement (700, 720, 730, 740, 750) avec une inversion/éverson contrôlée et/ou une dorsiflexion/flexion plantaire.
- 65 6. Mécanisme d'entraînement et d'évaluation selon la revendication 1, dans lequel le moyen d'application de perturbations comprend ledit mécanisme de coulissement (400, 430) et comprend en outre un coulissement antéropostérieur contrôlé.
- 70 7. Mécanisme d'entraînement et d'évaluation selon la revendication 1, comprenant en outre un cale-pied (220) agencé pour être resserré pour recevoir des chaussures de tailles différentes et/ou une attache latérale (230) pour empêcher la chaussure de glisser de manière latérale.
- 75 8. Mécanisme d'entraînement et d'évaluation selon la

- revendication 1, comprenant en outre un affichage de réalité virtuelle, dans lequel les membres inférieurs cibles et les positions de chaussures sont indiqués par des flèches pour aider le sujet à atteindre les positions des membres/pieds cibles souhaitées.
9. Mécanisme d'entraînement et d'évaluation selon la revendication 1, dans lequel une caméra Web est utilisée pour capturer et afficher la posture du membre inférieur en temps réel pour aider le sujet à aligner les membres inférieurs correctement dans le plan frontal.
10. Mécanisme d'entraînement et d'évaluation selon la revendication 1, dans lequel le moyen d'application de perturbations comprend ledit mécanisme de pivotement (100,130, 150, 160) et le mécanisme de pivotement comprend un câble (160).
11. Machine d'exercice/entraînement en plan sagittal comprenant un premier mécanisme d'entraînement et d'évaluation hors axes monté sur le côté gauche de la machine, et un deuxième mécanisme d'entraînement et d'évaluation hors axes monté sur le côté droit de la machine, dans laquelle lesdits premier et deuxième mécanismes sont tels que revendiqués dans l'une quelconque des revendications précédentes.
12. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon la revendication 2 pour mesurer la rigidité des articulations, dans laquelle une perturbation est appliquée au repose-pied (200) avec une vitesse et un angle contrôlés, la rotation et le couple de pivotement qui en résultent sont mesurés et la rigidité de pivotement est déterminée d'après l'inclinaison de la relation couple-angle.
13. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon la revendication 2 pour mesurer la viscoélasticité des articulations, dans laquelle une perturbation est appliquée au repose-pied (200) avec une vitesse et un angle contrôlés, la rotation et le torque de pivotement qui en résultent sont mesurés, et la perte énergétique est déterminée à partir de la zone délimitée par la boucle d'hystérésis dans la courbe angle-couple.
14. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon l'une quelconque des revendications 1 à 10 pour mesurer la proprioception, dans laquelle le repose-pied (200) est perturbé de manière aléatoire à une faible vitesse normalisée et un sujet est privé d'indices visuels et prié d'appuyer sur un interrupteur tenu à la main dès qu'il sent un mouvement et de définir le côté et la direction du mouvement lent au moment où il appuie sur l'interrupteur, et dans laquelle la proprioception est mesurée par l'angle de rotation ou la translation linéaire du moment de l'indice au moment où l'interrupteur est actionné.
15. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon l'une quelconque des revendications 1 à 10 pour mesurer le temps de réaction, dans laquelle un sujet est prié de réagir et de résister à une rotation à une vitesse contrôlée appliquée de manière aléatoire au repose-pied (200) dès qu'il sent un mouvement, et dans laquelle le laps de temps est mesuré pour déterminer le temps de réaction.
16. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon l'une quelconque des revendications 1 à 10 pour mesurer l'instabilité des articulations, dans laquelle ladite instabilité est déterminée comme la variation de la rotation du pied ou du coulisement médiolatéral du pied pendant un mouvement de marche sagittal.
17. Utilisation du mécanisme d'entraînement et d'évaluation hors axes selon l'une quelconque des revendications 1 à 10 pour mesurer la force musculaire, dans laquelle le mécanisme est verrouillé dans une position de rotation ou de translation neutre du pied et un utilisateur effectue une contraction maximale volontaire (CMV).

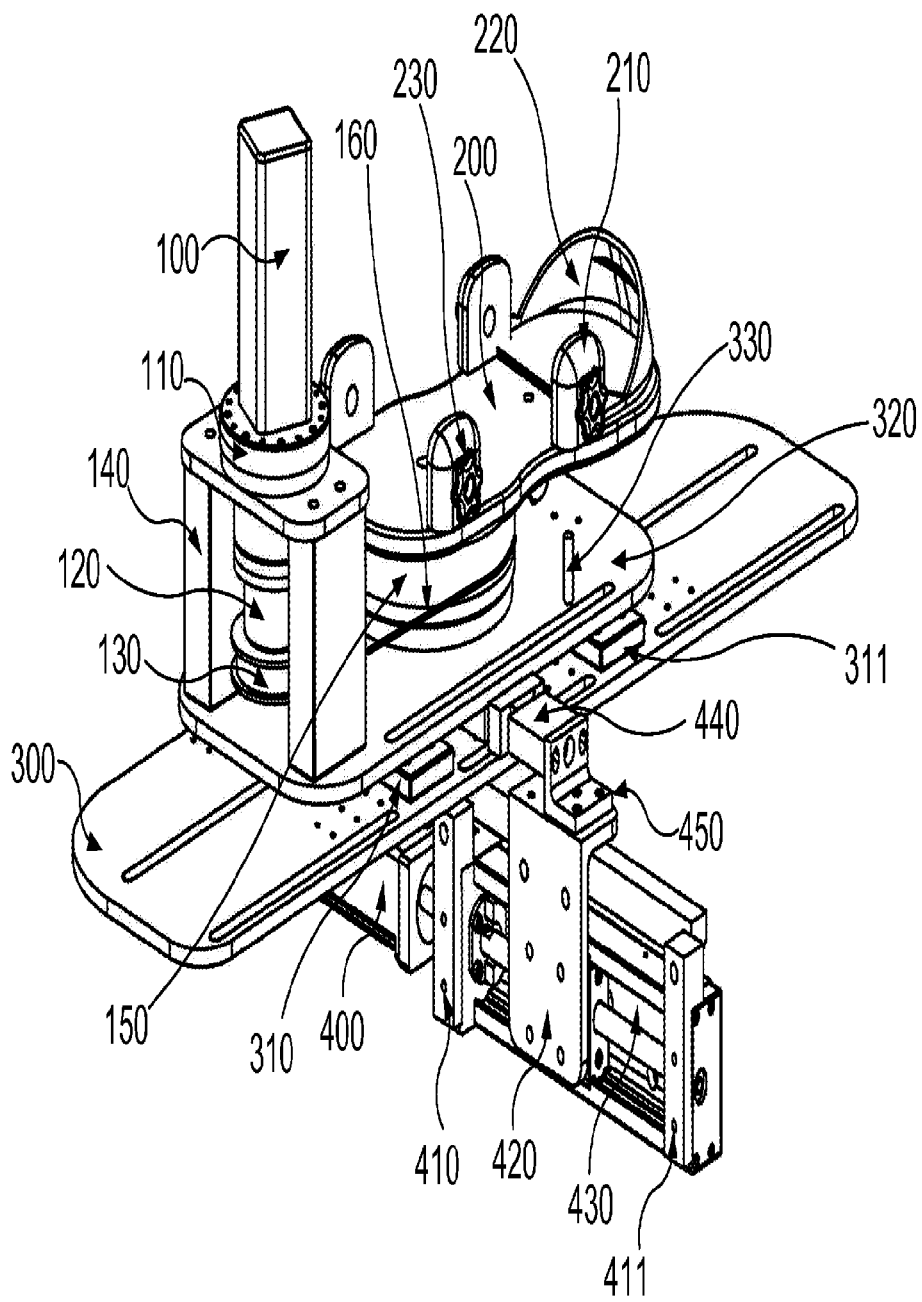


Fig. 1A

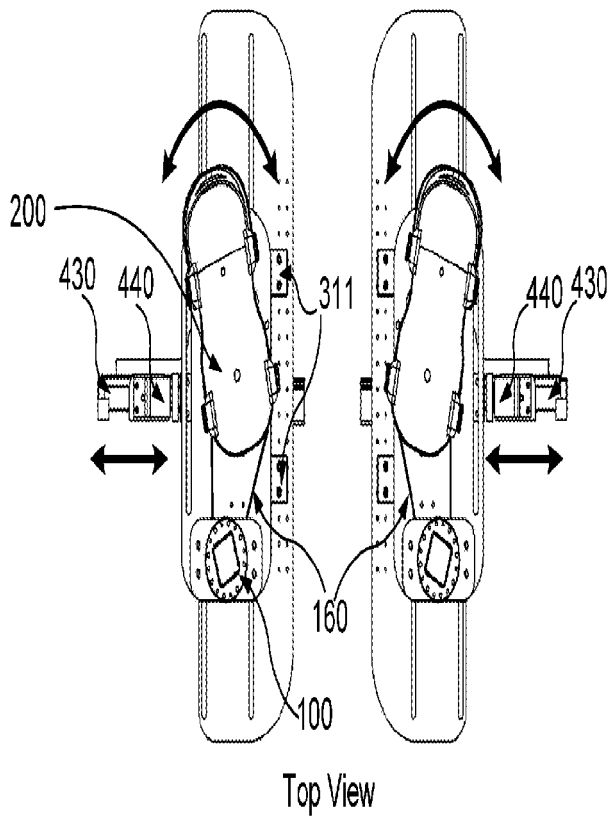


Fig. 1B

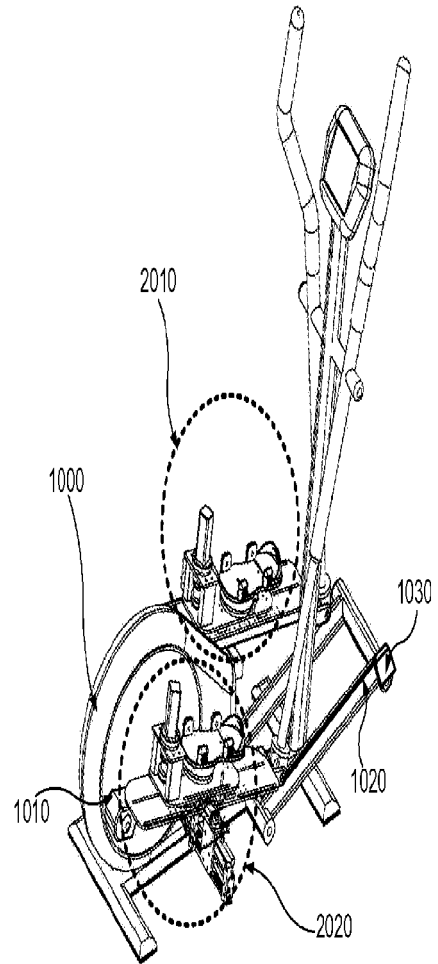


Fig. 1C

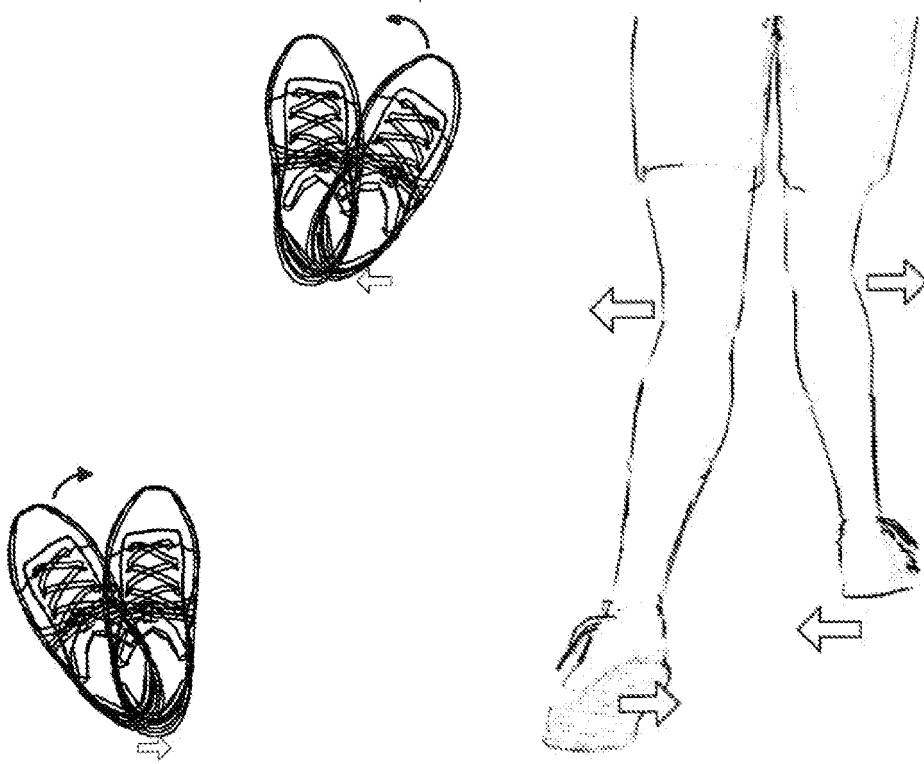


Fig. 2

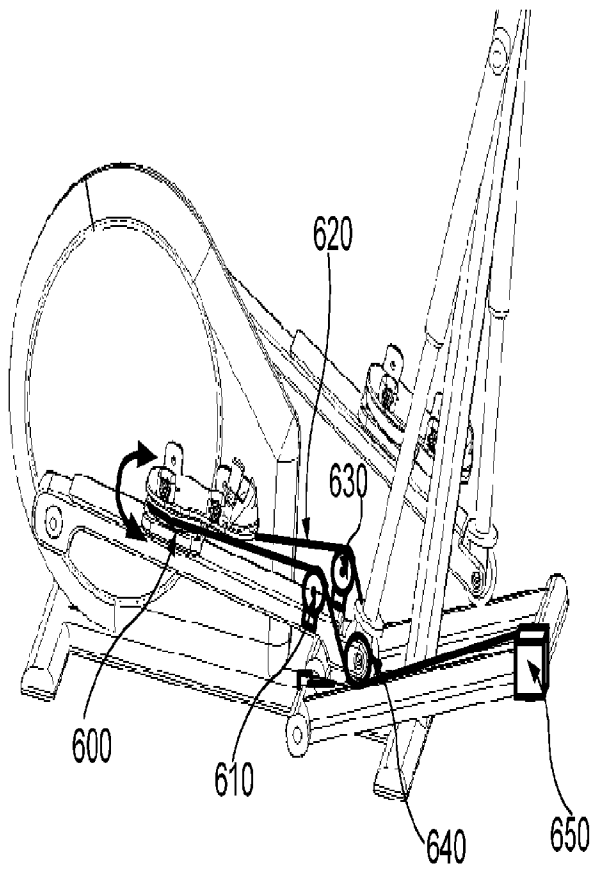


Fig. 3A

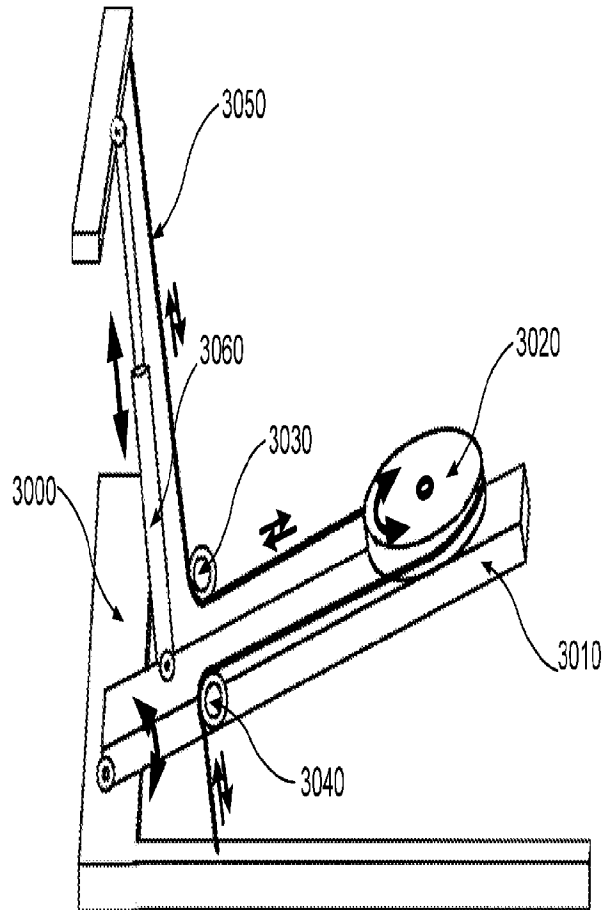


Fig. 3B

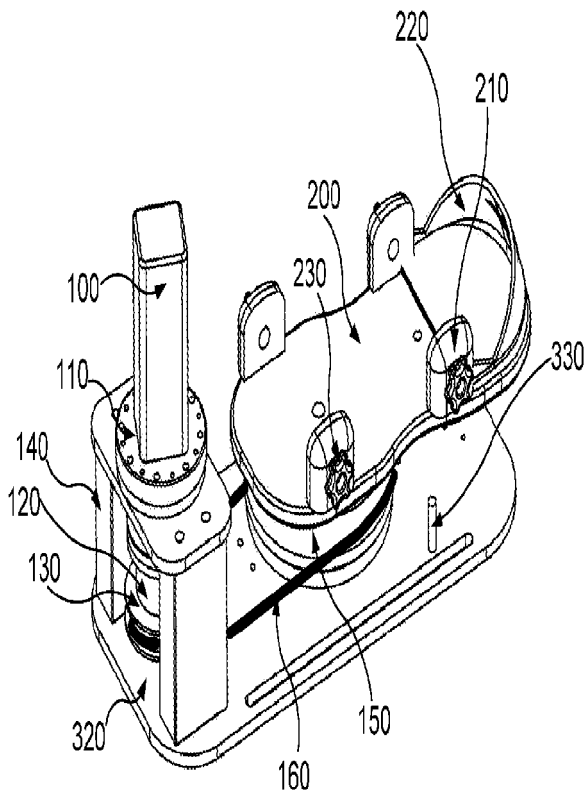


Fig. 4

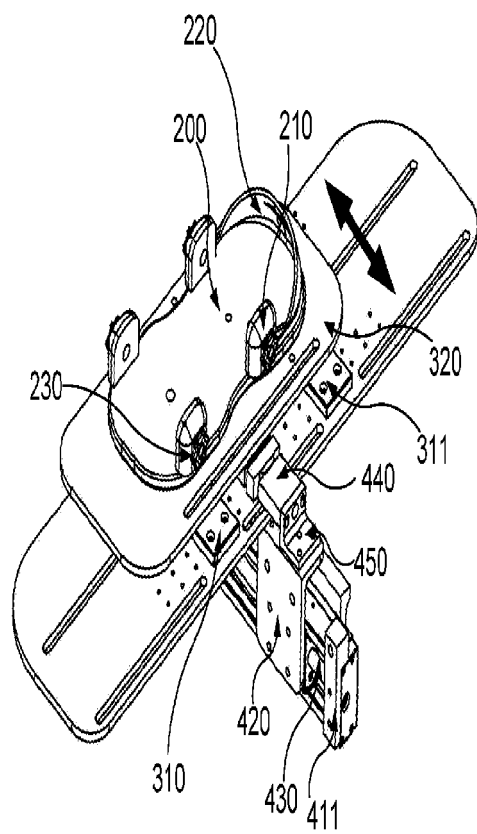


Fig. 5

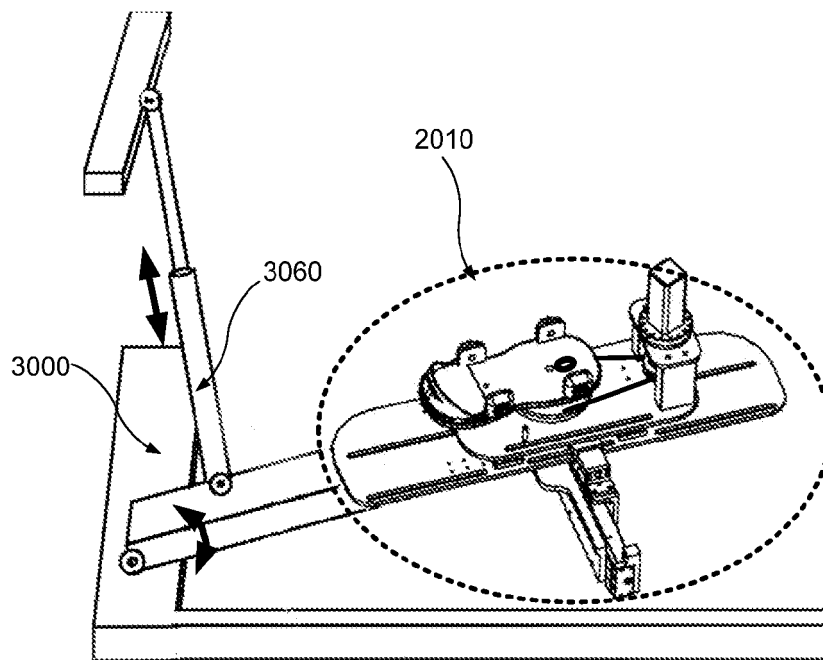


Fig. 6

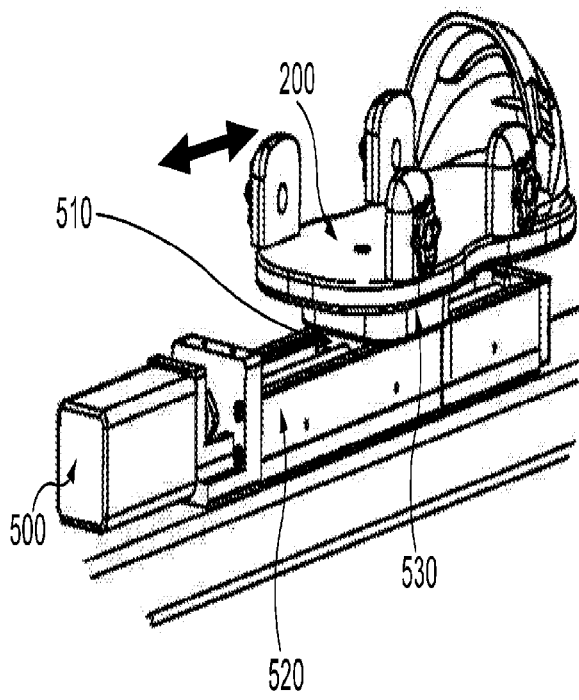


Fig. 7

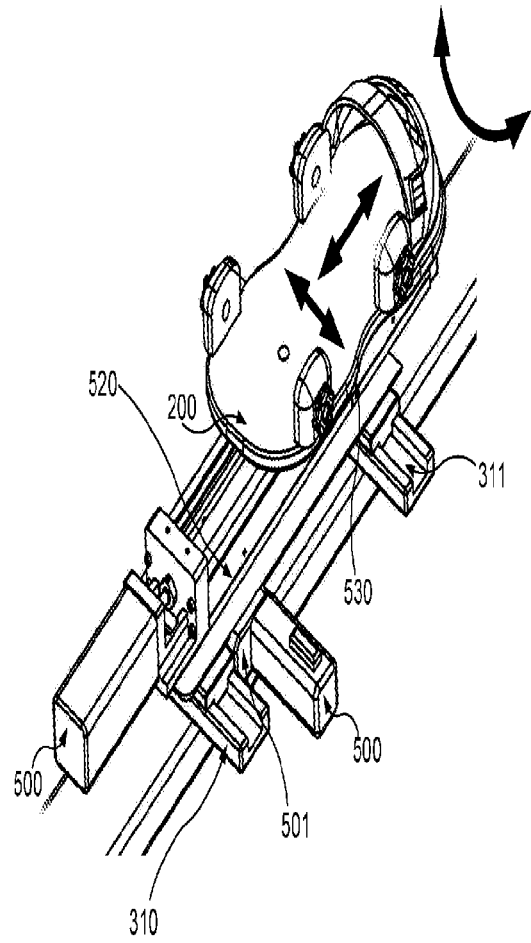


Fig. 8

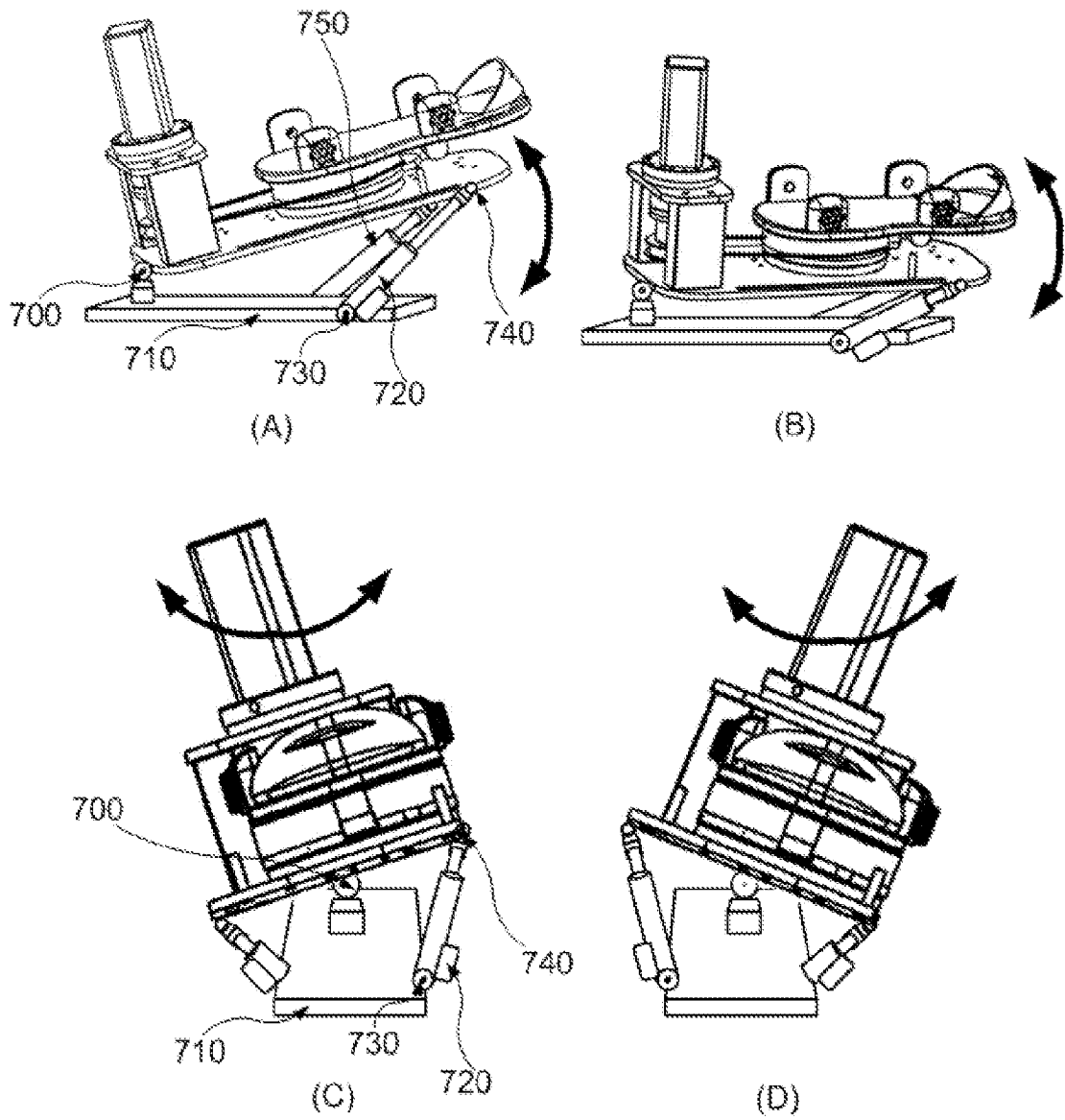


Fig. 9

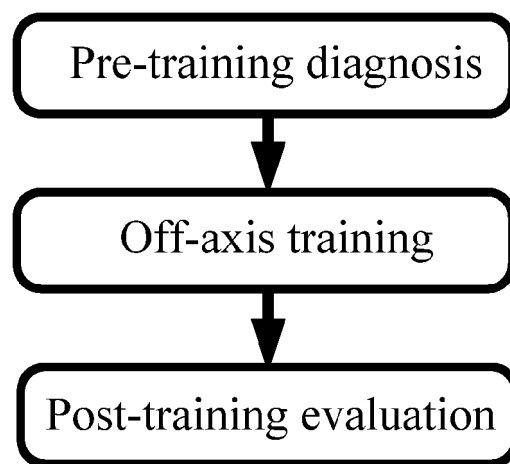


Fig. 10

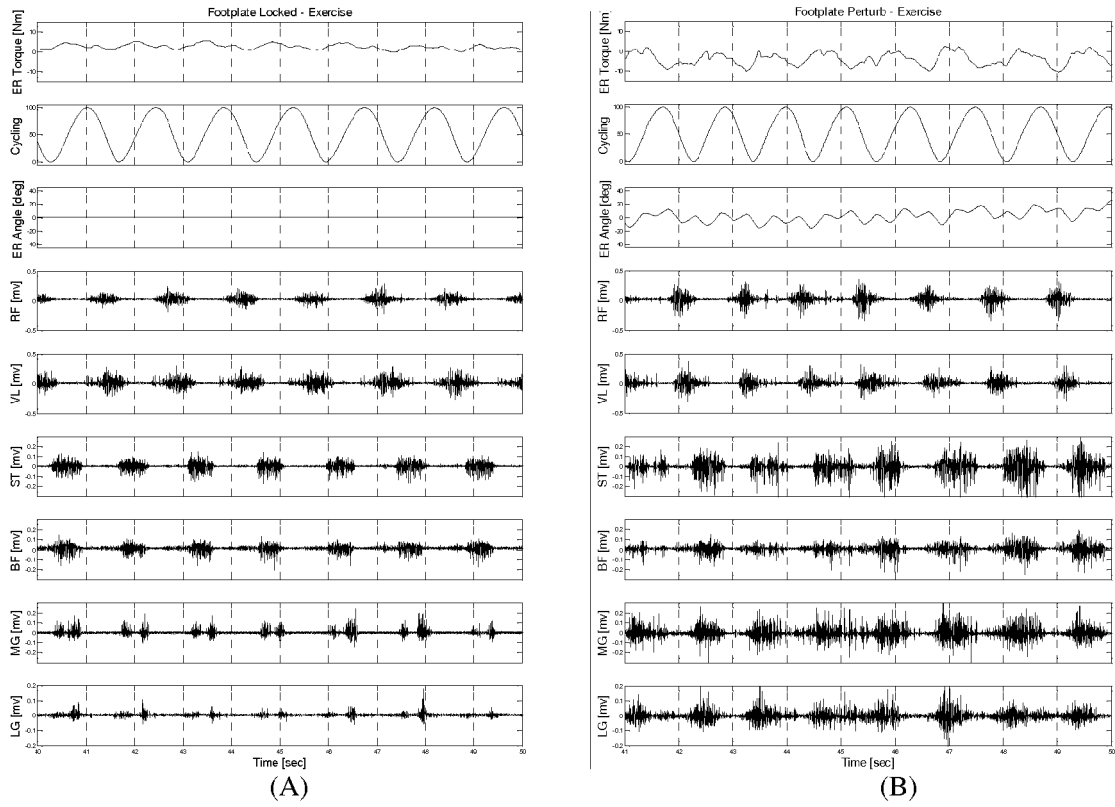


Fig. 11

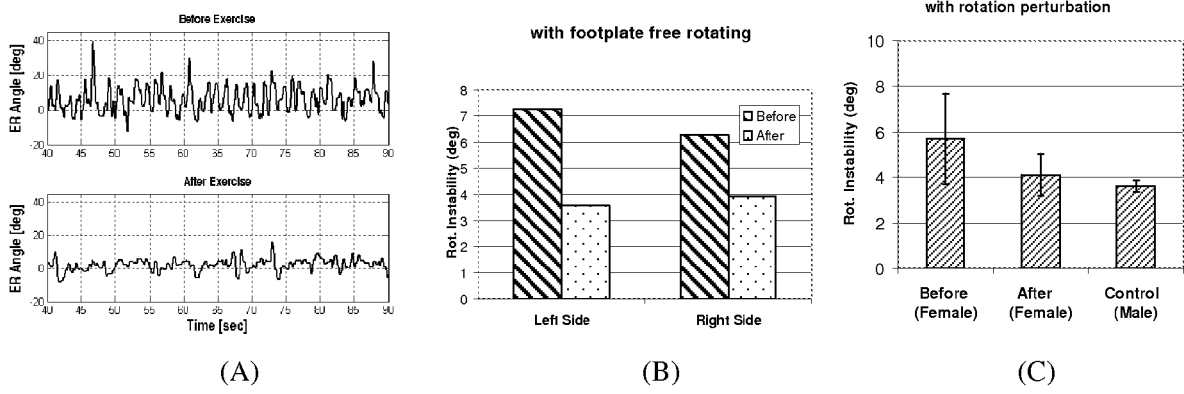


Fig. 12

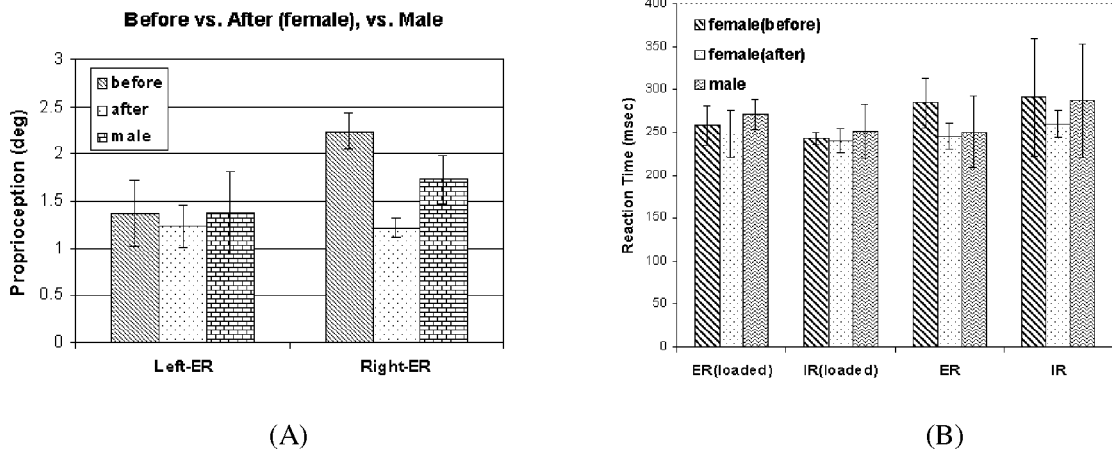


Fig. 13

REFERENCES CITED IN THE DESCRIPTION

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专利名称(译)	用于训练人类受试者以改善下肢的轴外神经肌肉控制的系统和方法		
公开(公告)号	EP2134427B1	公开(公告)日	2018-12-19
申请号	EP2008732785	申请日	2008-03-24
[标]申请(专利权)人(译)	REHABTEK		
申请(专利权)人(译)	REHABTEK LLC		
当前申请(专利权)人(译)	REHABTEK LLC		
[标]发明人	ZHANG LI QUN REN YUPENG PARK HYUNG SOON		
发明人	ZHANG, LI-QUN REN, YUPENG PARK, HYUNG-SOON		
IPC分类号	A61B5/00		
CPC分类号	A63B22/14 A61B5/1124 A61B5/1126 A61B5/162 A61B5/224 A61B5/4519 A61B5/4528 A63B22/001 A63B22/0046 A63B22/0056 A63B22/0664 A63B24/0003 A63B69/0053 A63B69/0064 A63B2220/16 A63B2220/30 A63B2220/51 A63B2230/08		
优先权	60/919401 2007-03-22 US		
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外部链接	Espacenet		

摘要(译)

前交叉韧带 (ACL) 是运动相关活动中最常受伤的膝关节韧带，尤其是在运动中。考虑到膝盖可以自由弯曲/伸展，但是关于离轴（胫骨旋转和外翻/内翻）的运动有限得多，ACL 损伤通常与过度的轴外负荷有关。结合矢状平面运动/运动的枢转/滑动机构被描述为用于评估非接触性ACL损伤的轴外神经机械和解剖学风险因素的诊断工具。枢转/滑动机构也被描述为用于轴外训练的干预工具，可能基于诊断，以减少ACL损伤的发生率。还可以使用枢转/滑动机制来评估训练结果。通常，枢转/滑动机构可以与许多矢状平面健身器一起使用，并且用于改善下肢的离轴控制并减少下肢损伤。

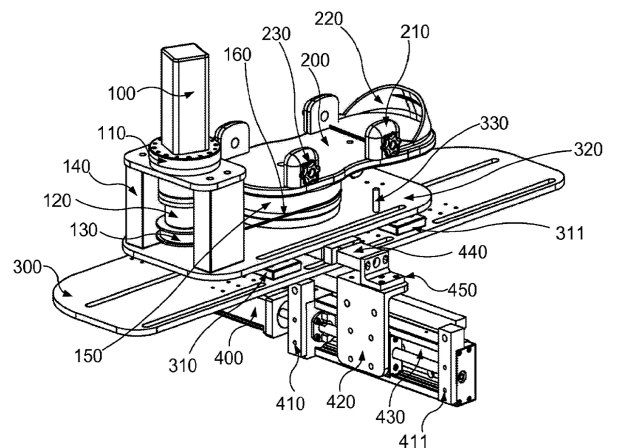


Fig. 1A