Original article

Honda Motor's robotic gait rehab instrument quantifies left & right legs' movements in terms of measures of angle between femur and perpendicular drawn down from hip joint, enabling doctors to easily grasp poststroke hemiplegic patients' degrees of the seriousness of asymmetry between both legs' ability to flex and extend and to orchestrate physical therapists' efforts to return patients' asymmetric walking patterns closer to sound symmetrical patterns in light of a left-right legs' spread-ability asymmetry degree index

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Key words: Gait cycle, Gait analysis, Robotic Rehab Instrument, Para-Sagittal plane

Abstract

Objective:

Our objective is to shed light on a key advantage of Honda Motor Co.'s "Honda Walking Assist" robotic rehab instrument over other types of rehab devices in substantially reviving poststroke hemiplegic patients' abilities to perform sound walking – namely, the ability to maintain a symmetry in the abilities of right and left legs to spread out their femurs on two different para-sagittal planes incorporating each of the patients' hip joints (greater trochanters).

These para-sagittal planes are planes sandwiching a patient's median sagittal plane that cuts vertically through the patient's body from posterior to anterior and divides it into right and left halves. (See Figure 1~Figure 7, attached photographs and explanatory diagram on Pages 152~3, 156~9)

Figure 1 Whereabouts of the Median Sagittal Plane and two Para-sagittal Planes sandwiching the median sagittal plane

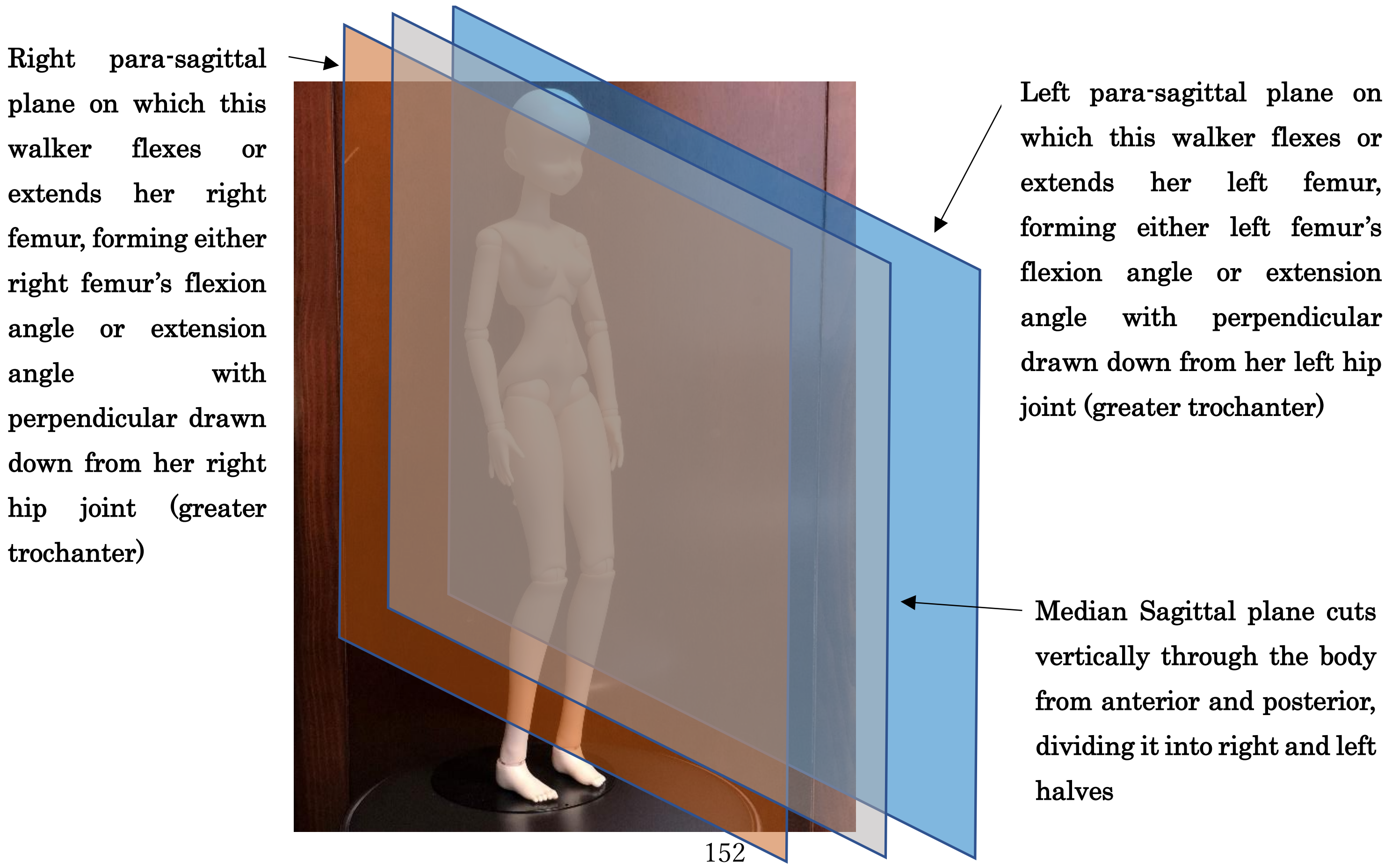


Figure 2. Positions to which HONDA ASSIST ® is fastened with Velcro strap belts around wearer's waist, hip joints and femurs

Front edge of right para-sagittal plane incorporating right hip joint when walker is viewed from his front

Front edge of left para-sagittal plane incorporating left hip joint when walker is viewed from his front

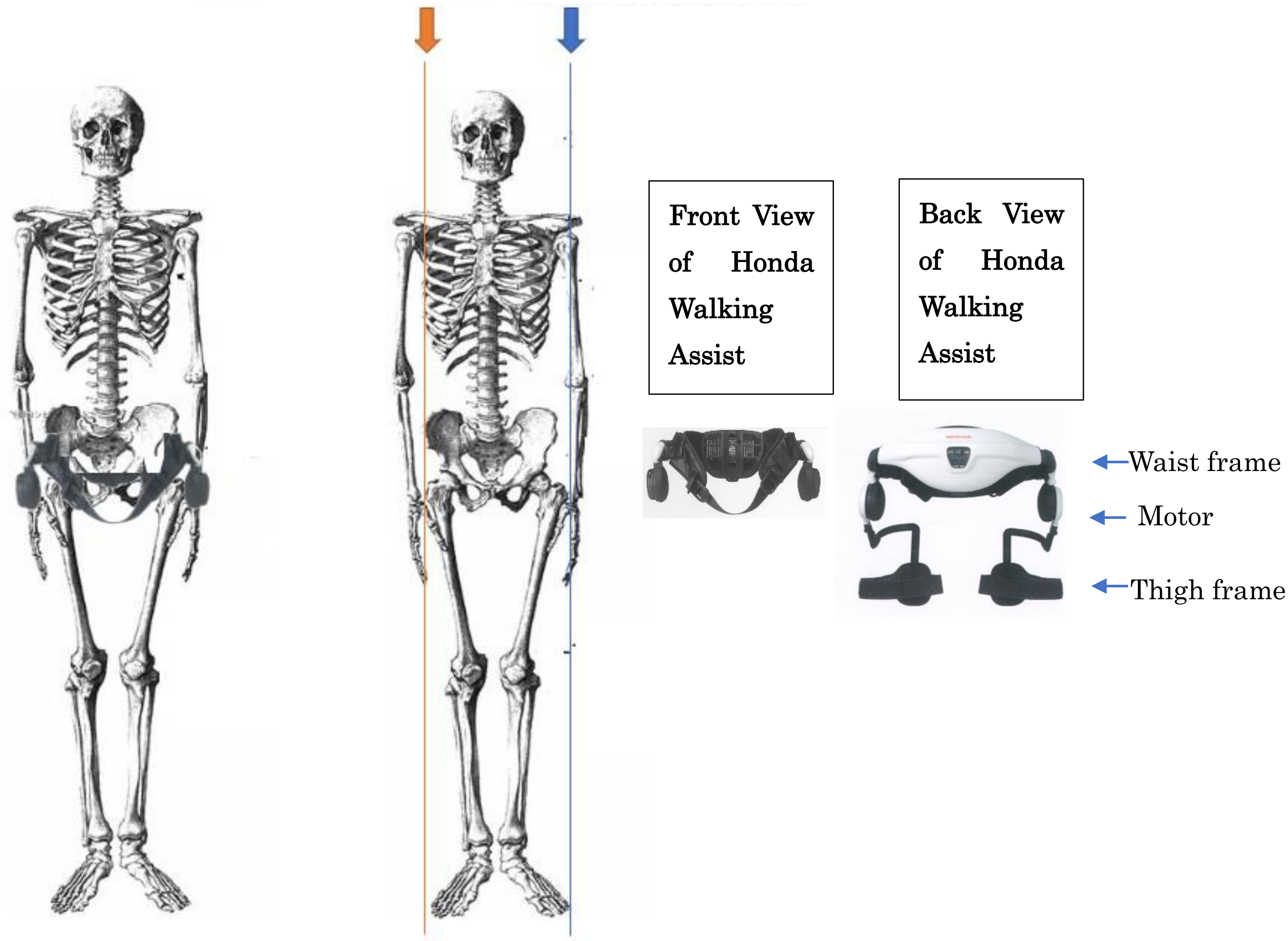


Figure 3. Honda Assist's motors pinch wearer's hip joints with in-motor angle sensors gauging angular measures between femurs and perpendiculars drawn down from hip joints, which act as pivots of swinging femurs

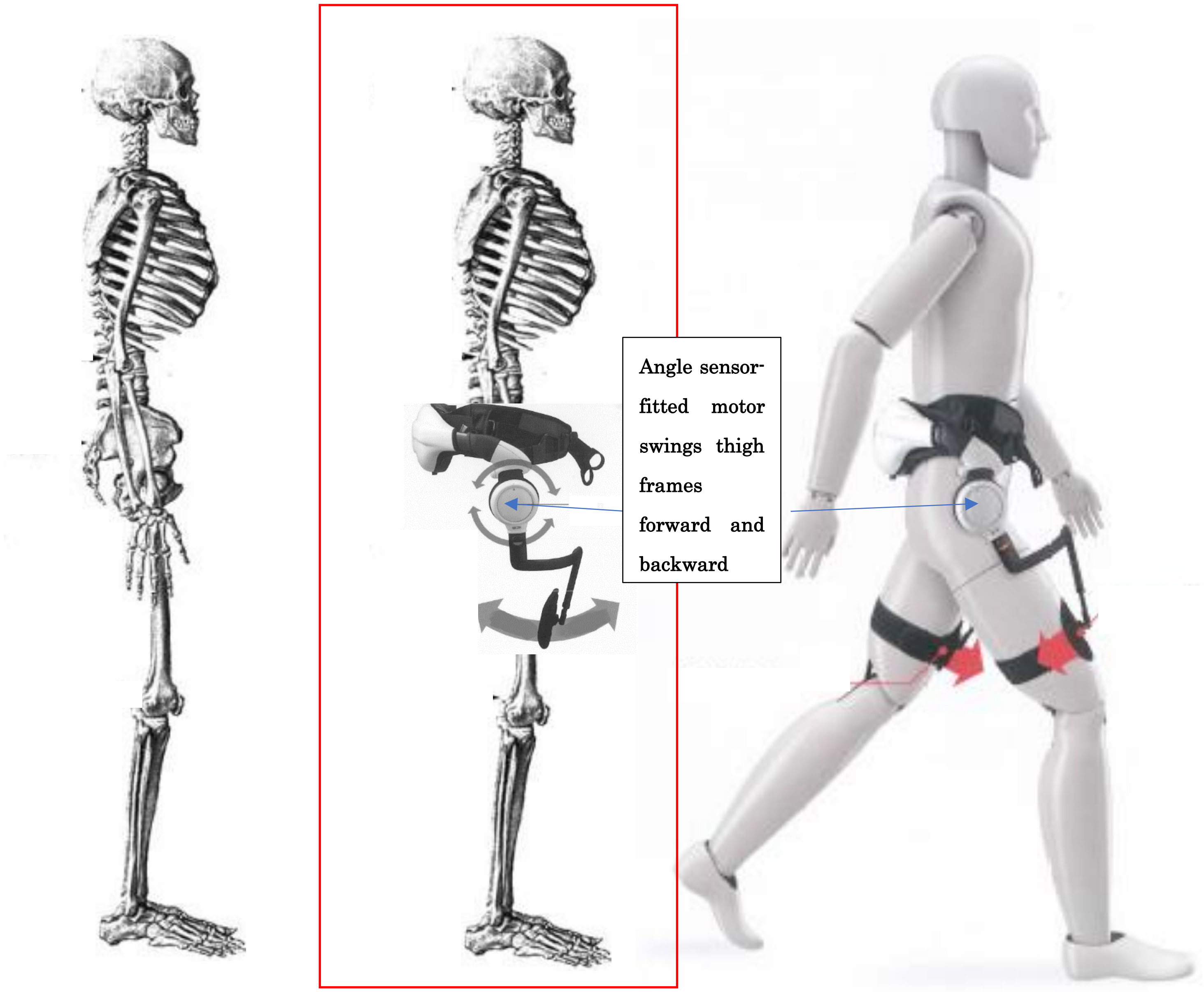


Figure 3.　Motors at both sides of waist frame pinch wearer's hip joints from which femurs dangle to swing forward and downward

The Honda rehab instrument's advantage lies in its ability to continuously quantify the movements of an examinee's right and left legs in terms of a pair of measures of angle that are present on different para-sagittal planes – the angular measures formed between each of the examinee's two femurs and the perpendiculars drawn down from the examinee's right and left hip joints on these separate planes.

The instrument's ability to gauge measures of angles between a person's femurs and the perpendiculars on each of the two parasagittal planes also enables the instrument to conduct measurements of maximum flexion and extension angles formed by each femur with the perpendiculars on the two para-sagittal planes during repeated gait cycles.

This capability opens the path for the instrument's computer to add the measured maximum flexion angle formed by one leg to the maximum extension angle formed by the opposite leg in a bid to compute a crucial index to gauge degrees of the seriousness of asymmetry between the left and right legs' respective abilities to flex and extend the legs.

Honda defines the sum of such maximum flexion angle formed by the right leg on the right para-sagittal plane and such maximum extension angle formed by the left leg on the opposite left para-sagittal plane as the "Right Scissors Angle (RSA)," while defining the sum of such maximum flexion angle formed by the left leg on the left para-sagittal plane and the maximum extension angle formed by the right leg on the right para-sagittal plane as the "Left Scissors Angle (LSA)." (Figure 4~ Figure 7)

A pair of the sums of such maximum flexion and extension angular measures represents a person's ability to spread out his right and left femurs apart from each other along the separate para-sagittal anteroposterior planes. It is easier for observers to conjure up the image of such maximum measures of angle when they observe a walker from the walker's side. (See Figures 1, pages153, 156-9)

Figure 4 What HONDA ASSIST® gauges are actually measure of angle between the projected straight line images of a femur and a perpendicular drawn down from hip joint

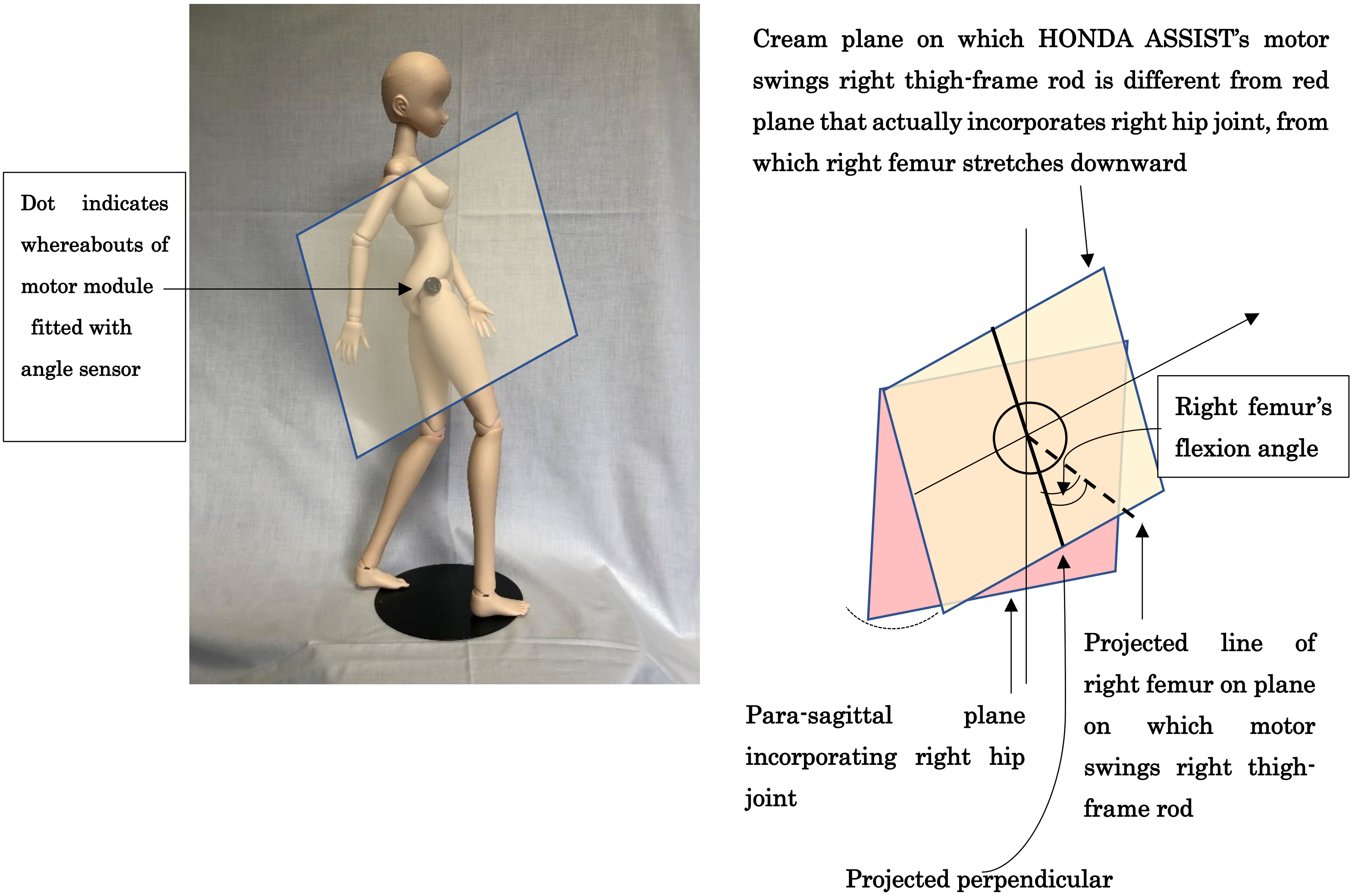
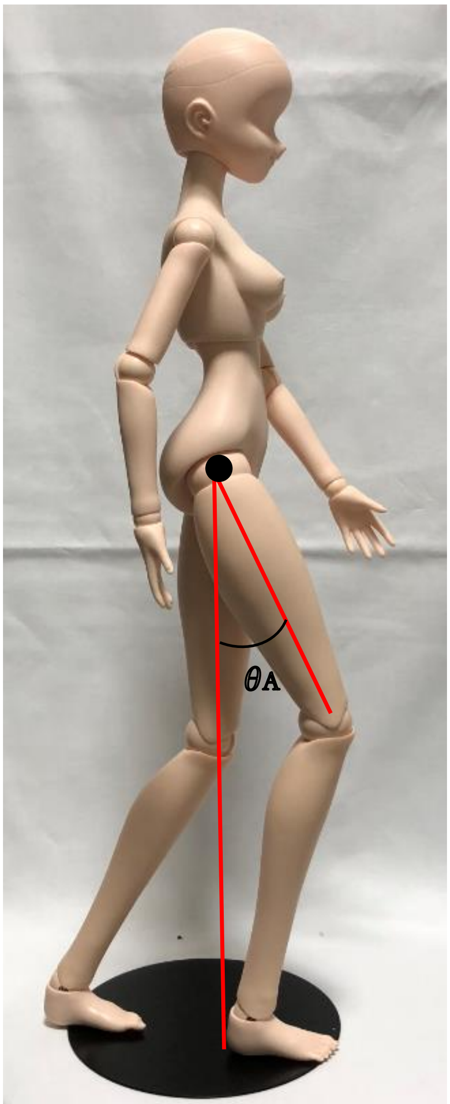


Figure 5 **A Right Scissors Angle (RSA) is the sum of the theta A and the theta B …when the theta A is the angular measure formed between the right femur's maximum flexion line and the perpendicular drawn down from her right hip joint on the right para-sagittal plane incorporating the walker's right hip joint and the theta B is the angular measure formed between the left femur's maximum extension line and the perpendicular drawn down from the left femur's hip joint on the walker's left para-sagittal plane incorporating the walker's left hip joint. Dots indicate the whereabouts of right and left hip joints. The left hip joint corresponding to the vertex at which the theta B's two blue lines intersect is on the left para-sagittal plane, which would be thereby invisible as it should be behind the walker's body.**



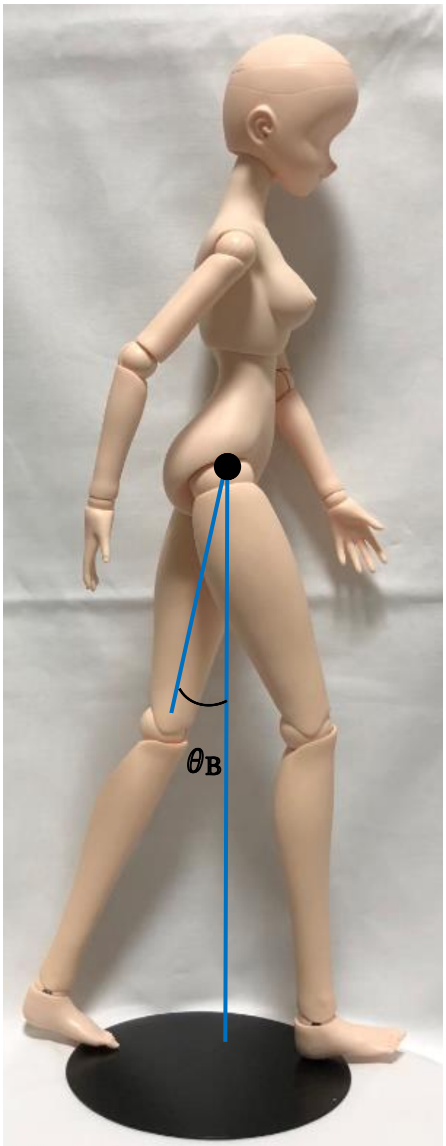


Figure 6 **A Left Scissors Angle (LSA) is the sum of the theta C and the theta D … when the theta C is the angular measure formed between the left femur's maximum flexion line and the perpendicular drawn down from her left hip joint on the left para-sagittal plane incorporating her left hip joint and the theta D is the angular measure formed between the right femur's maximum extension line and the perpendicular drawn down from the right femur's hip joint on the right para-sagittal plane incorporating the walker's right hip joint. Dots indicate the whereabouts of right and left hip joints. The left hip joint corresponding to the vertex at which the theta C's two blue lines intersect is on the left para-sagittal plane, which would be thereby invisible as it should be hidden behind the walker's body.**

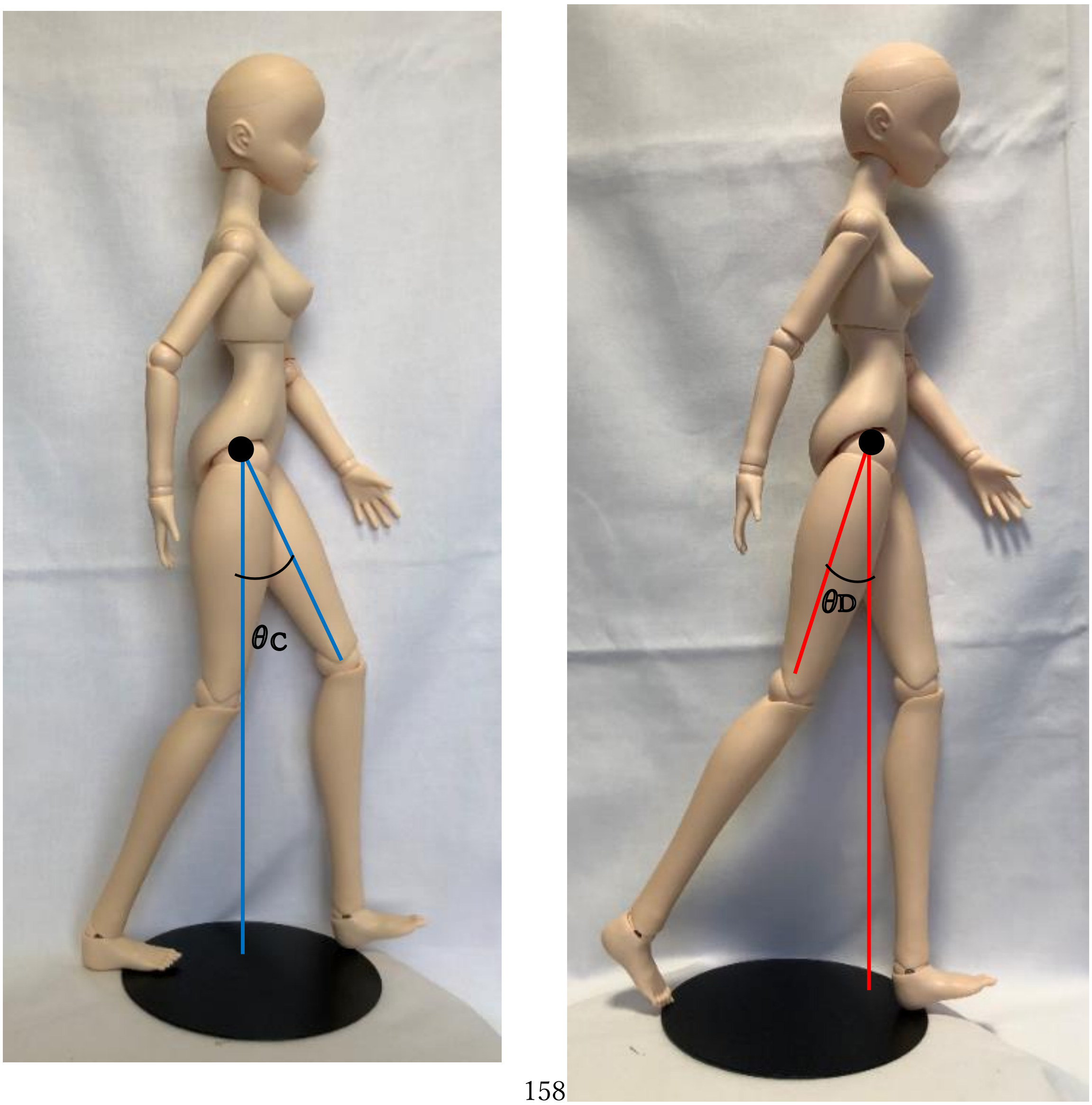
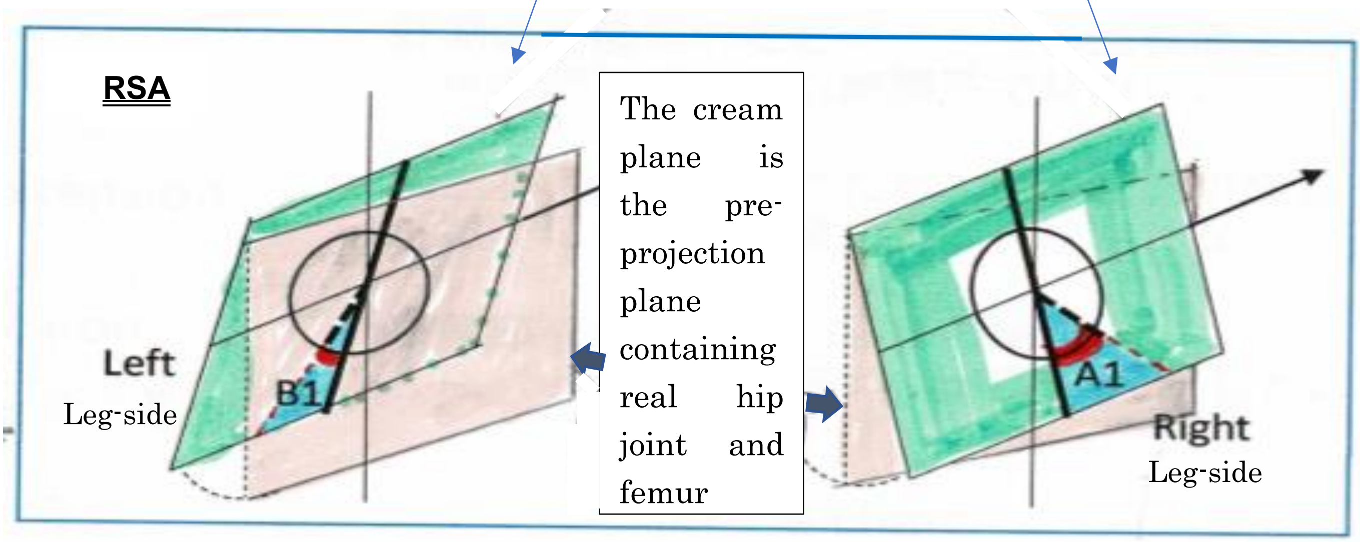


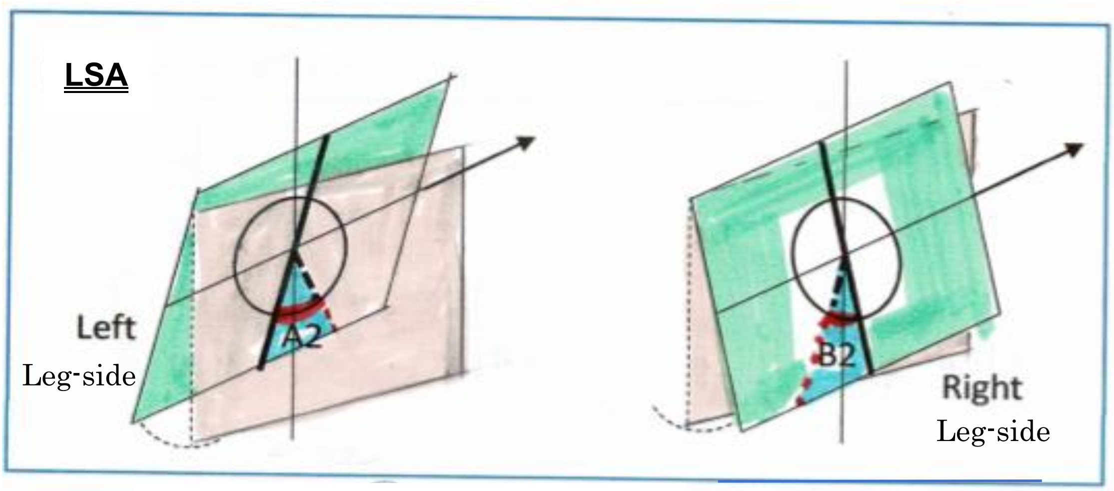
Figure 7 Which angular measures are added to obtain an <u>RSA</u> or <u>LSA</u>?

The green plane is the post-projection plane on which a motor swings the upper straight part of a thigh frame, while in-motor sensors gauge an angular measure between the projected straight-line images of a femur and a perpendicular drawn down from the hip joint from which the femur stretches downward.

A1＋B1＝Right Scissors Angle (RSA) … when A1 is the maximum flexion angle between the projected line images of the right femur and its adjacent perpendicular and B1 is the maximum extension angle between the projected line images of the left femur and its adjacent perpendicular.



A2＋B2＝Left Scissors Angle (LSA) … when A2 is the maximum flexion angle between the projected line images of the left femur and its adjacent perpendicular and B2 is the maximum extension angle between the projected line images of the right femur and its adjacent perpendicular.



Although human walkers produce incessantly variable measures of angles between his femurs and such perpendiculars with his hip joints acting as the pivot for the respective femur's swing, Honda Motor has developed an angle-sensor technology to keep track of, gauge and record the resultant angular measures that show up on the right and left para-sagittal planes as a sequence of numerical data, which the robotic instrument converts into a set of two line graphs on the Cartesian coordinate system by marking the angular measures as ordinates on the Y-axis with the passage of time represented by abscissas on the X-axis.

In addition, the instrument computes an index to measure degrees of the seriousness of asymmetry between a person's left and right legs' abilities to spread out his right and left femurs apart from each other along the separate para-sagittal anteroposterior planes by comparing the sizes of a sequence of RSAs and LSAs.

The RSA-LSA asymmetry degree index is computed by dividing whichever smaller value between an RSA and LSA by whichever larger value between the two angular measures. In other words, whichever smaller value between the RSA and LSA is used as a dividend, whereas whichever larger value between the two angular measures is used as a divisor.

Consequently, the instrument enables doctors and physical therapists to easily and instantaneously know the variability and quality of such patients' walking by checking -- on the screen of a tablet computer to which the gun belt-shaped rehab instrument wirelessly transmits a sequence of angular data it measures -- the RSA-LSA asymmetry degree index and the set of graphs.

We will explain the calculation formulas and definitions for the RSA and LSA in greater details later in the "Methods" segment of this medical dissertation.

The device's ability to compute the RSA and LSA in turn enables the device to quantify degrees of the seriousness of asymmetry between the RSA and LSA as an "RSA-LSA asymmetry degree index, which accurately represents degrees of asymmetry between the examinee's left and right legs' abilities to flex or extend themselves."

A quotient, a consequence of a mathematical formula of division, produces values ranging from zero to 1.0 with the value of 1.0 representing a symmetry. between the respective abilities of the right and left legs. Resultant quotient values are displayed on the screen of the tablet.

Closer to 1.0 an index reading turns out, greater the degrees of the soundness of an examinee's walking are. Therefore, doctors or physical therapists have only to specify appropriate settings for the quantity of a torque that should be imparted by the Honda instrument to the respective femurs of patients in the course of rehabilitation training sessions in an attempt to bring an index reading closer to 1.0.

It follows that the Honda rehab instrument gives doctors and physical therapists a clear-cut orientation and goal to guide their rehabilitation efforts.

In the medical dissertations we released on March 1 and November 11, 2019 on this website, we provided data and evidence to corroborate our findings that the Honda robotic rehabilitation device is effective in softening the degrees of asymmetry between the abilities of the left and right legs of poststroke hemiplegic patients to flex and extend their legs and thereby substantially reviving the soundness of their walking patterns in terms of degrees of symmetry in the two legs' respective abilities to flex and extend the legs.

In this dissertation, we would like to demonstrate that the Honda instrument is highly useful in enabling doctors and physical therapists to easily conduct an highly accurate and objective evaluation of degrees of the soundness of an examinee's walking patterns by letting them know degrees of laterality in the abilities of the examinee's left and right legs to flex and extend themselves by checking RSA-LSA asymmetry degree index's readings.

In so doing, let us present a comparison between the commendable observational gait analysis method of Dr. Jacquelin Perry and Dr. Judith

Burnfield, known as the Rancho Los Amigos method[1)], and Honda's assessment method that involves quantifying movements of examinees' legs in terms of measures of angles between their femurs and the perpendiculars drawn from their hip joints on the separate parasagittal planes incorporating the two joints and using the results of the femur-perpendicular angular measurements to obtain the RSA and LSA, which in turn represents each leg's ability to swing its femur and support the weight of his or her body.

Materials and Methods

<u>Equipment:</u>

This lightweight rechargeable battery-powered instrument, which Honda Motor named "Honda Assist," is a set of an ultra-thin computer-fitted hip frame and two thigh frames, which are fastened to a patient's body with two Velcro belts for left and right thighs and a waist clasp around the patient's waist. (See Figure 8)

This Velcro belts and clasp make the device easily detachable after each rehabilitation training session. The width of the hip frame can be adjusted within the range of 43.0 centimeters and 49.5 centimeters thanks to the strap mechanism. Let us call the device the "Honda Walking Assist (HWA)" in this paper to clarify the device's purpose.

Two electronic angle sensor-fitted motors are fixated to both sides of the gun belt-shaped hip frame.

The hip frame is worn by a wearer at the opposite side of his or her navel. At first glance, the two motors, which are fitted from above a wearer's clothes (usually, trousers or pantaloons) at positions right above the right and left hip joints (greater trochanters), look like the two guns of a cowboy picture's gunman which are suspended from the gun belt's both sides like holsters.

Now, suppose a situation where a doctor is observing the gait of a post-stroke hemiplegic patient who is trying to walk straight forward from the left to the right when the walker is viewed from the observing doctor who stands on the right-hand side of the walker on the floor of a nursing-care facility or a hospital.

Readers are then asked to conjure up the image of the mid-sagittal plane which the patient is now making, while advancing in the right direction. The sagittal plane cuts vertically through his body from anterior to posterior, dividing it into right and left halves.

Now, then, please conjure up an image of two para-sagittal planes which divide his body into unequal right and left parts.

You are then asked to imagine the two types of para-sagittal planes that incorporate the three-dimensional points of the patient's right and left hip joints (greater trochanters), which are softly pinched by the HWA motors, each of which has the shape of a flat cylinder. The motor looks like a woman's round powder compact.

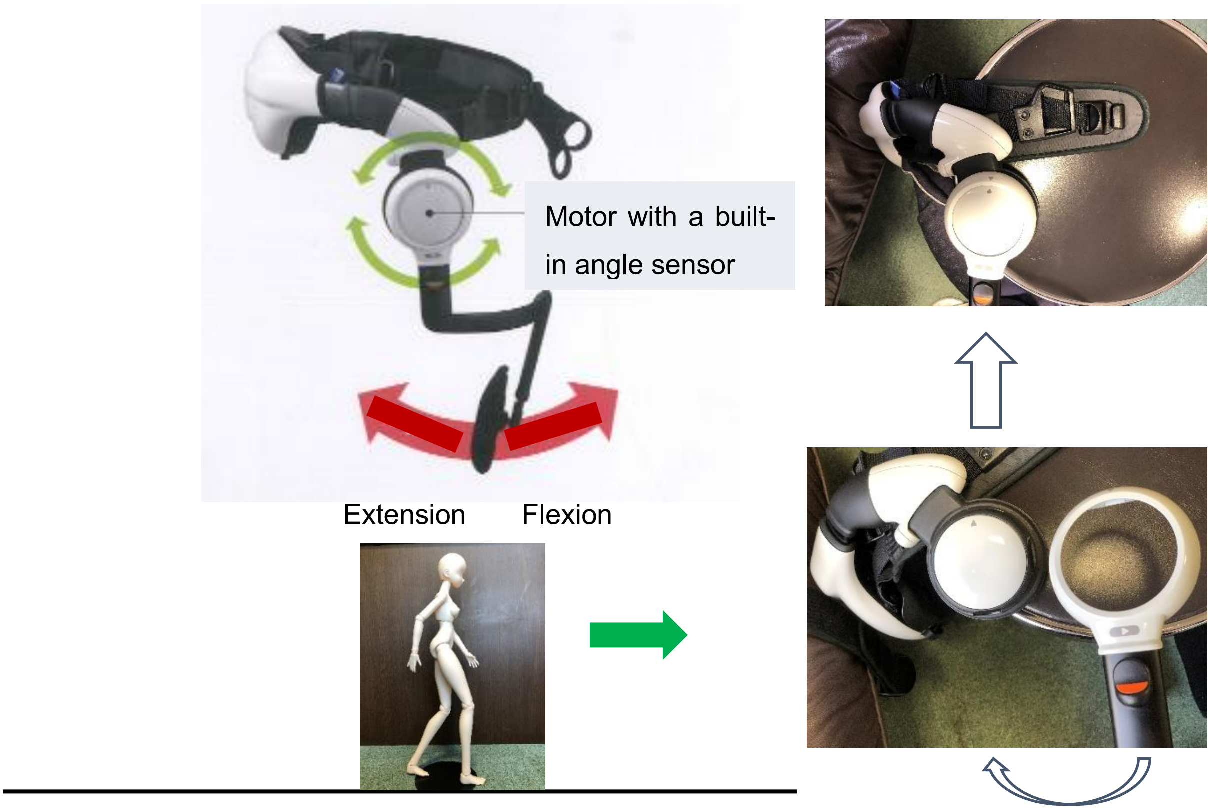
When an HWA-fitted person advances in the green arrow's direction as shown in the explanatory diagram and photos attached below (See Figure 8), the assist's right thigh frame pulls her right leg forward in the direction.

Please note the shape of its right-thigh rod in the side view of the assist. The initial part of the alloy rod stretches downward from the white ring, which fits onto the motor, engaging it tightly.

The rod is bent toward the front of her thigh at its first bend-point. This rod shape enables the forward pulling force to be imparted to the right leg from the moment when her right foot raises of the ground – and throughout the right leg's swing -- until the moment when the right heel is positioned for its initial contact with the ground.

Shortly after the heel strikes the ground, the right thigh frame starts to push the frontal part of the thigh to make the leg extend in the opposite direction. The push generates a force to cause the pelvis to move forward as if the femur became a vertical swing with the frontal center of the femur acting as a fulcrum.

Figure 8 HONDA ASSIST®



Short slender alloy rods, which stretch straightly downward from the white rings meshing with the motors, impart a torque – more precisely a forward-and-backward swinging force -- to the thigh frames, which are fixated onto the right and left thighs with a hook-and-loop fastener. The fastener is known as the “Magic Tape” in Japan and as the “Velcro“ overseas.

Through the intermediary of the rod, the assist’s motors communicate the forward-or-backward swinging forces to a wearer’s thighs via its thigh frames. The rods are swung by the motors “as if a pendulum of a grandfather’s old-day clock moved a pendulum bob forwards and backwards.”

The magnitude of a torque is specified by a doctor or experienced physical therapists after they checked degrees of the seriousness of asymmetry in the wearer’s right and left legs’ abilities to flex and extend themselves in light of the wearer’s right-left spread-angle asymmetry degree index computed by the hip-frame computer to which the in-motor angle sensors transmit the results of their measurements.

The sensors monitor and gauges incessantly- changing measures of angles formed by the wearer's right and left femurs and their respective perpendiculars drawn down from the hip joints through a mechanism that geometrically projects femur lines and perpendiculars onto the planes on which the motors swing the thigh rods.

The torque thus specified is continuously provided throughout multiple gait cycles until the walker reaches his or her destination point.

Summing up, the simple package configuration of the 2.7-kilogram Honda Assist consists of the following five components.

(1) A rechargeable battery-fitted hip frame that straps onto a wearer's waist

(2) Two motors slipping into positions that pinch the wearer's hip joints

(3) Two thigh frames that strap onto the wearer's thighs

(4) Hip-frame computer that communicates a doctor's torque settings for back- and forward swinging force to the motors

(5) A wireless signal transmitter-fitted controller tablet with which a doctor specifies and sets torque values that should be applied to each of the wearer's thighs in light of a right-left spread-angle asymmetry degree index

Methods

While a pendulum oscillates as a result of the universal gravitation which works on the swinging bob's mass which is initially displaced sideways from its equilibrium and resting position, the Honda Walking Assist (HWA) facilitates and supports the legs' flexion and extension on the basis of kinetic forces generated by the motors which are propelled by electric energy in the rechargeable lithium ion batteries.

The HWA incessantly communicates to a wearer's right and left thighs forward or backward swinging forces, which are specified and adjusted by a doctor or a well-trained physical therapist in light of an index representing degrees of the seriousness of asymmetry of the two legs' abilities to flex or extend themselves at each HWA wearer.

By determining and setting magnitudes of torques that should be applied to the right and left femurs of a poststroke hemiplegic patient to help him flex or extend his femurs, the doctor makes the HWA make up for what is lacking in the paralysis-side leg's ability to swing itself and then support this body's weight so that it may form an increasingly larger RSA or LSA to facilitate the doctor's attempt to revive a symmetry between the abilities of patient's two legs to swing themselves and support the body's weight.

A forth-or-back swinging forces from the motors are carefully optimized by a doctor or a veteran physical therapist after they check degrees of the seriousness of asymmetry in the abilities of the patients' both legs to form a "Right Scissors Angle (RSA)" and a "Left Scissors Angle (LSA)."

Now let us call this degree of LSA-RSA asymmetry the "degree of left-right asymmetry," because we have to refer to this asymmetry degree repeatedly in this paper.

Honda defines a "Left Scissors Angle (LSA)" as the sum of the measure of angle between the left leg's maximum flexion line and the perpendicular drawn down from the left hip joint (theta C of Figure 6) and the measure of angle between the right leg's maximum extension line and the perpendicular drawn down from the right hip joint (theta D of Figure 6). (See also Figure 4, Figure 7)

In other words, the LSA is the sum of the theta C and the theta D…when the theta C is an angle formed when a walker's left thigh reaches its peak forward advancement position as a result of the left leg's swing – thereby forming the maximum flexion measure of angle between the left femur's central straight line and the perpendicular drawn down from the left hip joint (left greater trochanter) -- and when the theta D is an angle formed a moment after the theta C's formation, when the walker's right femur reaches its peak backward extension position, thus forming the maximum extension measure of angle between the right femur's central straight line and the perpendicular dropped from the right hip joint (right greater trochanter).

In greater details, Honda computes the LSA by dividing the cumulative sum of all such maximum flexion angular measures formed by a walker's left femur and all such maximum extension angular measures formed by the walker's right femur when the walker traverses a standard distance (say, 10 meters) by the number of gait cycles logged by the walker by the time when he completes walking down the standard distance.

In other words, the cumulative sum is made the dividend with the number of gait cycles logged acting as the divisor. Honda performs this division to obtain the fairest assessment of the LSA, which tends to undergo slight ups and downs in its readings at a sequence of different gait cycles.

The reason why Honda engineers programmed the HWA to let it add the left femur's maximum flexion angular measure to the right femur's maximum extension angular measure despite the two measures being present on different para-sagittal planes is that **the LSA represents the left leg's ability to swing the left leg and, after the completion of the left swing phase, absorb a shock from the left heel's initial contact with the ground, and then accept and support the weight of the walker's body so that the right femur may be allowed to extend well to form an extension angle.**

On the other hand, Honda defines a "Right Scissors Angle (RSA)" as the sum of the measure of angle between the right leg's maximum flexion line and the perpendicular drawn down from the right hip joint to the ground (theta A of Figure 5) and the measure of angle between the left leg's maximum extension line and the perpendicular dropped from the left hip joint (theta B of Figure 5). (Please also check Figures 4 and 7)

In other words, the RSA is the sum of a theta A and a theta B …when the theta A is an angle formed when a walker's right femur reaches its peak forward advancement position as a result of the right leg's swing – thereby forming the maximum flexion measure of angle between the right femur's central straight line and the perpendicular drawn down from the right hip joint (right greater trochanter) -- and when the theta B is an angle formed a moment after the theta A's formation, when the walker's left femur reaches its peak backward extension position, thus forming the maximum extension measure of angle between the left femur's central straight line and the perpendicular dropped from the left hip joint (left greater trochanter).

In greater details, Honda computes the RSA by dividing the cumulative sum of all such maximum flexion angular measures formed by a walker's right femur and all such maximum extension angular measures formed by the walker's left femur when the walker traverses the standard distance by the number of gait cycles logged by the walker by the time when he completes walking down the distance.

In other words, the cumulative sum is made the dividend with the number of gait cycles logged acting as the divisor. Honda carries out this division to obtain the fairest assessment of the RSA, which tends to undergo slight ups and downs in its readings at different gait cycles.

The reason why Honda engineers programmed the HWA to let it add the right femur's maximum flexion angular measure to the left femur's maximum extension angular measure despite the two measures being present on different para-sagittal planes is that **the RSA represents the right leg's ability to swing the right leg and, after the completion of the right-swing phase, absorb a shock from the right heel's initial contact with the ground, and then accept and support the weight of the walker's body so that the left femur may be allowed to extend well to form an extension angle.**

Checking quotients obtained by divisions that are performed in accordance with a set of division formulae described in the subsequent table **(Table 1)**, after LSA and LSA values of an HWA-fitted walker are obtained **enables doctors and physical therapists to know degrees of the seriousness of asymmetry between the two legs' respective abilities** to move the HWA wearer forward through a sequence of femur flexion and extension moves.

Table 1. Mathematical Formulae used in computing an index to represents degrees of the seriousness of asymmetry between right and left legs' abilities to move forward HWA-fitted examinee

Condition	Calculation Formula	Criteria to determine which formula should be used to calculate degrees of the seriousness of asymmetry between Right Scissors Angle (RSA) and Left Scissors Angle (LSA)
RSA > LSA	LSA/RSA	Formula that should be used in cases where right leg's walking ability is superior to paralyzed left leg's
RSA = LSA	1	In cases where LSA and RSA produced same value readings
RSA< LSA	RSA/ LSA	Formula that should be used in cases where left leg's walking ability is superior to paralyzed right leg's

In cases where there is no laterality in the walking abilities of a patient's right and left leg, his right scissors angle is identical to his Left Scissors Angle (LSA). The condition RSA=LSA signifies this sameness.

In cases where there is a laterality in the two legs' walking abilities, whichever smaller between the RSA and LSA must be divided by whichever larger between the two types of measures of angle.

A resultant index reading that expresses degrees of the seriousness of LSA-RSA asymmetry in times of the presence of any laterality would produce readings below 1.0. In other words, if an index value computed in accordance with the table's formulae turns out to be below 1.0, it shows that there is a laterality in the walking abilities of the left and right legs at the examinee.

A quotient, a consequence of the above-described mathematical formula of division, produces values ranging from zero to 1.0 with the value of 1.0 representing a symmetry. Resultant quotient values are displayed on the screen of an HWA tablet.

Closer to 1.0 an index reading turns out, greater the degrees of the soundness of an examinee's walking are.

Therefore, doctors or physical therapists have only to specify appropriate settings for quantities of torque that should be imparted by the Honda instrument's motors to respective femurs of patients in the course of rehabilitation training sessions in an attempt to bring an index reading closer to 1.0. A motor can be set to apply a torque of up to 4 newton-meters in each of a femur's flexion and extension directions.

It follows that the Honda rehab instrument gives doctors and physical therapists a clear-cut orientation and goal that correctly guide their rehabilitation efforts.

Obtaining quotients on the basis of these formulae opens the path for doctors and physical therapists to know, specify and set appropriate magnitudes of torques that should be applied by the HWA to each of paralyzed and sound legs in a bid to soften degrees of the seriousness of asymmetry between the right and left legs' abilities to flex and extend themselves.

Backed by the HWA's mechanism to impart, to its wearer's thighs, forward-and-backward swinging forces specified by doctors and physical therapists, the HWA can help the doctors and therapists to produce fruits in their efforts to help poststroke hemiplegic patients attain sounder walking patterns by substantially reviving a symmetry in their right and left legs' abilities to flex and extend their legs.

To facilitate a clear understanding of the instrument's usefulness in evaluating, and rehabilitating a person's walking functions through the use of an analogy, the translation terms "Left Scissors Angle" and "Right Scissors Angle" are being used by authors to call attention to the concept of "scissors," which is, of course, a cutting instrument made of two blades, pivoted so that the cutting edges can be closed on what is to be cut.

In using these terms, each of a walker's two greater trochanters is likened to the pivot of scissors, whereas the straight center line of his femur is likened to one of the cutting instrument's two blades with the perpendicular drawn down from the hip joint likened to the other blade.

And it is crucial for readers to keep in mind that each of an RSA and LSA is in actuality the sum of a maximum flexion angular measure formed by one of the two femurs on one para-sagittal plane and a maximum extension angular measure formed by the other femur on a different para-sagittal plane with the sagittal plane between the two para-sagittal planes acting as the plane of symmetry.

The magnitude and amplitude of a sequence of RSAs and LSAs, which are respectively formed on the different para-sagittal planes that have symmetry with respect to the sagittal plane, are constantly monitored and recorded by the HWA computer.

These records, resultant print-out papers and line graphs displayed on the screen of an HWA tablet enable observers of patients to easily comprehend and analyze gait deficits at the examinees, by checking them, alongside a key index representing degrees of the seriousness of their RSA-LSA asymmetry.

It is crucial for doctors and therapists engaged in rehabilitation of post-stroke hemiplegic patients to grasp how widely and amply a walker can spread out his or her two legs as an LSA and RSA, even if the two types of angular measures are present on separate anteroposterior para-sagittal planes.

Concerning the HWA's Projection Capability

Technically, the HWA, in measuring an RSA and the LSA, geometrically "**projects"** perpendiculars drawn down from right and left hip joints as well as right and left femurs' respective center lines onto the two planes on which its motors swing the upper straight rods of two thigh frames forwards and backwards as if a light source were placed and kept at a position right beneath the pubic symphysis. (See Figures 4, 5, 6, 7 and 9)

This projection enables the hip-frame computer to measure and record an examinee's constantly-changing measures of flexion and extension angles between his femurs and perpendiculars drawn down from his hip joints. Once a projection is performed, a motor's angle sensor gauges angular measures between the projected femur lines and projected perpendiculars.

This projection enables the instrument to accurately measure RSAs and LSAs on para-sagittal planes incorporating an examinee's hip joints – be the examinee a poststroke hemiplegic patient or a healthy person -- while allowing it to continuously capture and put on record measures of angles formed by the examinee's femurs and perpendiculars.

Post-projection Right Scissors Angles (RSAs) and Left Scissors Angles (LSAs) thus measured on the motor planes with angle sensors are identical to pre-projection measures of RSAs and LSAs actually formed by the two femurs and the perpendiculars dropped from their respective hip joints on para-sagittal planes sandwiching the sagittal plane.

The HWA plots and displays measures of angles formed by an examinee's right and left femurs with their respective perpendiculars as two line graphs on the table's screen with Y-axis ordinates that represent angular measures.

The resultant Y-ordinates either ascend or descend, drawing a set of graphs on the Cartesian coordinate system as a walker goes through various phases of his gait cycles with the passage of time and communicating detailed, accurate and easy-to-understand information on movements of an examinee's legs to observers.

This feature also allows the HWA to record, display and print out a resultant set of line graphs representing coordinates on the graphs' X-axis and Y-axis, with readings on the X-axis expressing the passage of time and those on the Y-axis measures of angles.

This graph-drawing feature also facilitates doctors' instantaneous comprehension and in-depth analysis of degrees of the soundness of examinees' walking patterns, which are essentially degrees of the seriousness of asymmetry between the two legs' abilities to flex and extend themselves and support the weight of a walker's body following the completion of each leg's swing phase.

This projection capability enables the instrument, with its angle sensors, to track and measure constantly-changing flexion and extension angels made by right and left legs despite the fact that those angular measures spring up on parasagittal planes incorporating greater trochanters.

As a matter of course, the sensors cannot be surgically implanted into a human's hip joints.

Still, the robotic assist's projection capability, which brings angular measures that require measuring to obtain RSA and LSA readings out of a human's body onto the motor planes, enables a string of flexion and extension angles, including their MAXIMUM readings – the very addends used to compute RSAs and LSAs -- to be measured accurately.

The HWA's two motor planes on which the upper parts of its alloy thigh frames are swung, lean on each other like the legs of a very tall isosceles triangle, or like the two sides of the alphabetical letter of an "A" as a result of the presence of a human's subcutaneous fat at their thighs.

If readers kindly remember how the two legs of the Eiffel Tower extend toward the sky in the tower's multiple postcards, it may help them graphically evoke the image of the mutual reclination of the two motor planes in their minds. Despite the mutual reclination, the robotic assist's projection capability enables the LSA and RSA to be measured accurately.

The battery-powered HONDA ASSIST® imparts amounts of back-and-forth swinging forces specified by a doctor or an experienced physical therapist to the thighs through its thigh frames, which swing "as if a grandfather's old-day clock moved a massive pendulum bob forward and backwards."

And the HWA tirelessly performs enormous amounts of leg-flexion and leg-extension work to help hemiplegic patients improve the quality of their walking unlike human physical therapists who could develop serious fatigue as a living creature if they were required to manually provide hemiplegic patients with same quantities of leg-flexion and leg-extension services as the HWA does.

This kinetic-energy support from the HWA's motors is continuously provided through the intermediation of its motor-thigh frame engagement mechanism throughout multiple gait cycles until the walker reaches his or her destination point.

In so doing, the HWA goes on improving a post-stroke hemiplegic patient's walking ability by effectively "teaching" such a patient how to walk with greater degrees of left-right symmetry. This in turns appears to stimulate and start his brain's crucial "learning process" about how to walk correctly, or with greater LSA-RSA symmetry degrees, by causing some brain cells that have remained unscathed by his stroke to acquire the function of keeping the results of his learning as a memory.

Object of Study

Movements of two femurs of a 78-year-old female at a sequence of phases during the gait cycles of the female with a normal walking-ability were quantified in terms of afore-explained angular measures, recorded and analyzed with the aid of the Honda robotic rehab instrument. The female traversed a standard distance of ten meters on the flat ground at our rehabilitation center.

Data of the female was collected on August 2, 2018, to check if the robotic assist has an ability to facilitate an accurate evaluation of the characteristics of humans' gait cycle and the degrees of the left-right asymmetry as defined in this paper.

During this data collection occasion, we did not let the HWA apply a torque (forward-and-backward swinging force) to the female's thighs because we opted to concentrate on checking if the HWA has a high level of capability to allow observers to evaluate movements of humans' both legs, their walking patterns, gait characteristics and gait deficits, if any, by quantifying the movements of their legs in terms of a pair of measures of angle.

Data furnished by this equipment

The tablet, which comes as a set with the HWA hip frame and a pair of thigh frames, enables physical therapists and doctors to show patients data representing the present state of the quality of their walking as well as degrees of improvements in their walking quality right after each rehabilitation training session on the basis of a comparison of the latest data with the patients' past data.

All types of relevant key data on legs' movements are automatically stored by the HWA computer and can be displayed on the tablet's screen. The data can also be printed out in the form of Excel spreadsheet data and a set of line graphs that represent the movements of an examinee's right and left femurs. This feature enables data at the same patient to be compared historically to facilitate an objective and in-depth analysis.

Figure 2 presents an idea of how a skeleton would look like if doctors fastened a Honda Assist to a skeleton. Figure 3 is a graphic representation of a doll to which the robotic assist was fastened.

These figures should give readers an understanding of the whereabouts of the position on a human body to which the robotic assist is designed to be fastened with Velcro belts and a waist clasp as well as the whereabouts of the positions of the HWA's motors and its hip frame in relation to an HWA wearer. They should also give readers a basic idea on how the motors and thigh frames would impart its forward-and-backward swinging forces to its wearer's thighs.

Figure 9 shows a healthy walking-ability person who wore a HONDA ASSIST® for our study. The person traversed a standard distance of10 meters. She complied with physical therapists' standard measurement instructions to start walking from a position about 1 meter before a starting line drawn on the floor of a rehabilitation center. She was also instructed to try to keep walking with a homogeneous pace. She walked straight forward, passing the goal line as shown in the upper-left segemt of Figure 9.

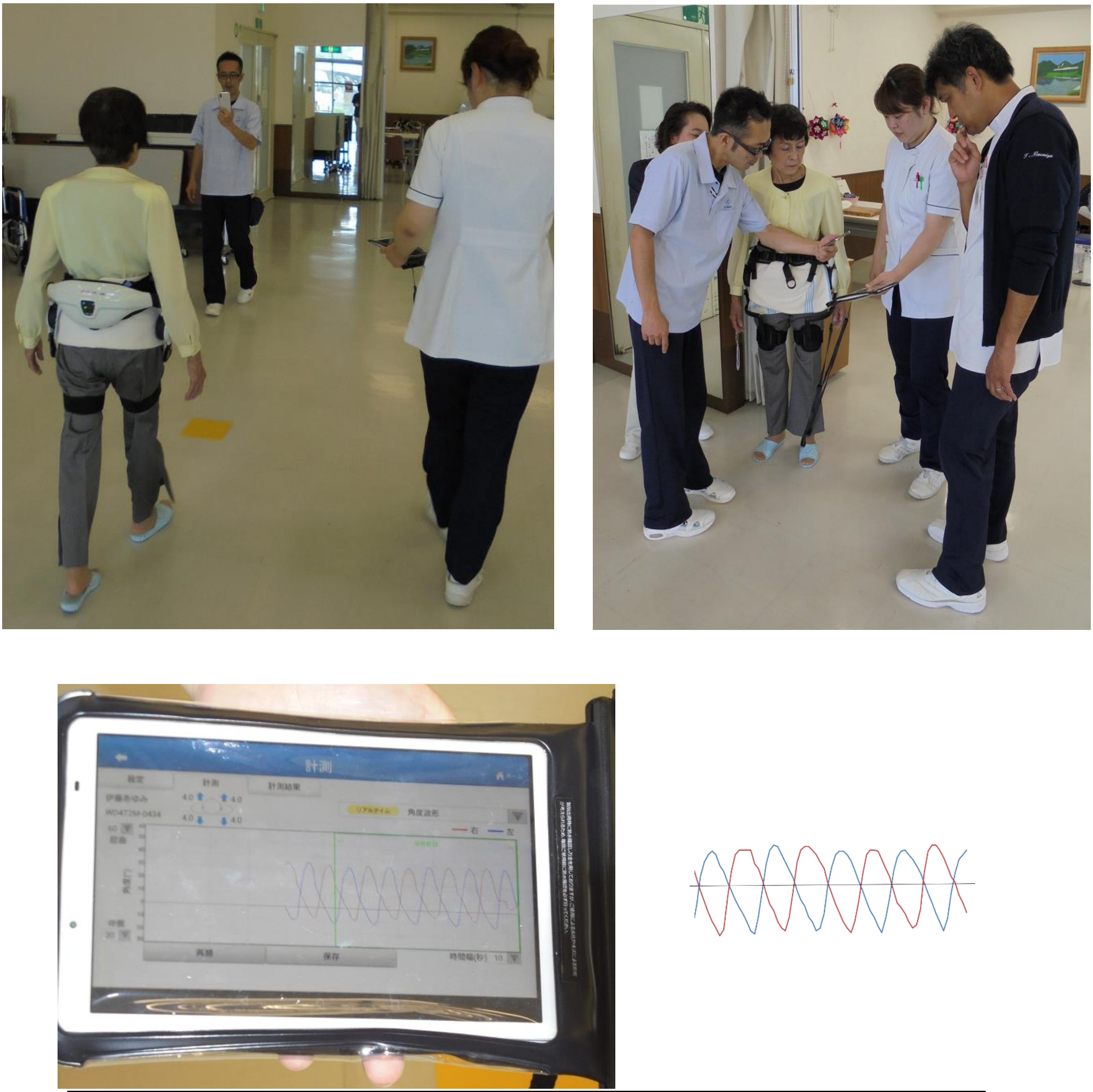
After the examinee completed walking in accordance with the instructions, a professional physical therapist showed the examinee the results of her measurements by displaying the data on the screen of a tablet controller held by the therapist’s left hand. The upper-right picture of Figure 9 showed the scene of the explanation. The results of the examinee’s measurements showed the detailed characteristics of her walking patterns.

The picture presented at the lower-left segment of Figure 9 shows the screen of the tablet controller exactly when it was displaying the characteristics of the examinee’s gait cycle patterns a moment after her gait measurements were completed at her 10-meter walk session.

The lower-right picture showing a set of blue and red graphs is that of the examinee’s leg movements which were drawn by the HWA. The HWA quantified the movements of her right and left legs in terms of measures of angle, thereby drawing the blue and red graphs with the passage of time. The HWA plotted continuous readings of the measures of angles formed by her femurs and the perpendiculars dropped from her right and left hip joints with the anugular measures used as ordinates on the Y-axis on the Cartesin coordinate system. The time that passed from the onset of the walking session were presented as abcissas on the X-axis.

The same image presents the central black line which horizontally divides the graphs into almost equal-sized halves. The black line was later added in the course of our study to call attention to a close resemblance of the shapes of the two graphs with a typical sine curb. The phenomenon stemmed from the fact that the examinee demonstrated high levels of the soundness of the quality of her walking during the study session, which is attested to by the very small degree of laterality between RSAs and LSAs formed by her femurs and the perpendiculars dropped from her hip joints.

Figure 9　A ten-meter walking by a healthy walk-ability person wearing the HONDA ASSIST® robotic rehabilitation instrument

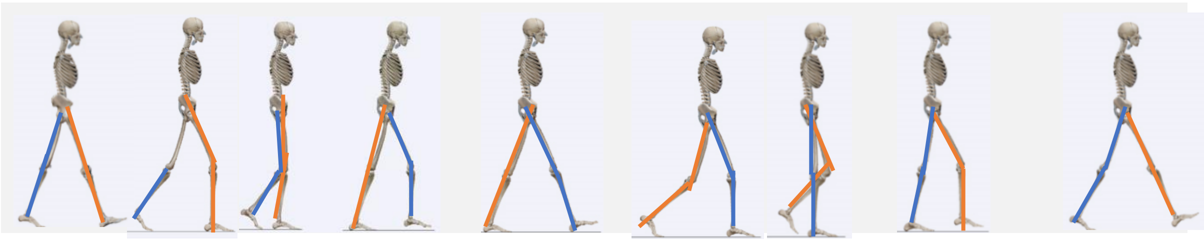


This is the examinee's walking-pattern graphs drawn by the robotic instrument on the basis of measures of angles formed by her femurs and adjacent perpendiculars dropped from her hip joints.　The graphs are being shown by a physical therapist to the examinee, who has just finished walking.　The right graphs are the printed-out results of the examinee's gait measurement.

Results

Table 2. Observational Gait Analysis

First half cycle		Latter half cycle	
Phase 1 0~10%	Phase 2 10~50%	Phase 3 50~60%	Phase 4 60~100%
Both legs support body	Single (right) leg supports body weight	Both legs support body	Single (left) leg supports body weight
Right Stance Phase			*Right SwingPhase*
	Left Swing Phase	Left Stance Phase	



90%	0%	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
previous cycle	current cycle										

Side	Right	Left	Right	Left	Right	Left	Right
Events	I.C.	Toe off	Heel rise	I.C.	Toe off	Heel rise	I.C.

Side		Right	Right	Right	Right	Right	Right	Right
Events	Initial Contact	Loading Response	Mid stance	Terminal stance	Pre swing	Initial swing	Mid swing	Terminal swing
	I.C	L.R.	M.St.	T.St.	P.Sw.	I.S.	M.Sw.	T.Sw.
	Front right foot's heel strikes ground in its I.C.	Both legs support body's weight	Rear left foot is lifted off of the ground and the left foot swings	Heel of front right foot leaves the ground at the end of the terminal stance	Both legs support body's weight	Start of right leg's swing. Front heel leaves ground	Front foot away from ground.Both legs become vertical and overlap when seen from walker's side	Tibia's vertical state ends. Right heel strikes ground

Side		Left	Left	Left	Left	Left	Left	Left
Events		Pre swing	Initial swing	Mid swing	Terminal swing	Loading Response	Mid stance	Terminal stance
		P.Sw.	I.S.	M.Sw.	T.Sw.	L.R.	M.St.	T.St.
		Both legs support body's weight	Start of left leg's swing. Rear left foot leaves ground	Rear foot away from ground. Both legs become vertical and overlap when seen from walker's side	Tibia's vertical state ends. Left heel' strikes ground in its I.C.	Both legs support body's weight	Right front foot create clearance from the ground and the leg swings	Heel of rear left foot leaves ground at the end of terminal stance

Gait Cycle

The global medical community’s standard method for representing a human’s gait cycle was devised by Dr. Jacquelin Perry who worked at the Rancho Los Amigos National Rehabilitation Center and co-authored the admirable textbook “GAIT ANALYSIS: Normal and Pathologic Function-(SLACK)” with Dr. Judith Burnfield.[1)]

The characteristics of this analytical method is to divide one gait cycle into eight phases and describe events that take place in each phase by the use of language in terms of spatial and temporal characteristics of two lower limbs.

Table 2 provides a summary of this gait cycle and the results of an analysis performed with this method.

Human beings walk upright on two legs with each of the legs swinging altermatively. Hence, one gait cycle of a healthy walking-ability person consists of two almost-identical half cycles.

During the first half-cycle, one of the legs which acts as the front leg when the walker is viewed from his side by an observer standing on the walker’s right-hand side plays the role of supporting his body’s weight. During the latter half-cycle, the other rear leg assumes the body-supporting role which the front leg has just completed playing during the first half cycle.

Let us summarily present main events that occur during these half cycles by categorizing the events as those belonging to one of following four primary phases (Phases 1 to 4) as below.

In doing so, let us measure a gait cycle from the front right heel’s strike on the ground to the subsequent right heel strike on the ground in accordance with the conventional tacit model on the assumption that the person is advancing from the left to the right with an observer standing on the walker’s right-hand side.

Initial half cycle	Phase 1	The right heel's initial contact (I.C.) with the ground occurs a moment before the onset of a new cycle. A loading response continues during the Phase I (0~10%), during which both feet maintain contact with the ground.
	Phase 2	Phase 2 is the entire time that the front right leg single-handedly supports the body's weight. During this, the opposite left leg swings. This phase ends when the left heel strikes the ground. (left foot's I.C. with the ground).
Latter half cycle	Phase 3	At Phase 3, left foot's loading response occurs. During this phase, both feet maintains contact with the ground.
	Phase 4	Phase 4 is the entire time that the left leg single-handedly supports the body's weight. During this, right leg swings. This phase ends when the right heel strikes ground again (right heel's I.C. recurs)

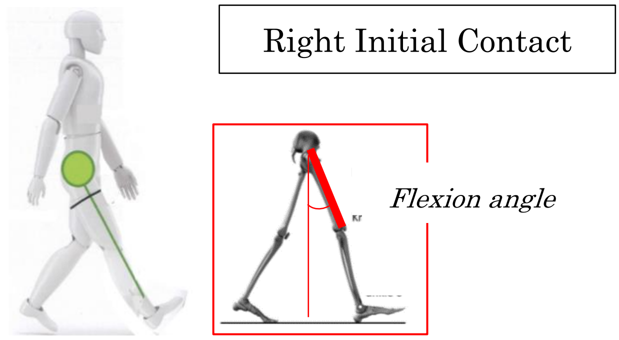
Table 3 describes events that occur during each of the above-mentioned four phases.

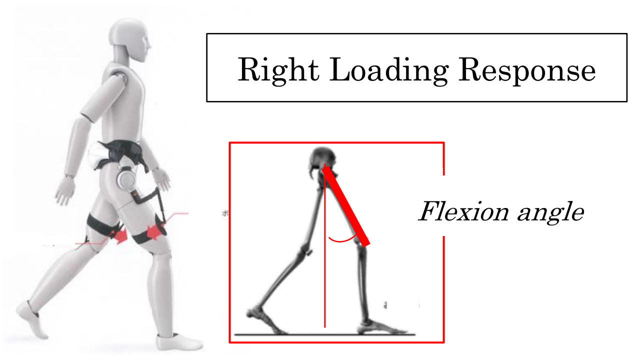
Figures on the far-right column of the table show the state of angles formed, firstly during the initial half-cycle, by a walker's right femur with the perpendicular drawn down from the walker's right hip joint on the right-hand para-sagittal plane and, secondly during the latter half-cycle, the state of angles formed by the walker's left femur with the opposite left-side perpendicular dropped from the left hip joint on the left para-sagittal plane.

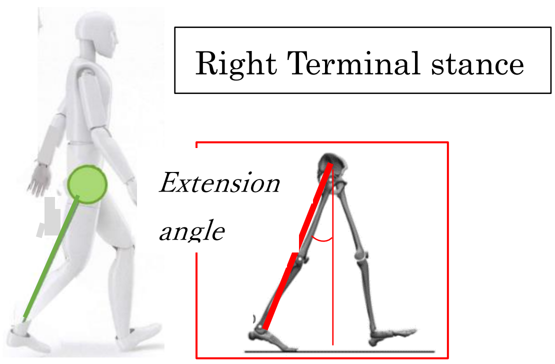
Among angles formed by one of the walker's femurs and the perpendicular dropped from the hip joint from which the femur dangles, those formed by the femur seen being in front of the perpendicular when the walker is observed from his right-hand side are *flexion angles, while* angles formed by a femur seen being behind the perpendicular dropped from the hip joint from which the femur dangles are *extension angles*.

Table 3. Gait cycle expressed in terms of spatial and temporal characteristics of two lower limbs observed at either one of Four Phases
Flexion and Extension angles formed by the two lower limbs during the Four Phases shown on the far-right column

Cycle	Phase	Events	Comments
First half cycle		Initial Contact (I.C) of front foot	Front right heel strikes the ground
	Phase I (0~10%) Both legs' support	Loading Response (L.R) of front right leg	
			Left foot is pushed on the ground and lifted off of the ground Left toe leaves ground
	Phase II (10%~50%) Front leg supports body weight without the other's aid Opposite rear leg swings	Mid~Terminal stances of front right leg	Front right foot is in stance phase

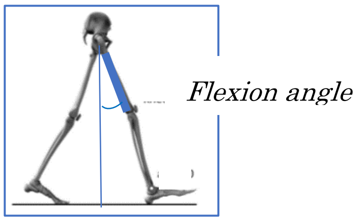




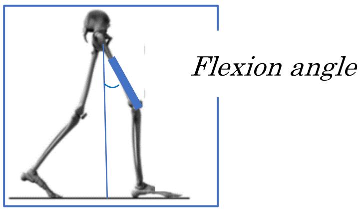


Cycle	Phase	Events	Comments
		Initial Contact(I.C) of opposite rear left foot	Left heel strikes the ground
Latter half cycle	Phase III (50%~60%) Both legs support body's weight	Loading Response (L.R) of opposite rear left leg takes place	
			Right foot is pushed on the ground and lifted off Right toe leaves ground
	Phase IV (60%~100%) Front right leg swings Rear leg supports body weight unaided	Mid~Terminal stances of opposite left rear leg	Opposite left leg is in stance phase

Left Initial Contact



Left Loading Response



Right toe off

Left Terminal stance

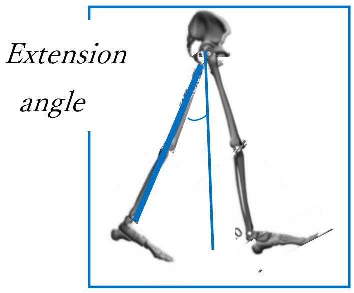


Figure 10. Healthy Person's Gait Cycle graphically represented by HONDA ASSIST ® as Red and Blue Graphs by Quantifying the Movements of Right Femur (red line) and Left Femur (blue line) in terms of a Pair of Measures of Angle.

First half cycle		Latter half cycle	
Phase I 0~10%	Phase II 10~50%	Phase III 50~60%	Phase IV 60~100%

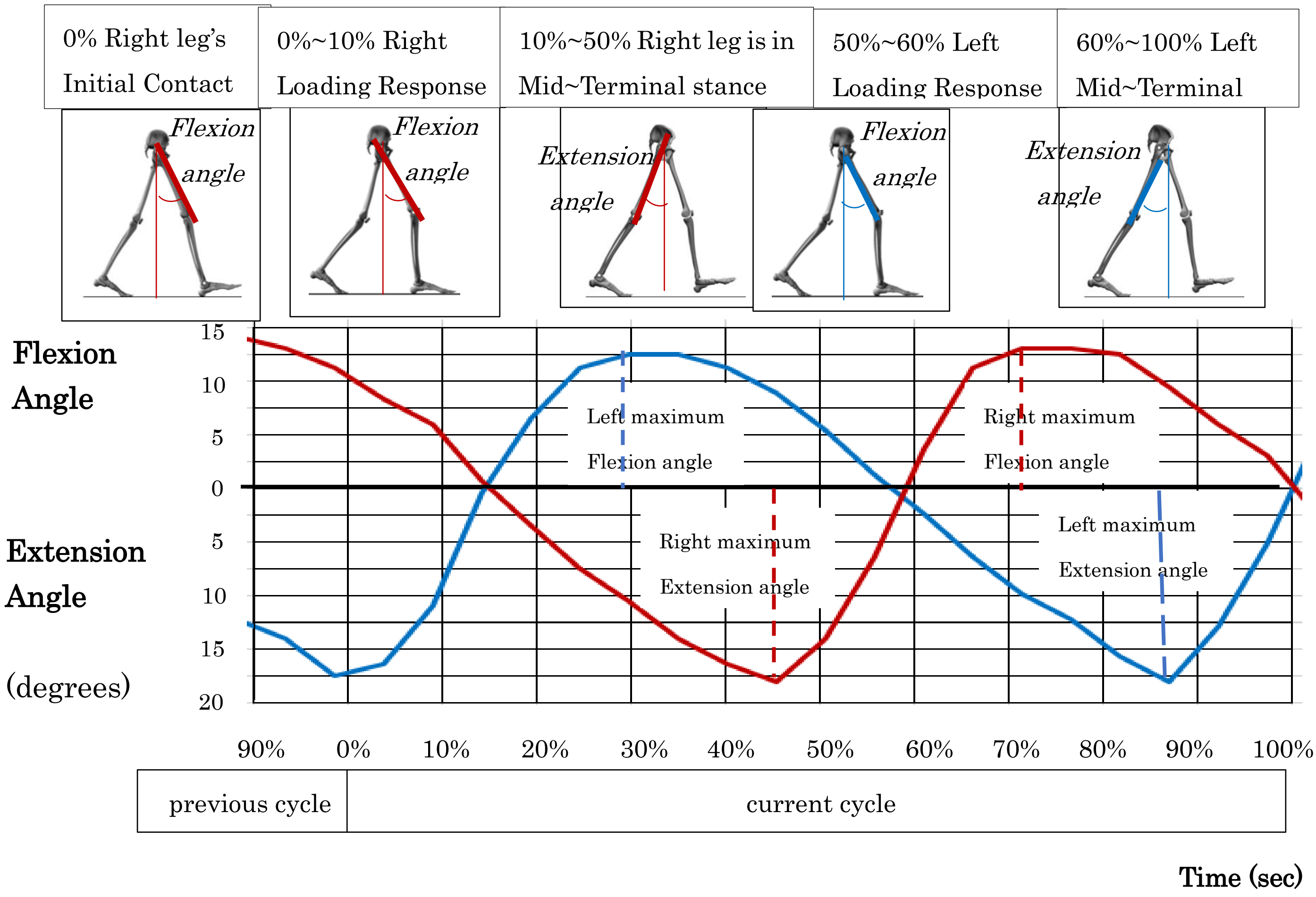


Figure 10 presents a set of red and blue line graphs drawn by the Honda instrument in light of a sequence of a pair of measures of angle between a healthy walking-ability person's femurs and the perpendiculars dropped from the hip joints from which the femurs dangle. To draw the graphs, the robotic instrument quantified the pendulum-like movements of the person's two legs in terms of such measures of angle.

The red graph shows a continuous sequence of changes in measures of angle between the 79-year-old female walker's right femur and the perpendicular drawn down from her right greater trochanter on her right-hand para-sagittal plane. The measures of angle thus gauged were dotted as ordinates on the Y-axis on the Cartesian coordinate system while the passage of time was represented as abscissas on the X-axis.

On the other hand, the blue graph shows a continuous sequence of changes in measures of angle between her left femur and the perpendicular dropped from her left hip joint on the left-hand para-sagittal plane. (For further explanations, please see Figures 4, 5, 6, 7)

This figure and Table 3 are the results of our attempts to show **which segments of the two graphs drawn with Honda's robotic technology to quantify movements of a walker's legs in terms with a pair of measures of angle** correspond to the two lower limbs' temporal and spatial characteristics at each of phases of a gait cycle observed and then described with the use of language in accordance with the Rancho Los Amigos method for helping humans comprehend a human's gait cycle by isolating the shortest repeatable task performed by each of the two limbs.

The Honda technology also involves computing an RSA-LSA asymmetry index explained in this paper's preceding sections, evaluating degrees of the seriousness of asymmetry in the both legs' abilities to move forward the intellectual subject who use the legs in light of the index's readings and then substantially reviving the subject's sound walking by orienting physical therapists' rehabilitation efforts towards the clear-cut, simple goal of bringing the index's readings closer to 1.0

If we try to summarily describe anew the spatial and temporal characteristics of the female examinee's two lower limbs in a series of events in the phases of her gait cycle with the use of a language as in Figure 10 and Table 3 in accordance with the afore-described conventional tacit model, we have to point out, first of all, that the right foot's initial contact with the ground occurs at the onset of her gait (0% of gait cycle time). In other words, the right heel strikes the ground.

Between 0% to 10% of the gait cycle time, a loading response occurs.

In this event, the right leg absorbs a shock stemming from the right foot's initial contact with the ground, begins to support the weight of a walker's body which had been previously supported by the left leg. Finally, at the end of the loading response, the weight of the body comes to be fully supported by the right leg. Around this moment, the left foot is pushed to the ground and then is lifted off of the ground.

After the passage of roughly 10% of the walker's gait cycle time, her left leg starts to swing.

During the 10~50% of the cycle time; her right leg is in the Mid- to Terminal stance. During this phase, the status of a series of angles formed by her left leg with the perpendicular dropped from her left hip joint shifts from a string of diminishing extension angles to a sequence of growing flexion angles. Amidst this shift, her left femur attains the maximum flexion angle with the perpendicular by posting its maximum forward advancement angular measure.

During the same 10~50% of the cycle time, the right leg shifts from the Mid- to the Terminal stance, while the angle formed by the right femur with the perpendicular dropped from the right hip joint shifts from a series of diminishing flexion angles to a sequence of expanding extension angles. Amid the terminal-stance phase of the right leg, its femur attains its maximum extension measure of angle with the perpendicular dropped from the right hip joint.

Events that occur during the subsequent latter half of a gait cycle can be described as being essentially analogous with the events that took place in the first half-cycle if only we correctly assumes that the walker’s right and left legs swapped their roles of supporting a body’s weight or swinging a leg to bring about the walker’s forward progression.

Discussion

Stroke cases are quite common in Japan, especially among the elderly that have come to occupy a burgeoning area of Japanese society’s population pyramid graph amid the progression of the graying of the Japanese populace. Most of these stroke cases are not fatal. Consequently, a burgeoning number of Japanese elderly have become sufferers of poststroke hemiplegia.

The sufferers’ full recovery from post-stroke hemiplegia cannot be attained in most cases. However, starting efficient rehabilitation efforts as speedily as possible after a poststroke hemiplegic patient recovered from his or her initial acute stage is critical to enable the patient to recover the soundness of walking as much as possible.

The essence of the soundness of a human’s walking lies in a symmetry in the abilities of his left and right legs to flex and extend themselves and spread out femurs amply and widely on different para-sagittal planes incorporating left and right hip joints.

The Honda instrument concentrates its main efforts on evaluating degrees of this asymmetry and then eliminating the asymmetry as far as possible by teaming up with doctors and physical therapists who specify what quantities of torque should be applied to each of the two femurs by the instrument in order to revive the vital symmetry.

To facilitate rehabilitation of sufferers of a post-stroke hemiplegia, various rehabilitation apparatus has been developed by researchers in and out of the academia and are being used at many geriatric nursing-care institutions for the elderly across the world.

Evaluating accurately the state of such patients' walking functions at multiple stages of months of rehabilitation courses is crucial to know whether doctors and physical therapists are responding to patients' conditions properly.

Having some data (or video records) of a patient's walking patterns before he or she underwent a stroke would be an ideal to enable a comparison between the past data and data on the present state of poststroke hemiplegic patients.

Possessing the two types of data would enable doctors and physical therapists to know if their rehabilitation efforts of patients' walking functions have produced fruits and to what extent they have produced positive effects.

However, usually such past records are not available.

Therefore, the absence of such data leaves doctors with no alternative but to compare a patient's walking patterns and spatial and temporal characteristics of his or her two lower limbs during a gait cycle with those of a normal walking-ability person whose age matches the patient's.

HONDA ASSIST is one of rehabilitation instruments developed by the international human community to facilitate walking training for hemiplegic patients in view of the presence of a growing number of the elderly suffering from poststroke hemiplegia and other hemiplegia cases that have causes other than a stroke.

The key advantage of the Honda robotic instrument over the other types of rehabilitation apparatus is that it can quantify the movements of a human's right and left legs in terms of a pair of measures of angles formed by his femurs with the perpendiculars dropped from the hip joints from which the femurs dangle either on the right-hand para-sagittal plane (in quantifying the movements of the right lower limb) or on the left-hand para-sagittal plane (in quantifying the movements of the left lower limb), thus producing an index representing degrees of the seriousness of asymmetry between the right and left legs' respective abilities to move forward the intellectual subject who use the two lower limbs.

The index and a pair of graphs representing measures of angle formed by each of the two femurs with the perpendiculars can be shown to patients, doctors and physical therapists right after such measurements are performed, while the angular measures and RSA-LSA asymmetry degree index readings are automatically stored in the Honda instrument's computer memory to facilitate a later in-depth analysis and a historical comparison.

In this manner, the Honda instrument enables an objective and accurate evaluation of the quality, laterality and variability of poststroke hemiplegic patients' walking to be carried out.

Such objective, accurate evaluation is indispensable to produce as large rehabilitation effects as possible by giving physical therapists and doctors a clear-cut, easy-to-understand orientation and goal for their rehabilitation efforts in light of RSA-LSA asymmetry index readings, while encouraging patients themselves to strive more during rehabilitation courses to recover the soundness of their walking.

Gait analysis data gathered with the Honda instrument can be used to substantially revive the soundness of walking at both poststroke hemiplegic patients who have been previously given access only to physical therapists' manual rehabilitation or access only to rehabilitation training with other types of rehabilitation instruments.

Conclusion

We compared the gait cycle of a healthy walking-ability person whose two femurs' detailed spatial and temporal characteristics were quantified as a pair of measures of angle by HONDA ASSIST with a gait cycle analysis performed with the Rancho Los Amigos method.

Consecuently, we have concluded that a crucial advantage of the Honda instrument over the Rancho Los Amigos method is that it enables doctors and physical therapists to conjure up images of walking patterns and degres of gait deficits at poststroke hemiplegic patients by simply taking a look at a pair of graphs drawn by the instrument in accordance with measures of flexion and extension angles formed by the patients' femurs and the perpendiculars and a RSA-LSA asymmetry degree index it computes.

This numerical and graphical representation capability of the Honda instrument frees doctors and physical therapists from the danger of being confused and annoyed by ambiguities that are oftentimes involved in the use of language in describing temporal and spatial characteristics of the two lower limbs.

The Honda instrument's numerical and graphic representation capability can give physical therapists and doctors a correct, clear-cut orientation and an easy-to-understand goal for their rehabilitation efforts, that is, checking an RSA-LSA asymmetry degree index and then seeking to bring the index reading closer to 1.0 throuth their rehabilitation training sessions.

The Honda robotic instrument which quantifies the movements of two legs in terms of a pair of measures of angle enable doctors and physical therapists to evaluate the quality, laterality and variability of patients' gait patterns objectively and instantaneously, while giving them a correct orientation and a clear goal in seeking to revive the soundness of the patients' walking through rehabilitation courses.

The author and co-authors do not have any conflict of interest to disclose regarding this academic paper.

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1. Jacqueline Perry, Judith M. Burnfield: GAIT ANALYSIS: Normal and Pathological Function.　Second ed. SLACK Inc., Thorofare, 2010, pp.4-16.