Seating Biomechanics and Systems

- Human body is not designed to sit, at least not for prolonged periods of time, in the same position
- For people with disabilities who are unable to walk and require the use of wheeled mobility and seating devices, sitting is necessary
- Identifying the most effective seating system for a such a specific need can be challenging

In a seated position, the pelvis and thighs act as the base of support and the hip joints are placed in a flexed position, resulting in a potentially unstable base of support

Seating Biomechanics and Systems

Posterior and lateral view of seated postures

In a seated posture, the pelvis is free to tilt and rotate in multiple directions, ultimately affecting the position and posture of the rest of the upper body. The seated body, therefore, is <u>unstable</u>.

SEATING AND COMMON PATHOLOGIES

Slouched posture with sacral sitting

Improper posture can result in long-term formation of contractures and deformities.

The most common is the pelvis rotating in a posterior direction, resulting
in sacral sitting, flexion of the lumbar spine, and kyphotic posture.
Also, sacral sitting in decreased trunk control

Scoliosis of the spine

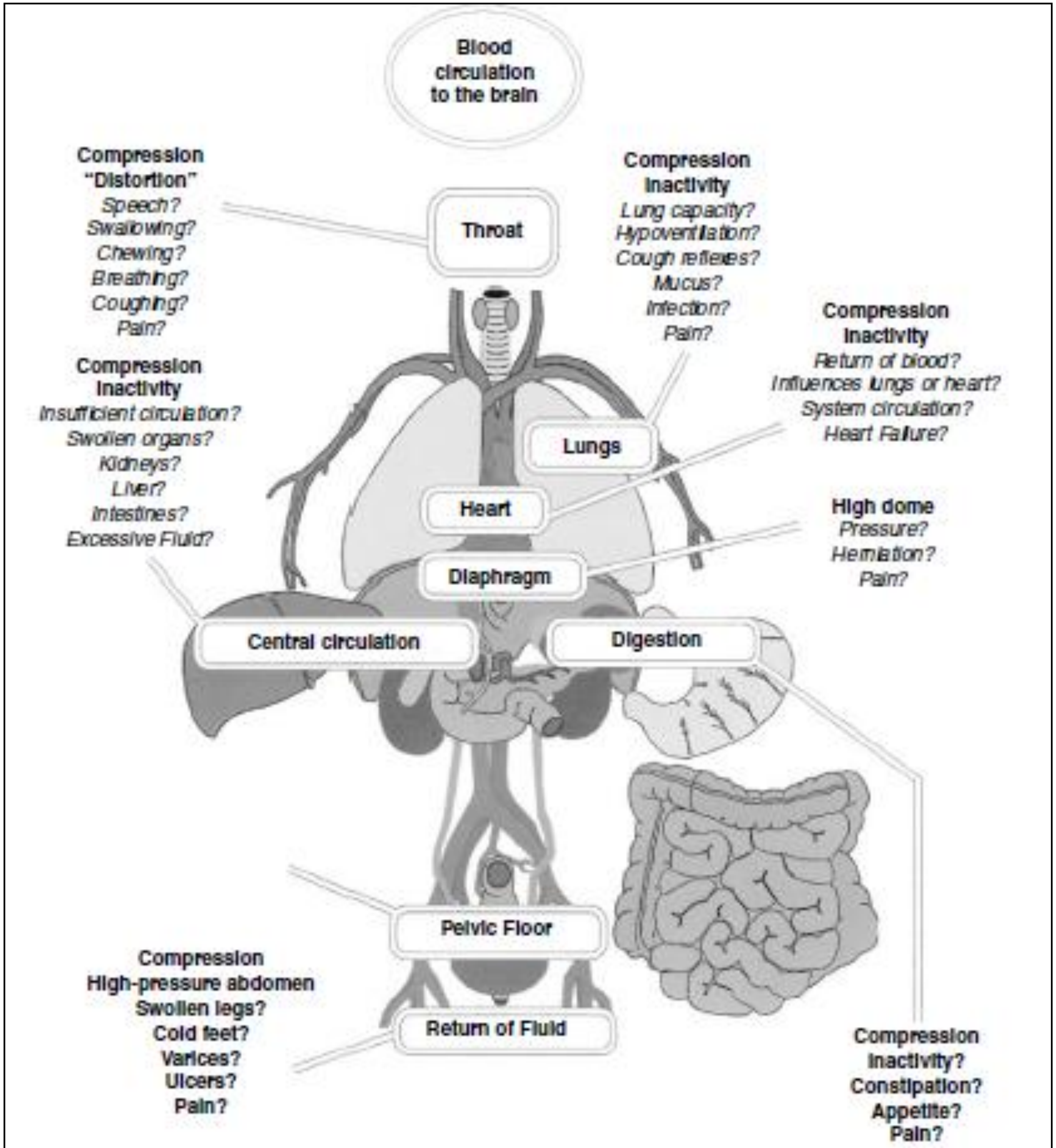
The pelvis tilts to the left or right, whereby the spine and trunk will compensate in the opposite direction, causing a scoliosis or lateral flexion deformity of the spine

Lordosis of the spine

The pelvis rotates in an anterior direction, resulting in increased flexion of the lumbar spine, due to proximal trunk weakness in people with muscular dystrophy

Windswept deformity

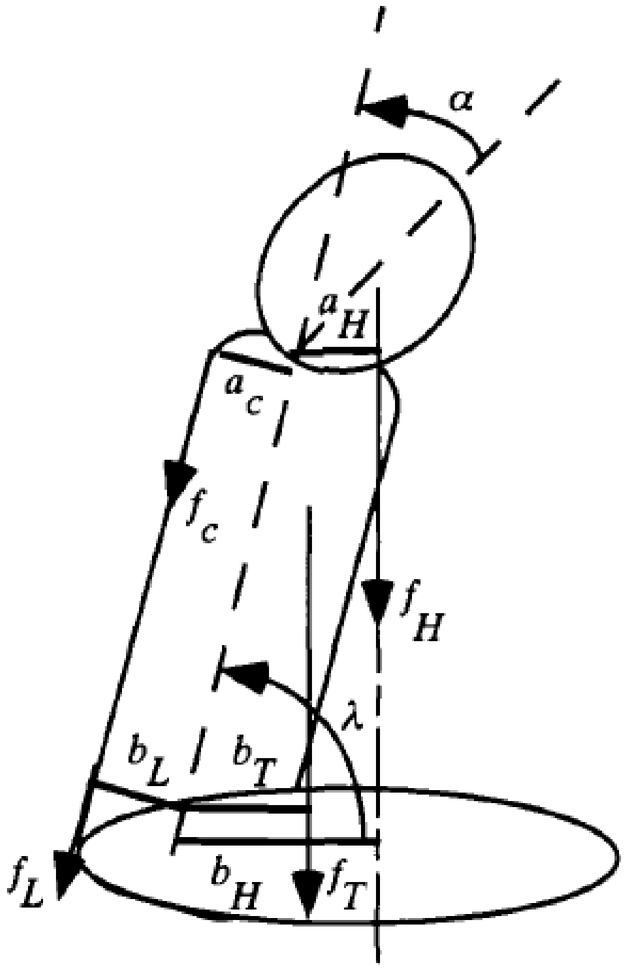
The pelvis can rotate to the left or right in combination with other movements, causing what is termed a "windswept deformity," whereby the thighs migrate to the left or right



Possible influences on organs in prolonged slouched sitting posture

Sitting has been associated with secondary complications such as pressure sores, back pain, joint contractures, postural deformities, and edema in the lower extremities

Seating and spine

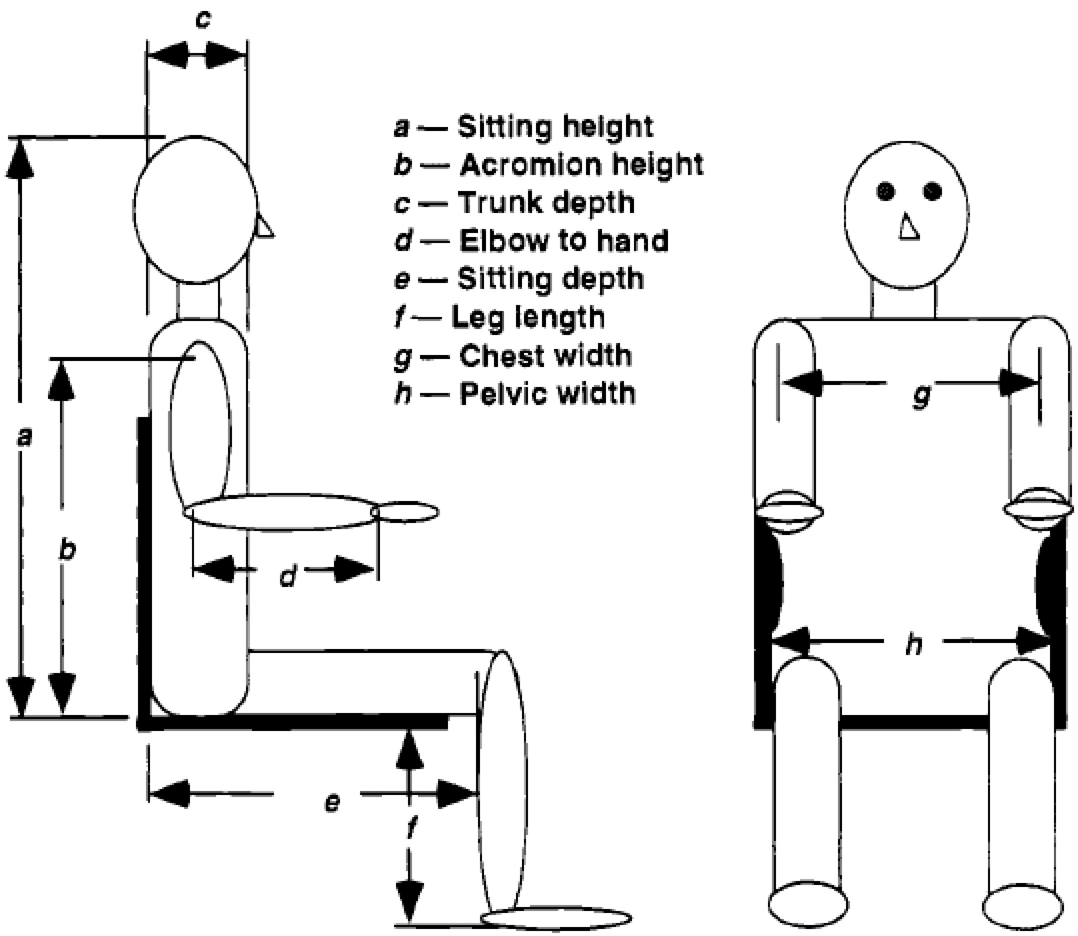


Schematic diagram of forces acting on the spine

$$f_c = f_H \frac{a_H}{a_c} \qquad f_L = \frac{f_T b_T + f_H b_H}{b_L}$$

α_C = moment arm of the cervical spine extensor muscles
a_H = moment arm of the head's weight
b_H = moment arm of the head's weight
b_L = moment arm of the lumber spine extensor muscles
b_T = moment arm for the torso's weight
f_H = weight of the head and neck
f_T = weight of the torso
f_C = force due to the cervical spine extensor muscles
f_L = force due to the lumbar spine extensor muscles

Studies have shown a decrease in disk pressure when lumbar support was added at the level of the 4th and 5th lumbar vertebrae. The use of armrests has also been shown to reduce disk pressure.



Anthropometric measurements used in seating

SEATING SYSTEMS

- Prefabricated: linear sitting system - generically contoured
- Modular or adjustable: components that can be adjusted, added, or removed to address a specific postural need such as lateral trunk supports and thigh guides
- Custom-contoured system

Medically, a system should address issues of soft tissue management, comfort, reducing the potential for or accommodation of orthopedic deformities, and maintain vital organ capacity.
Functionally, the system should address the movements and supports that the user may need to perform such activities, such as to reach or access objects, transfers, sit at tables, and other activities of daily living.
Personal needs

Seating systems components: at least a seat and back support, often supports for the arms, legs, and the head. Adjustable features may include reclining backrests, tilt-in-space, seat elevators, and standing systems

SEAT SUPPORTS
BACK SUPPORTS
ARM SUPPORTS
FOOT AND LEG SUPPORTS
HEAD SUPPORTS
TILT FRAMES AND RECLINING BACKRESTS

Adjustable power tilt, recline, elevating leg rests, and seat elevation

STANDING SYSTEMS

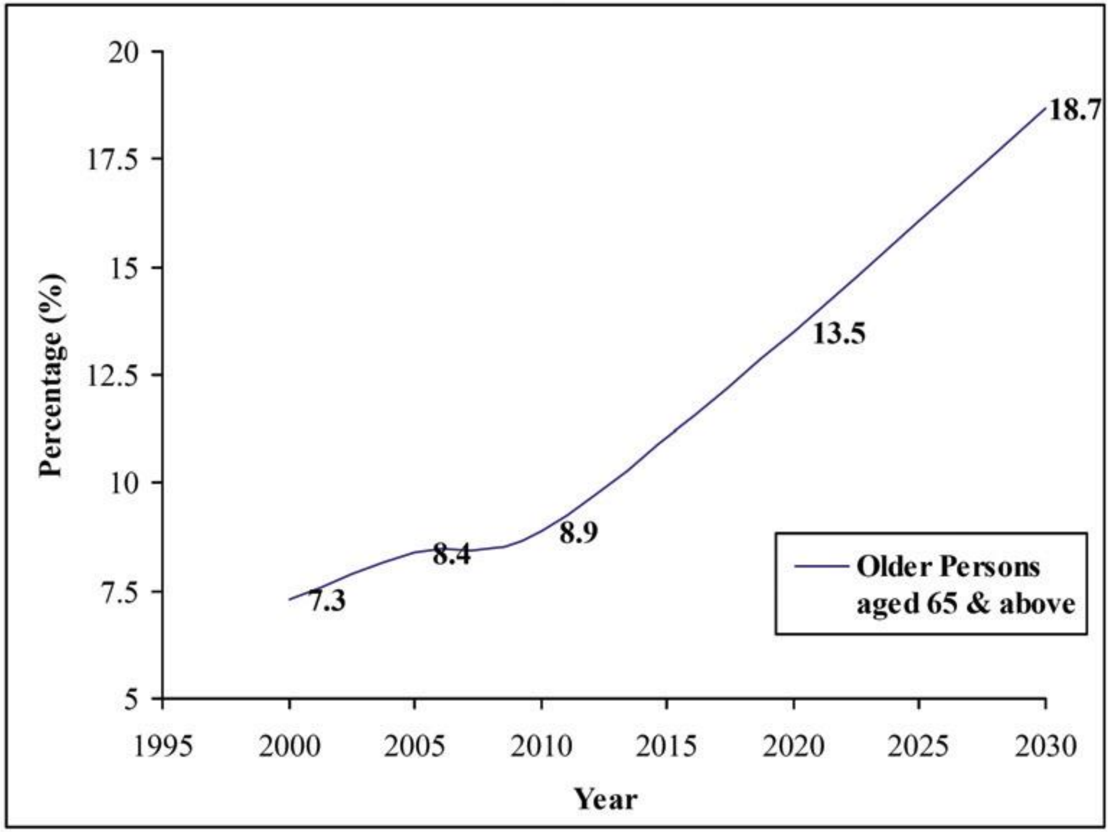
SEAT ELEVATION SYSTEMS

Wheelchairs

- Mobility devices, in particular wheelchairs and scooters*, make up a significant portion of assistive devices in use today.
- Continued growth in the wheelchair market due to increasing aging populations, longevity, and increased incidence of traumatic combat-related injuries, and more effective therapies for chronic diseases.
- Manual - electric power wheelchairs.
- Need for continued advancements in wheelchair technology.

From being chairs with wheels providing some minimal mobility to advanced orthoses

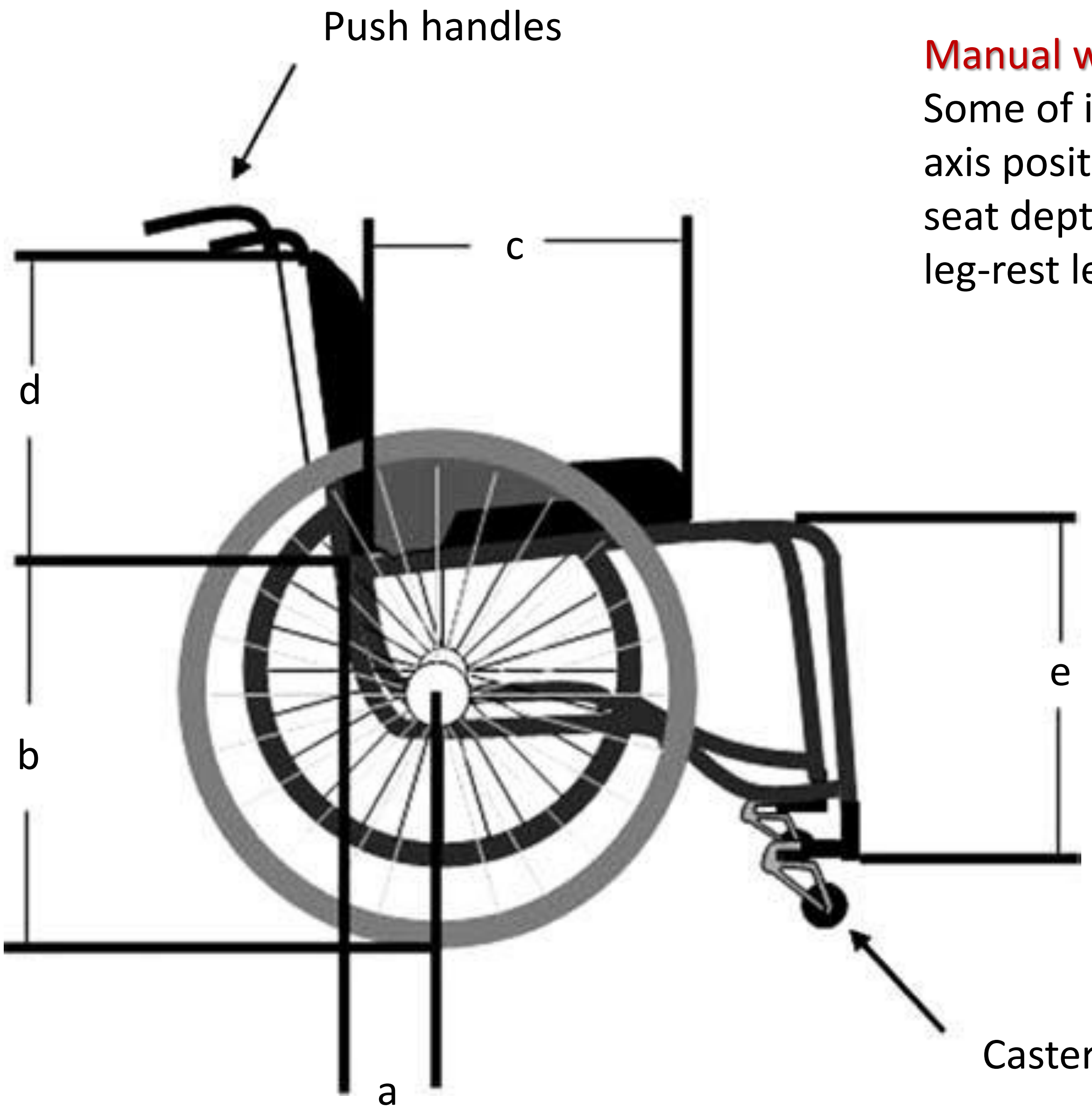
*Πατινι, διτροχο καροτσακι



Proportion of Resident Population Aged 65 & Over From 2000 – 2030
Source: Singapore Department of Statistics (DOS), 2005

Current ISO 7176 Standards for Wheelchairs

ISO number	Document title
00	Nomenclature, Terms, and Definitions
01	Determination of Static Stability
02	Determination of Dynamic Stability of Electric Wheelchairs
03	Determination of Effectiveness of Brakes
04	Determination of Estimated Range of Electric Wheelchairs
05	Determination of Overall Dimensions, Weight, and Turning Space
06	Determination of Maximum Speed, Acceleration, and Retardation for Electric Wheelchairs
07	Determination of Seating and Dimensions
08	Static, Impact, and Fatigue Strength Testing
09	Climatic Tests for Electric Wheelchairs
10	Determination of Obstacle Climbing Ability of Electric Wheelchairs
11	Wheelchair Test Dummies
13	Determination of the Coefficient of Friction Test Surfaces
14	Testing of Power and Control Systems for Electric Wheelchairs
15	Guidelines for Information Disclosure
16	Flammability Characteristics
17	Serial Interface Compatibility (Multiple Master Multiple Slave)
18	Stair Traversing Wheelchair Testing
19	Wheelchair Tie-Downs and Occupant Restraints
20	Stand-up Wheelchair Testing
21	Electromagnetic Compatibility for Electric Wheelchairs
22	Wheelchair Setup Procedures for Testing
23	Battery Testing



Manual wheelchair:
Some of its critical dimensions: (a) axis position; (b) seat height; (c) seat depth; (d) backrest height; (e) leg-rest length.

BASIC STRUCTURAL COMPONENTS

Frame:

Materials: steel, chrome, aluminum, titanium, and other lightweight composite materials

"Add-on" suspension elements to decrease shock and vibration and make for a smoother overall ride

Seat height: seat height is placed at a level where the individual will have the necessary knee clearance to fit under tables, counters, sinks, etc.

Seat depth: support the individual's thighs

Seat width: slightly larger than individual's buttocks

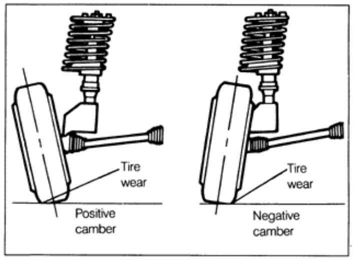
Back height: depending on the amount of postural support needed and comfort

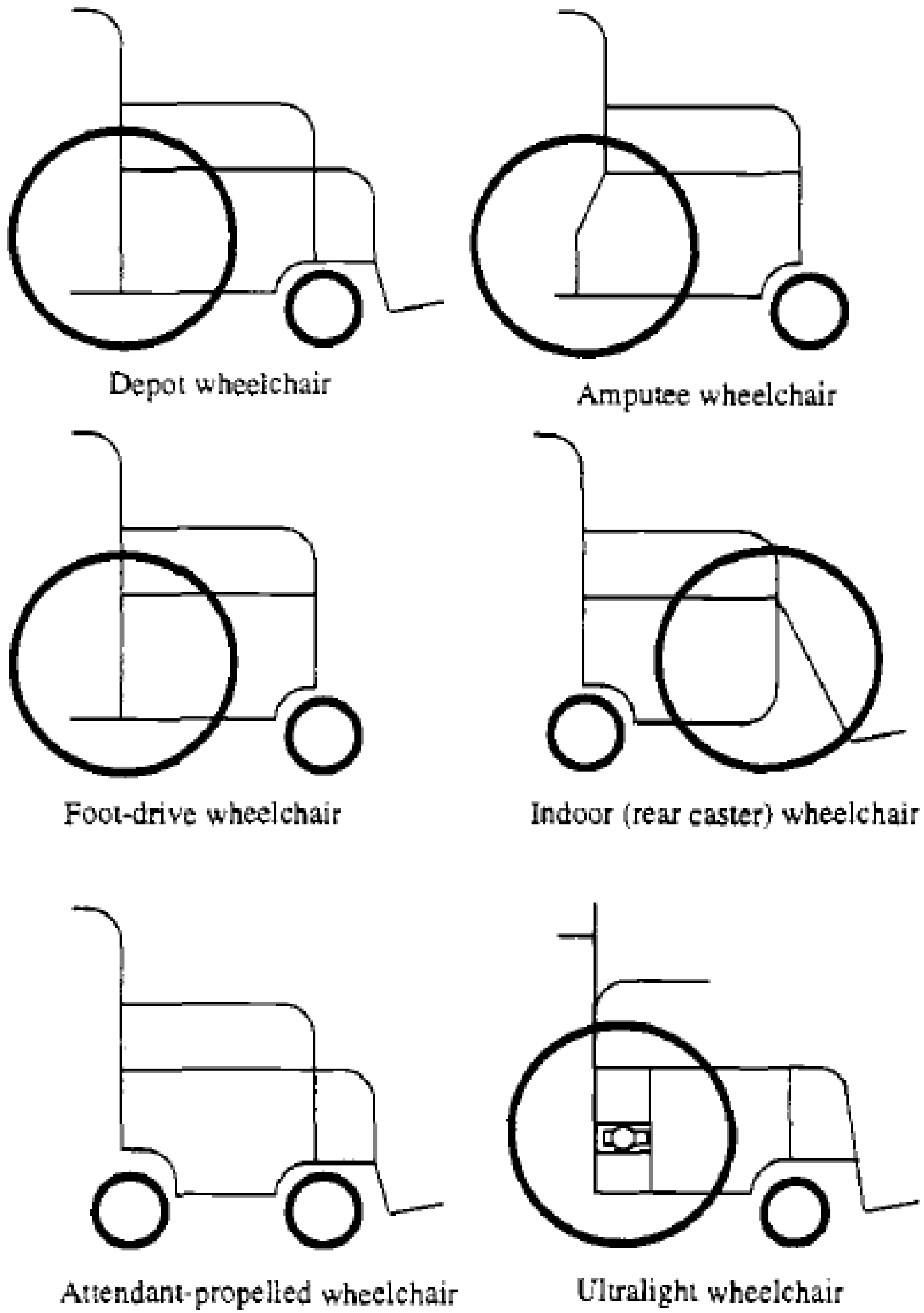
Seat and back angles

Armrests and footrests

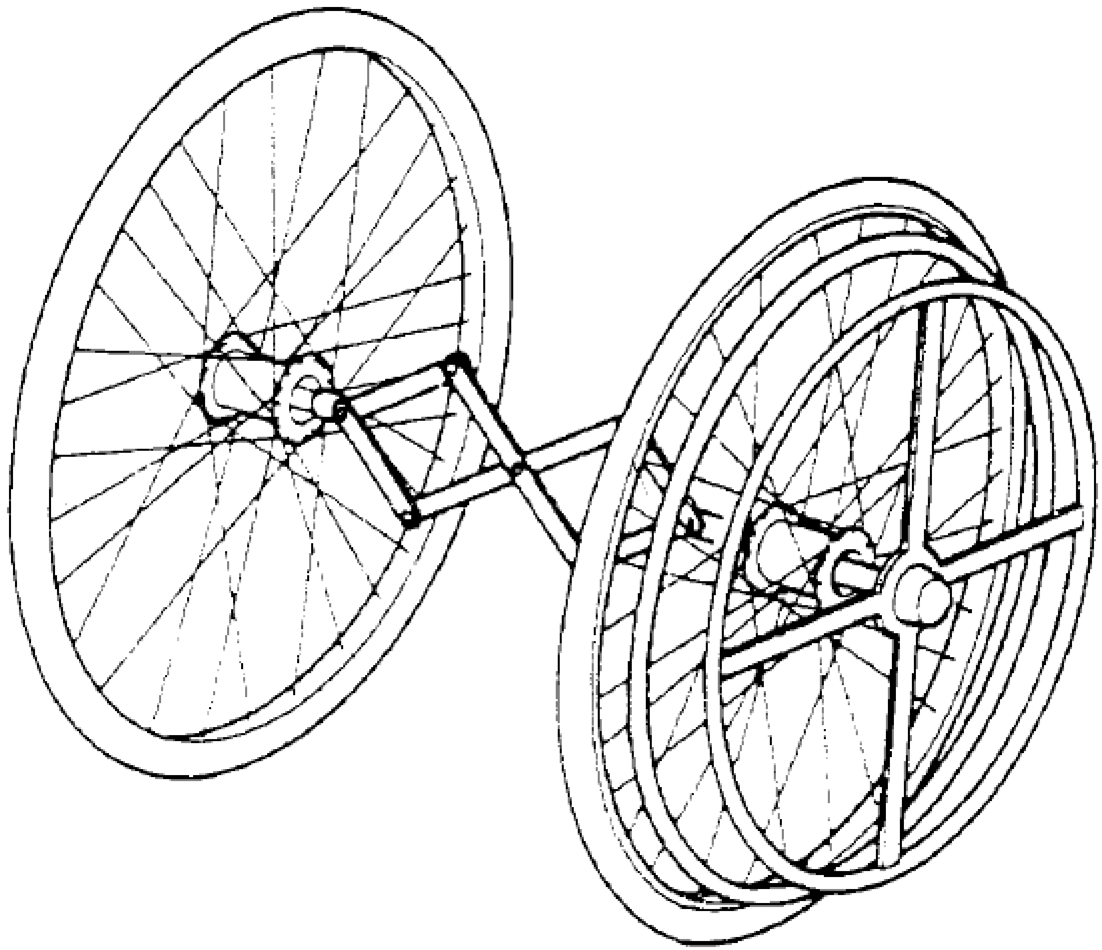
Wheels and tires

Rear-wheel camber: The camber angle is the amount of rear -wheel tilt





Side view schematic showing differences between: depot or hospital chair, amputee chair, foot-drive chair, indoor chair, attendant-propelled chair, and ultralight chair.



Hemiplegic (one-arm drive) wheelchair

Sports wheelchair

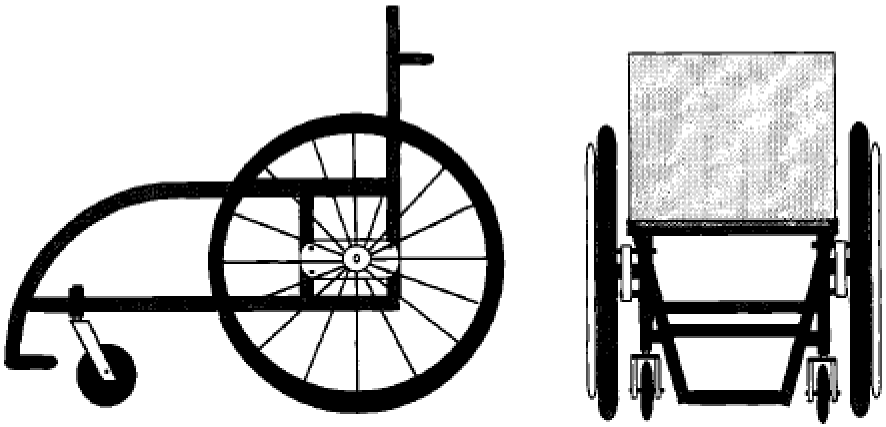
Aluminum three-wheeled court sports ultralight wheelchair with plastic foot-plate and tubular feet guards. This wheelchair also has radical camber.

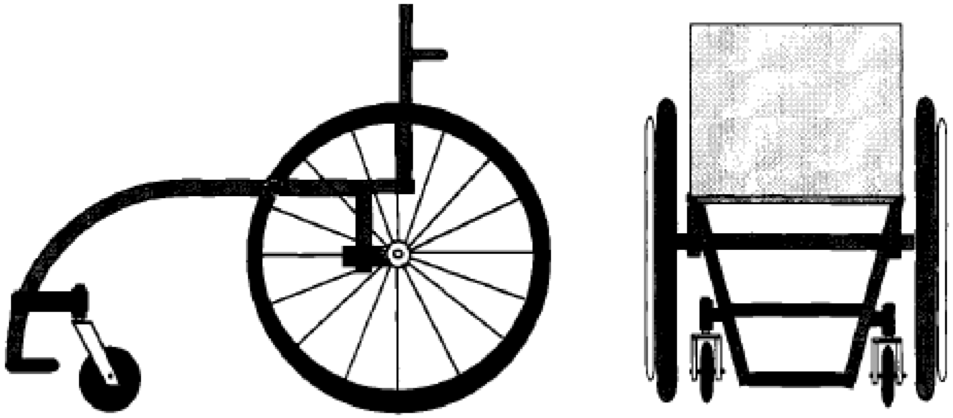
FRAME DESIGN

Frame types, folding and rigid

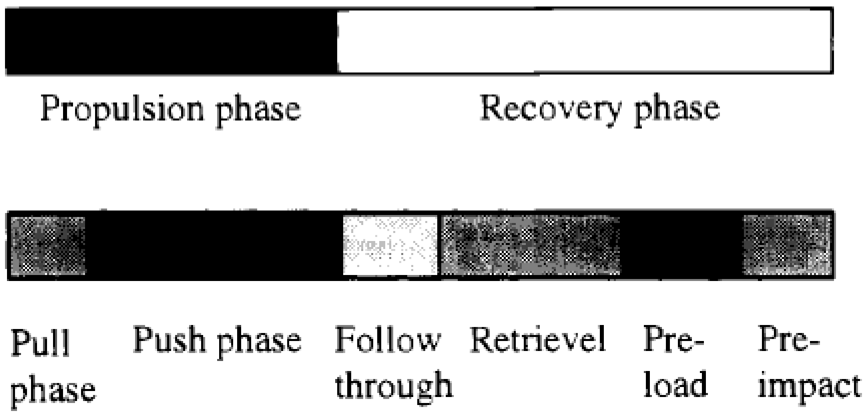
Carbon-fiber composite rigid, box-frame, ultralight wheelchair with roller-blade casters.

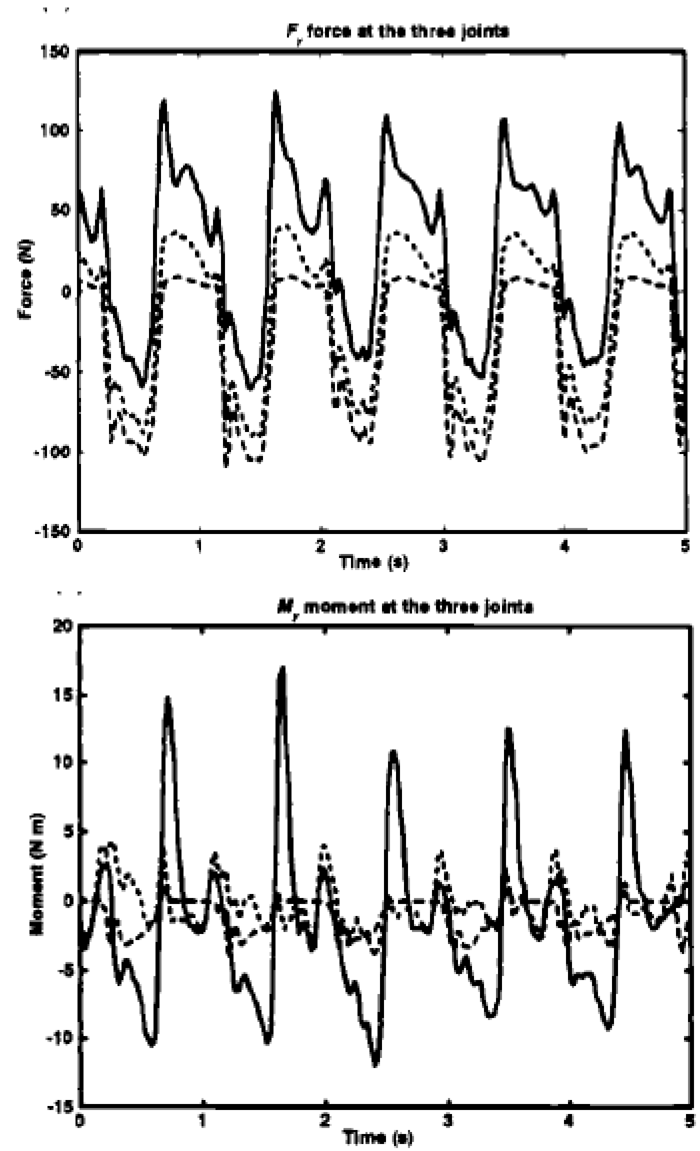
Frame styles, the box frame and the cantilever frame





Kinetics of wheelchair propulsion



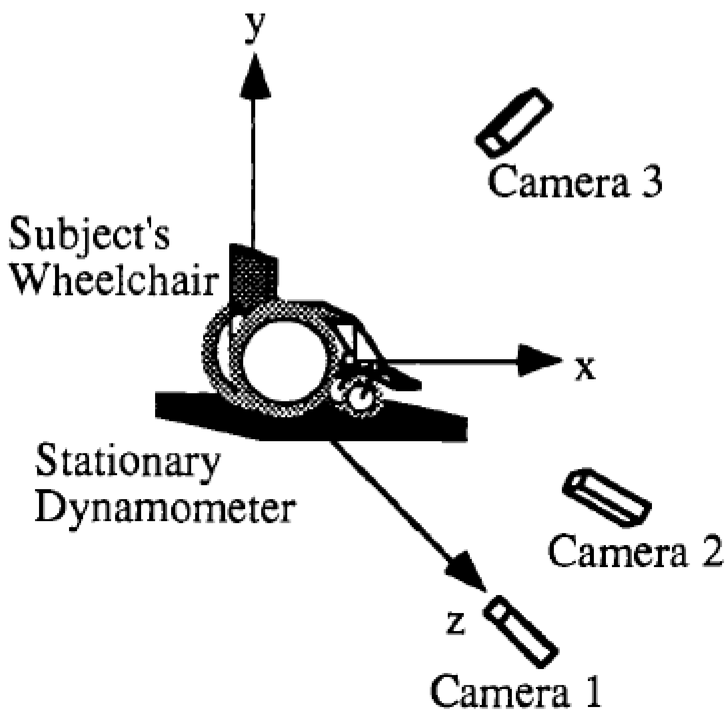


Net joint moments and forces during manual wheelchair propulsion at 5 km h^{-1} on a wheelchair dynamometer set to 10 W.

Wheelchair propulsion injury

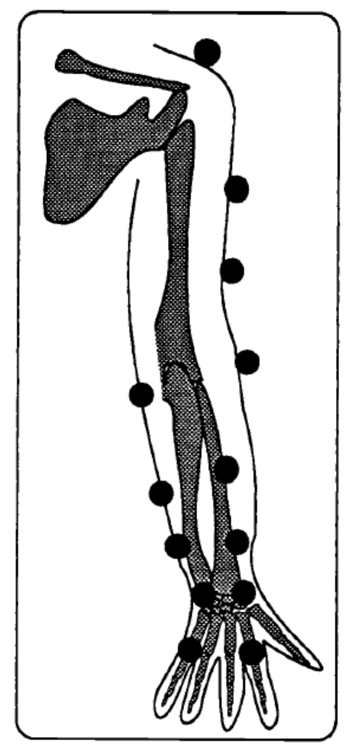
The most commonly reported site of musculo-skeletal injury in manual wheelchair users (MWU) is the shoulder pain to be between 73% and 31%.
Elbow, wrist, and hand pain are also commonly reported

Kinematics of wheelchair propulsion



Three-camera set-up on a stationary wheelchair dynamometer for recording 3D kinematics

Videotaping people while propelling at different speeds against various resistances



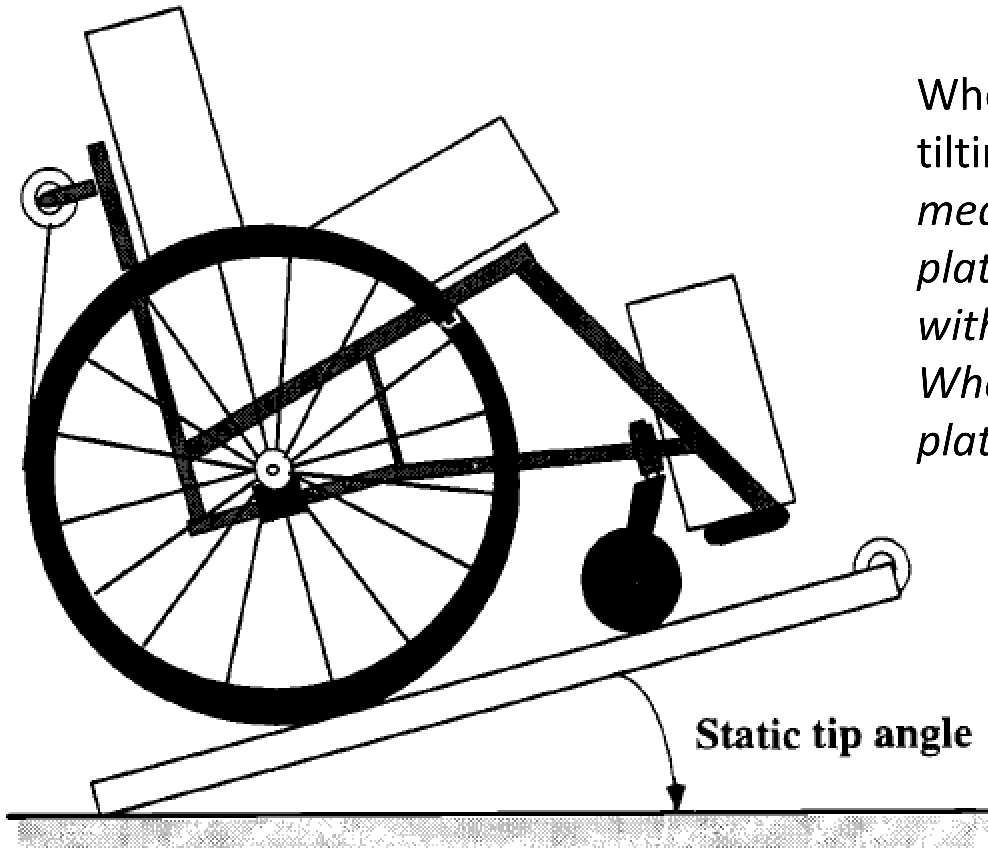
WHEELCHAIR SAFETY, STANDARDS AND TESTING

Manual wheelchairs: active duty lightweight, active duty normal and depot or institutional wheelchairs
Power wheelchairs : active indoor and outdoor use (class 3), active indoor with some outdoor use (class 2**)** and primarily indoor use (class 1)

STANDARD TESTS

A variety of tests are used to evaluate the safety and durability of devices:
(1) Stability tests (static and dynamic),
(2) Strength tests (static, impact and fatigue)
(3) Energy consumption tests

STATIC STABILITY: A simple measure of how stable and secure a wheelchair is during normal activities of daily living is to determine static stability parameters.



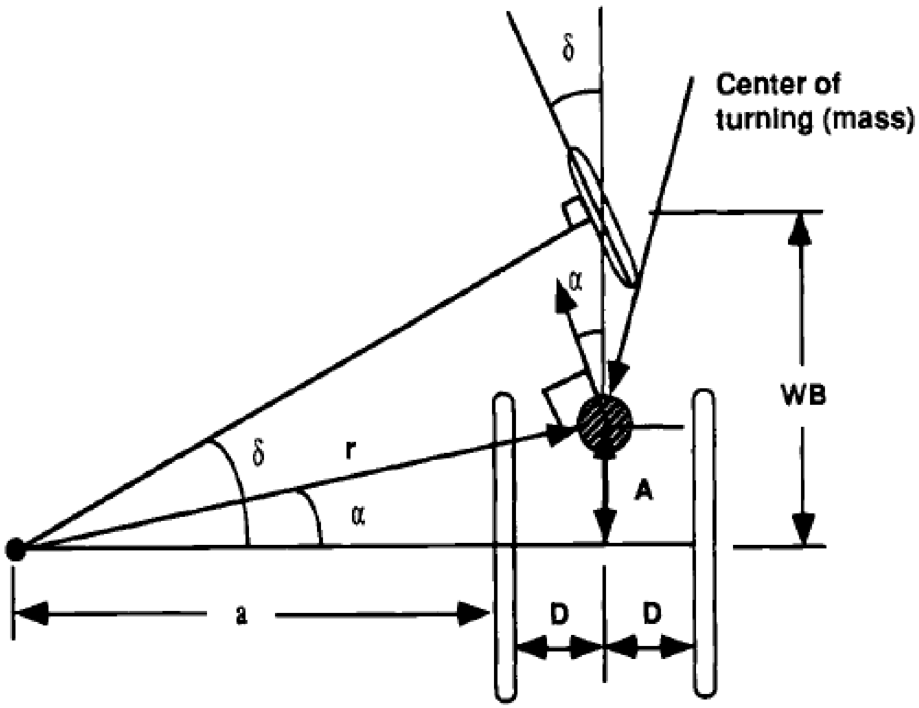
Wheelchairs are tested on a simple tilting platform: *Static tip angle is measured by slowly raising a platform with the wheelchair loaded with the appropriate sized dummy. When both uphill wheels lift off the platform the angle is recorded.*

	Strap		Brake		Block	
	M	SD	M	SD	M	SD
55 kg person with paraplegia	10.47	2.181	11.38	1.784	20.08	3.104
100 kg ambulatory person	11.47	1.993	11.39	1.957	18.66	3.685
100 kg ISO	7.31	2.590	8.30	2.796	14.38	4.991
dummy	7.31	2.590	8.30	2.796	14.38	4.991

A GEOMETRIC APPROACH TO STATIC STABILITY

The center of gravity of wheelchair system must remain within the footprint

Fixed dynamic analysis of racing wheelchair roll stability



$$v_{4c} = \left[\frac{rg}{L}\left(D_p - L_p\right)\right]^{\frac{1}{2}}$$

$$L_p = L \sin\tilde{\beta} \quad \text{and} \quad D_p = D\cos\tilde{\beta}$$

$$v_{3c} = \left[\frac{rg(D_{p3} - L_{p3})\sqrt{D^2 + WB_3^2}}{LWB_3}\right]^{\frac{1}{2}}$$

$$v_{3c} = v_{4c}\sqrt{\frac{D_p(WB_3 - A) - L_pWB_3}{(D_p - L_p)WB_3}}$$

$$WB_3 \gg A \quad \Rightarrow \quad v_{3c} \approx v_{4c}.$$

$$L_{p3} = (LWB_3 \sin\tilde{\beta})/\sqrt{D^2 + WB_3^2}$$

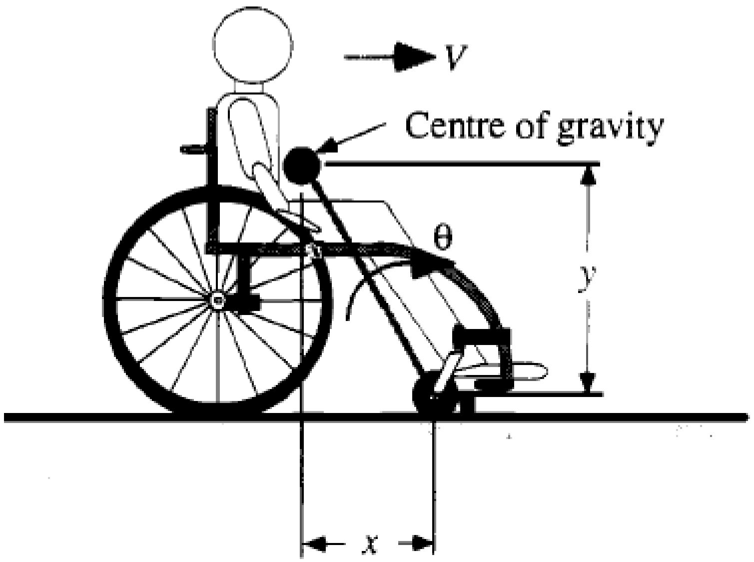
$$D_{p3} = (D(WB_3 - A)\cos\tilde{\beta})/\sqrt{D^2 + WB_3^2}$$

Static strength

(1) static stress tests : determination of the static strength of wheelchair and components
(2) impact tests

- *Test laboratory scientists performing a seat impact test with a 25 kg lead-shot-filled soccer ball. This test evaluates the strength of the seating surface and seat material.*
- The backrest is tested by swinging a weight pendulum into the backrest from a pre-specified height

Forward impact stability



For the wheelchair and rider to overturn, the center of gravity must be raised above the front axes of the wheelchair:

$$\Delta h = \left(\sqrt{x^2 + y^2} - y\right)$$

If the wheelchair hider are to overturn, the kinetic energy remaining after the impulse must be sufficient to lift the center of gravity for the system through the distance given above. This condition is given by:

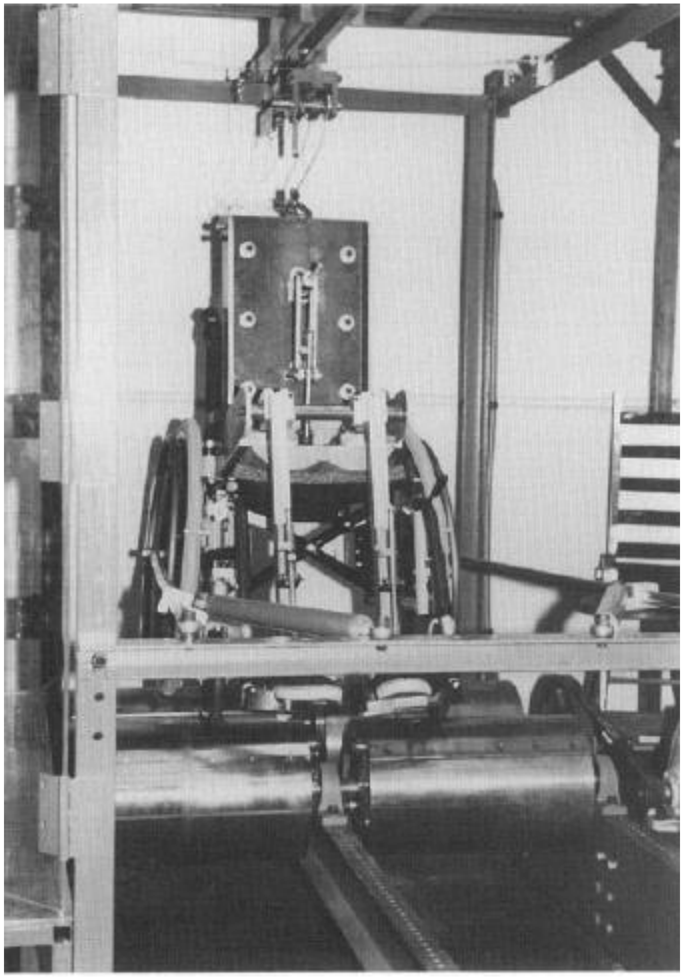
$$\frac{1}{2} I_0 \dot{\theta}^2 \geqslant Mg\Delta h = Mg\left(\sqrt{x^2 + y^2} - y\right)$$

The critical velocity for flipping a wheelchair and rider about the front axles is:

$$v^2 \geqslant \frac{2gI_0}{My}\left(\sqrt{1 + \frac{x^2}{y^2}} - 1\right)$$

FATIGUE STRENGTH TESTS

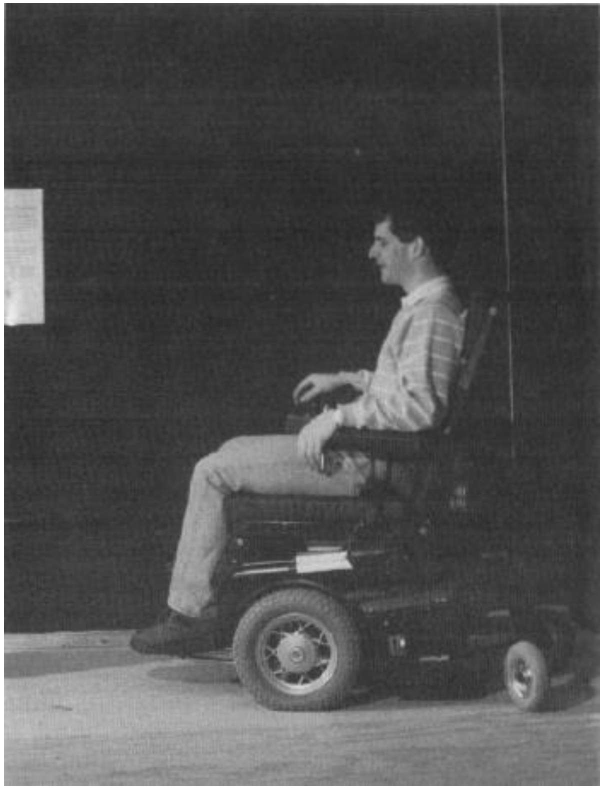
Double-drum fatigue testing (ISO testing)



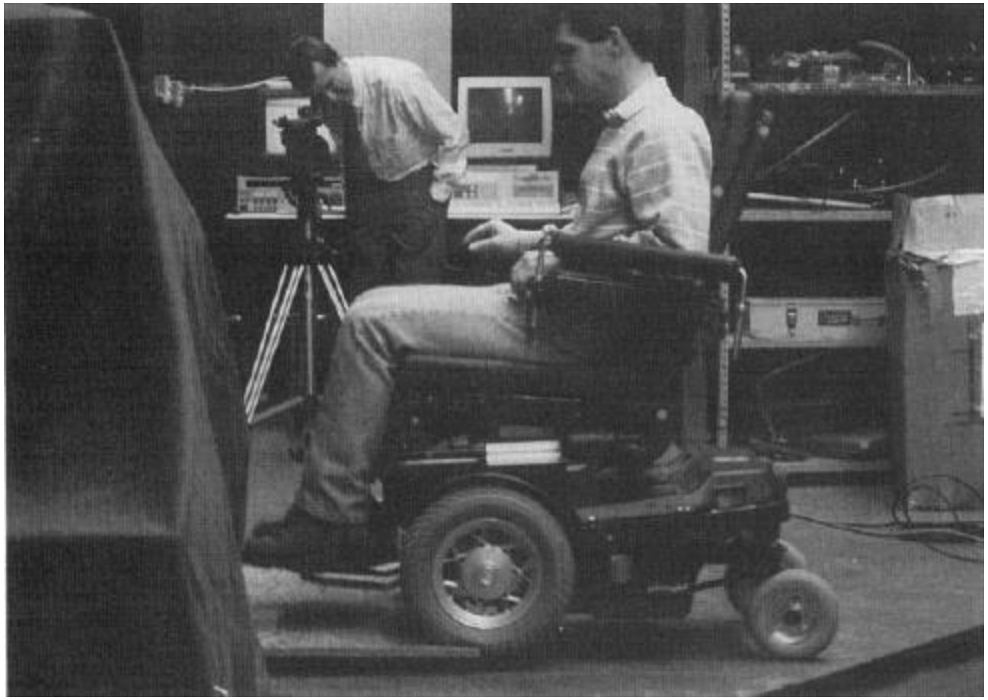
Wheelchair double-drum tester for measuring durability of manual and powered wheelchairs and scooters when exposed to large numbers of small bumps.

DESIGNING FOR SAFE OPERATION

Powered wheelchairs are not always driven on flat, level surfaces. People drive up and down hills, around turns and over curb-cuts. The dynamic stability of the power wheelchair is tested while driving up and down a ramp at full speed and at full braking.



Dynamic stability testing of a power wheelchair. Power wheelchairs are driven up and down slopes and along side slopes. Test technicians drive power wheelchairs on a ramp at various angles and record its behavior..



Power-wheelchair users encounter a variety of obstacles while driving. The ability to climb obstacles is important to some consumers. The obstacle-climbing ability test determines the maximum height of an obstacle that the power wheelchair can safely conquer

Engineering Better Electric-Powered Wheelchairs To Enhance Rehabilitative and Assistive Needs of Disabled and Aged Populations

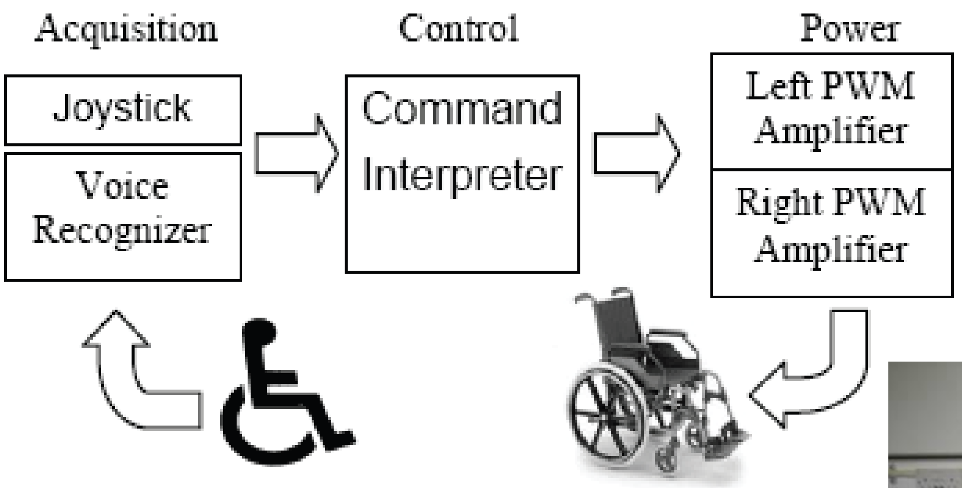
Existing Electric-Powered Wheelchair Technology

Electric powered wheelchairs use chemical batteries as their energy source but it makes the wheelchair bulkier and difficult to transport

Control system: joystick is the most commonly used mode of input for the wheelchair. The major drawback of joystick control is that users with upper limb disability would find it difficult to maneuver the wheelchair

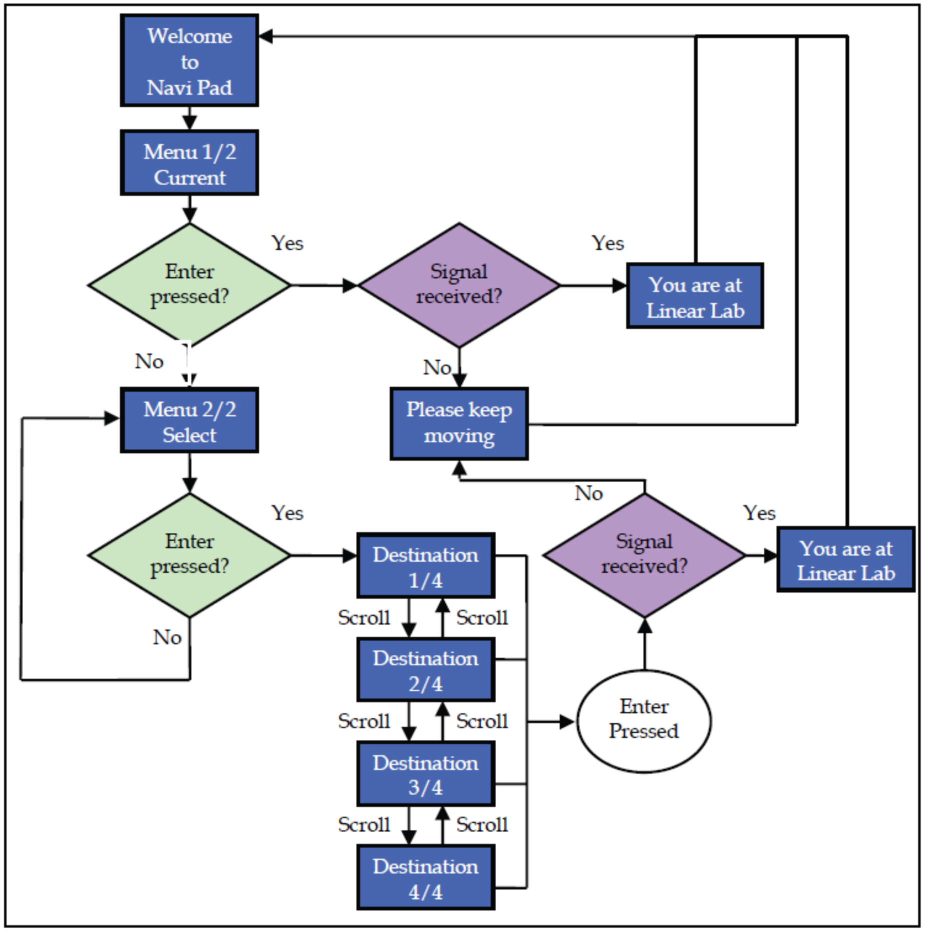
- force sensing joystick, Jones et al. (1998)
- Oskoei & Hu (2008) propose a myoelectric based virtual joystick which utilizes myoelectric signals from the forearm of the user to navigate the wheelchair.

Microcontroller Based Voice-Activated Powered Wheelchair Control

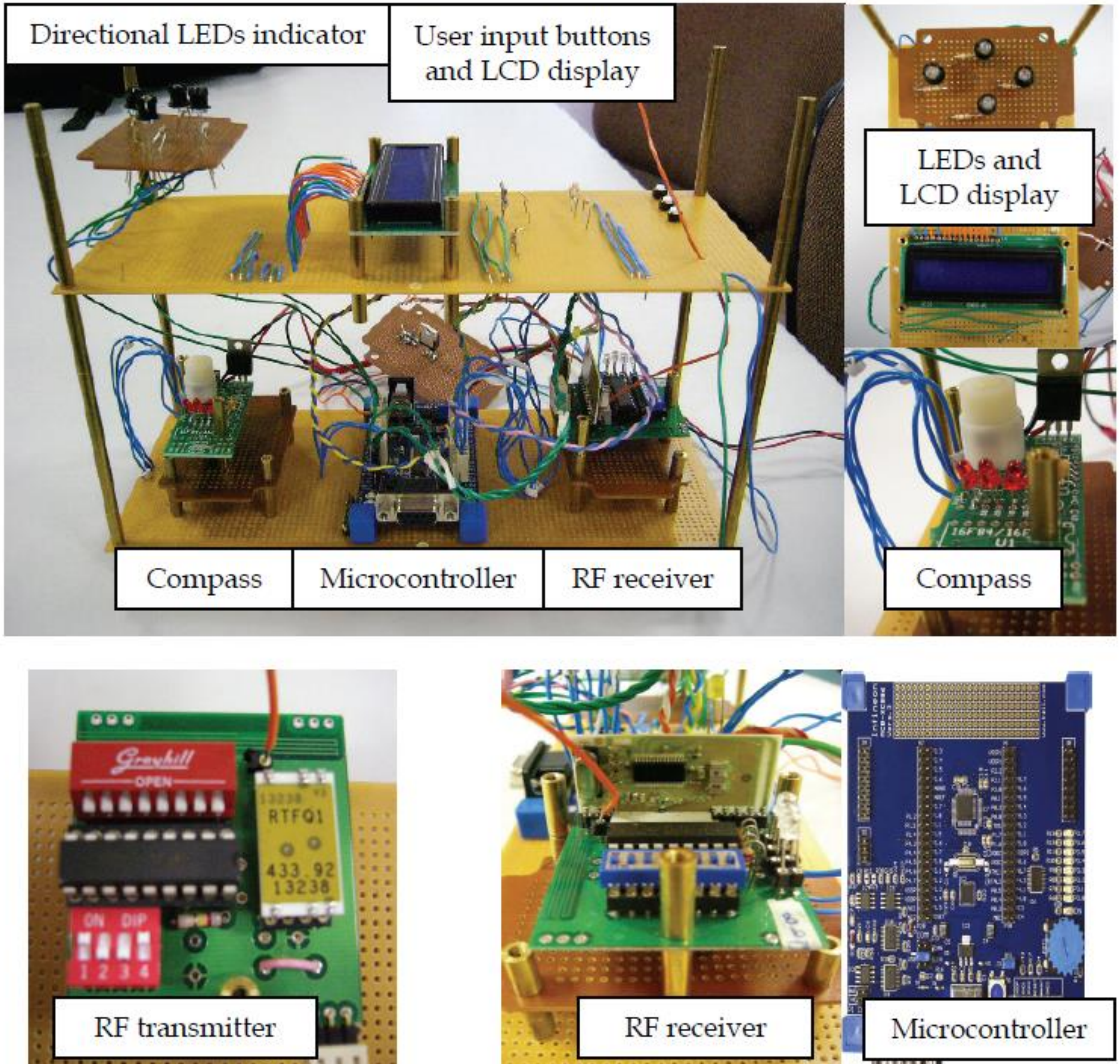


Block Diagram of an Electric Powered Wheelchair

Personal Navigation System Based Wireless Sensor Network Technology



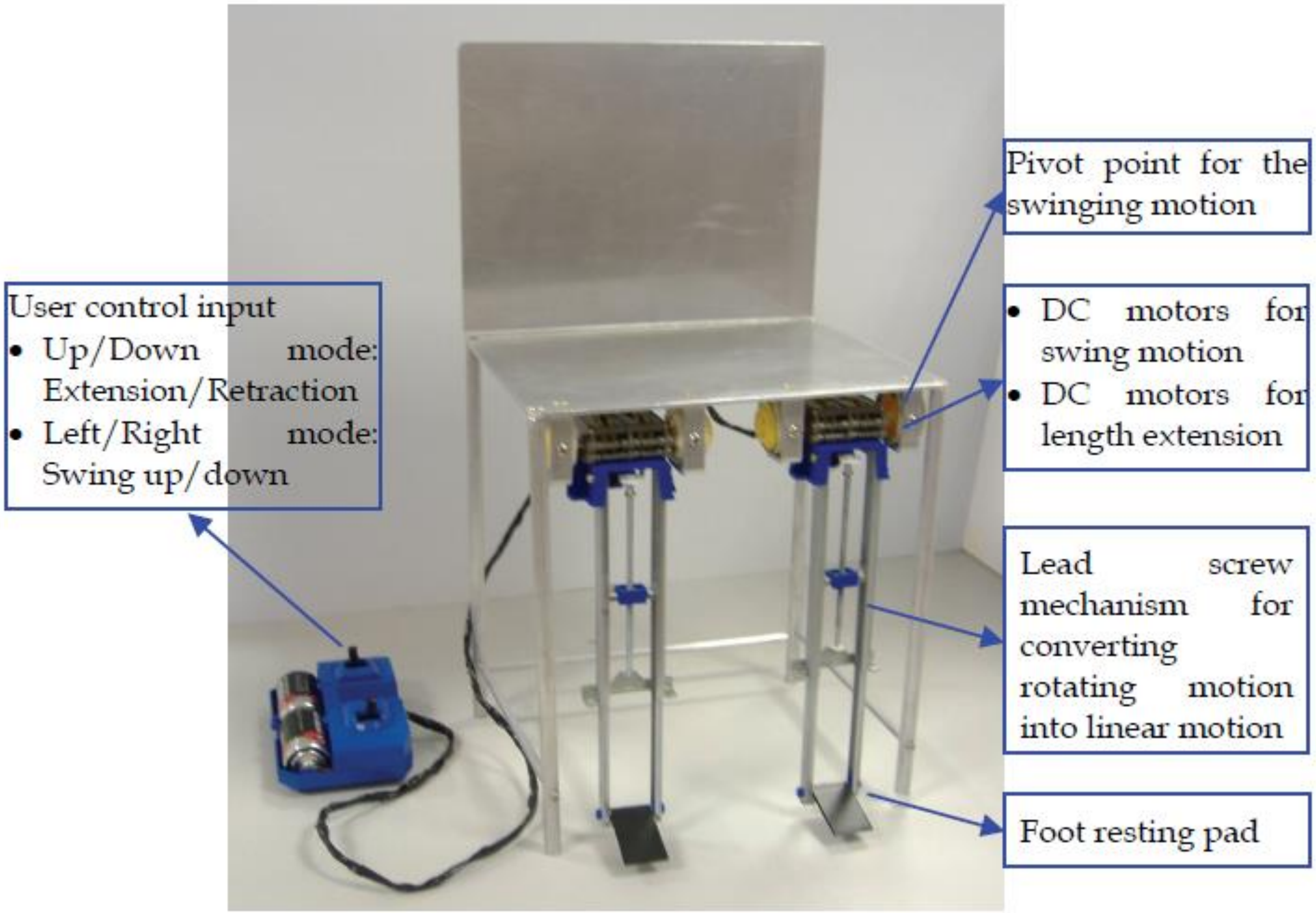
The line tracking system: light sensors are used to differentiate white and dark lines that are attached onto the ground surface



Hardware prototype of personal navigation system based wireless sensor network

Motorized Foot Rest for Electric Powered Wheelchair

The conventional foot rests are adjusted manually by some external assistances to meet the desired height and position. Minimum exercise-poor blood circulation



Prototype of the motorized foot rest

Components	Descriptions
Control system	A joystick to control the rotational and linear movements by moving the control stick to the left, right, forwards and backwards.
Rotational and linear drives and motoring	DC motors and gearboxes to control the rotational and linear movements of the foot rest
Movable mast	Movable mast, threaded shaft/lead-screw to convert rotational motion to linear motion. When motor starts to rotate, the leadscrew rotates accordingly to produce the linear motion.

Motorized foot rest at stationary position

Motorized foot rest after swing angle adjustment

Motorized foot rest after length adjustment

Illustration of leg lifting exercise
(Assistive need)

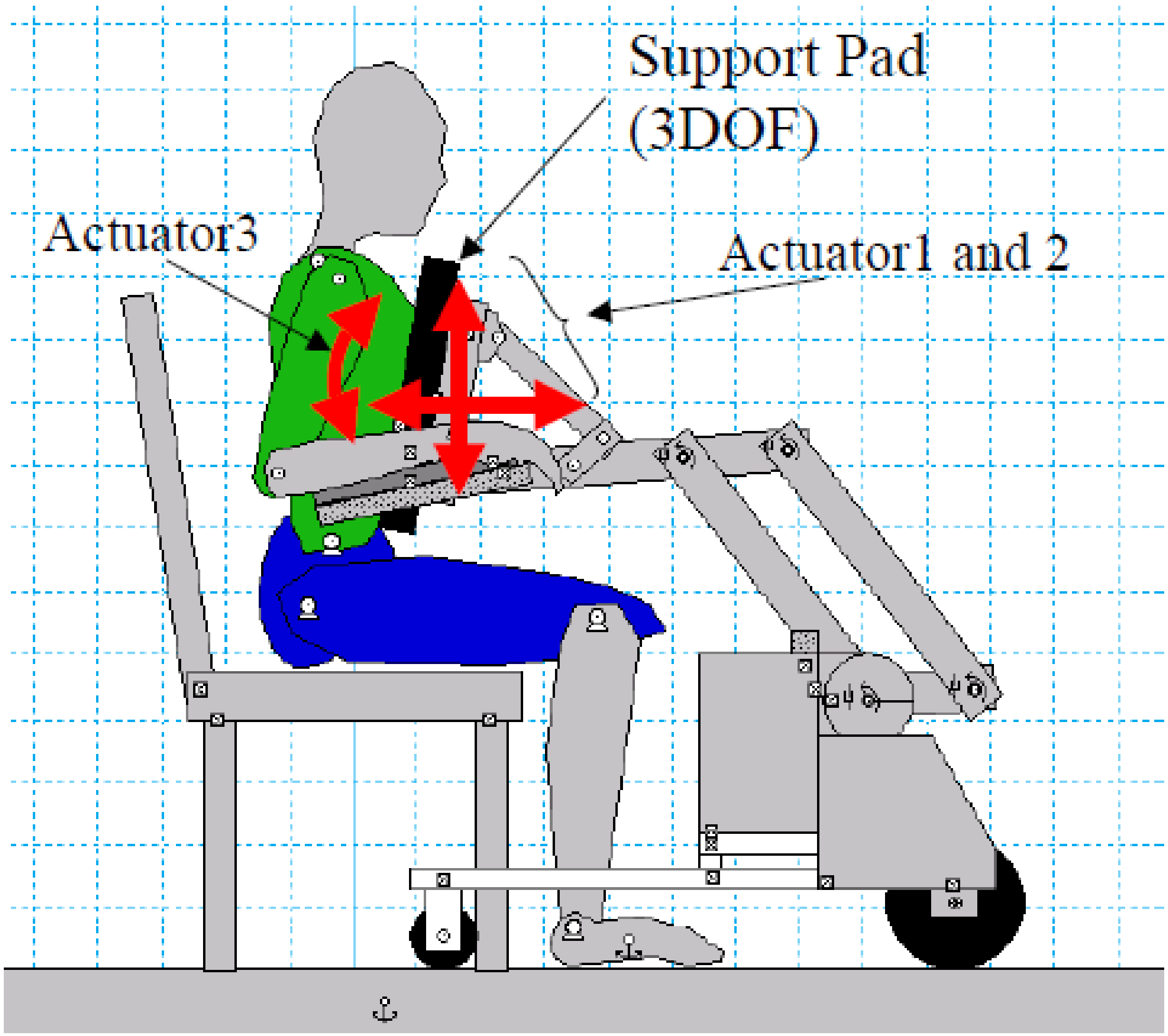
Illustration of walking exercise
(Rehabilitative need)

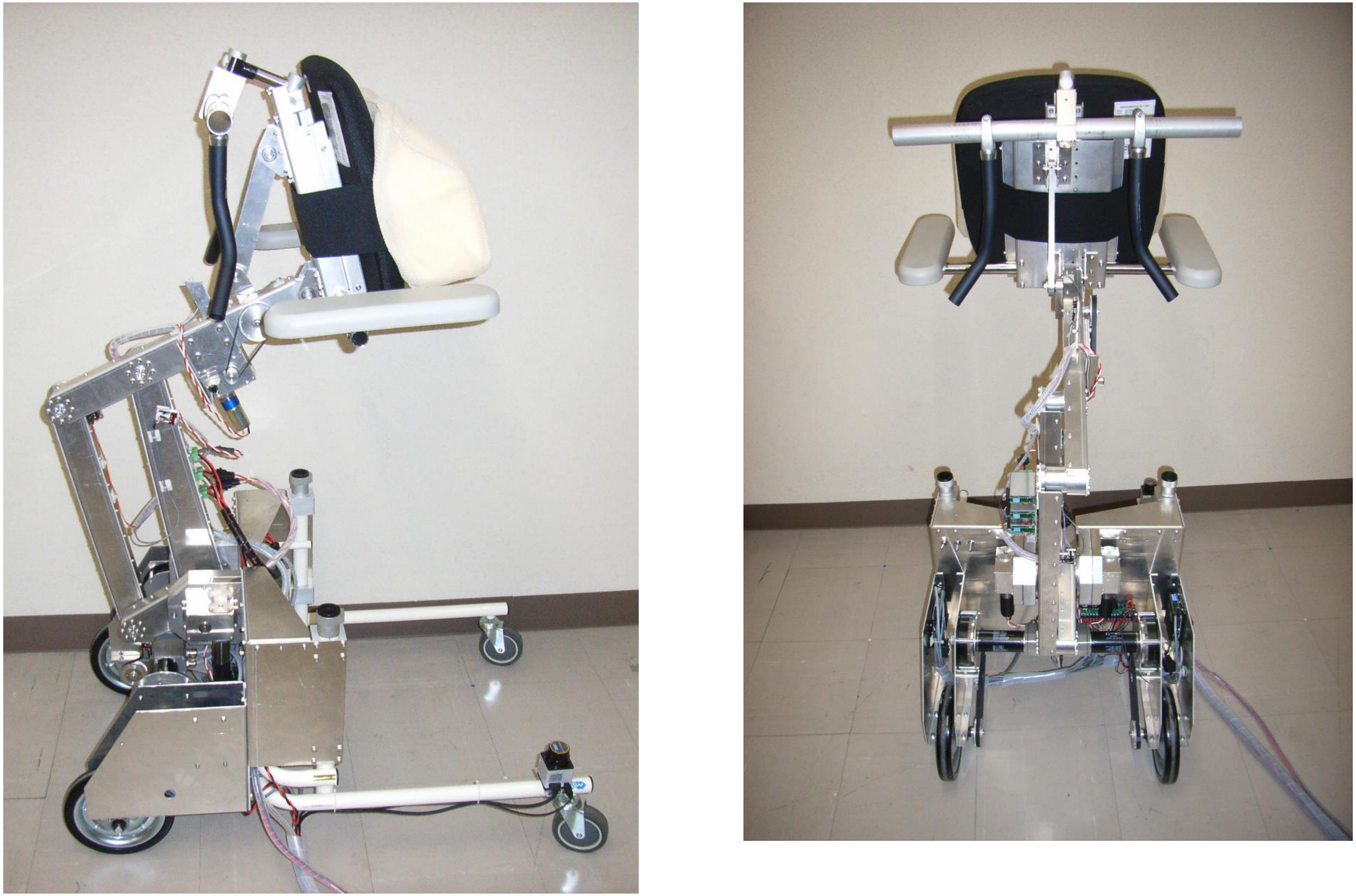
A Rehabilitation Walker with a Standing Assistance Device

Development of a walker system with power assistance device for standing up motion

- Based on a walker which is popular assistance device for aged person.
- For using the remaining physical strength, the system uses the motion pattern which is based on the typical standing up motion by nursing specialist as control reference.

System Configuration



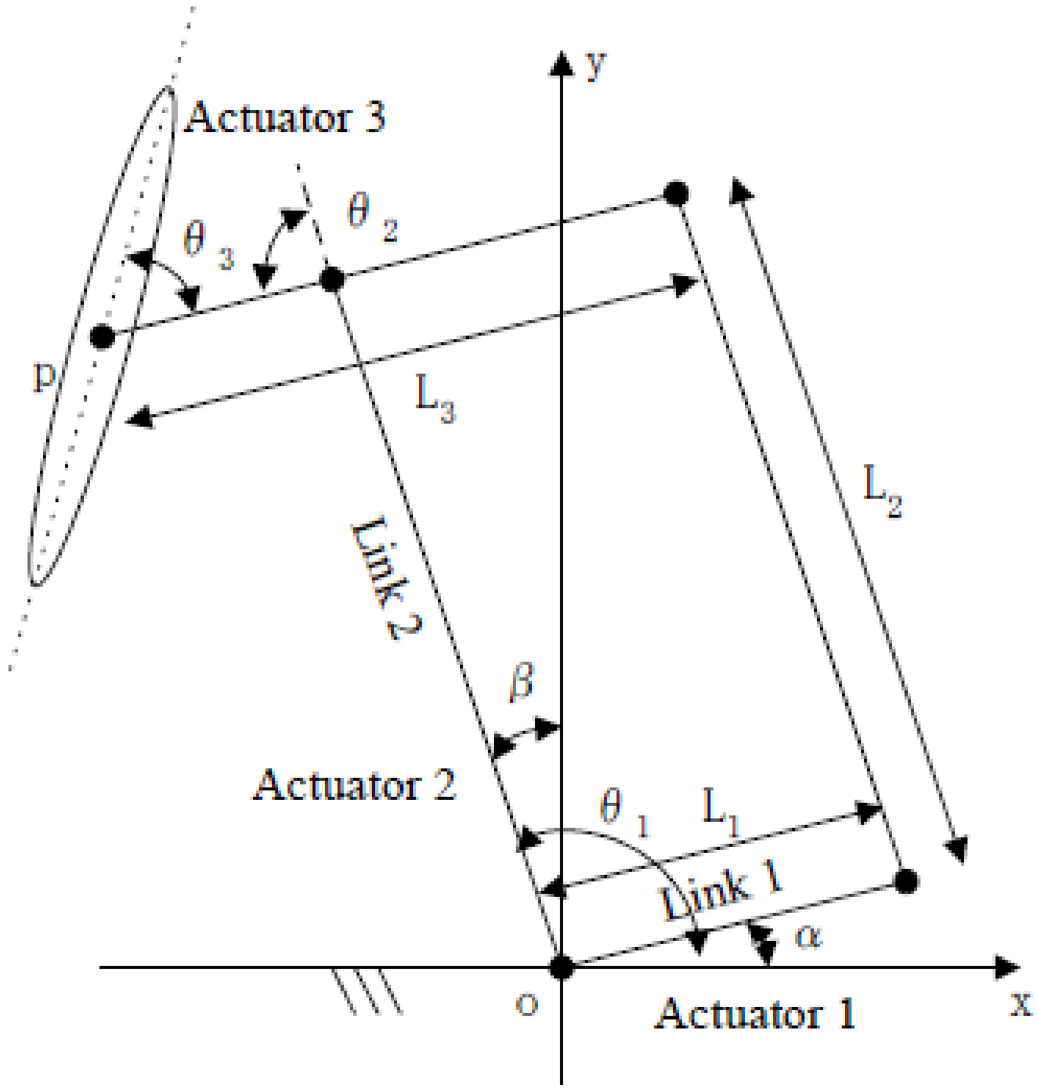


The prototype. Its weight is about 35 kg without batteries. Our prototype requires an external power supply and control PC.

The proposed support pad. (1) is the pad with a low repulsion cushion, (2) is the arm holder and (3) is a handle. Its diameter is 0.24[m] which is easy to grip for the elderly. The support pad has force sensors in its body.

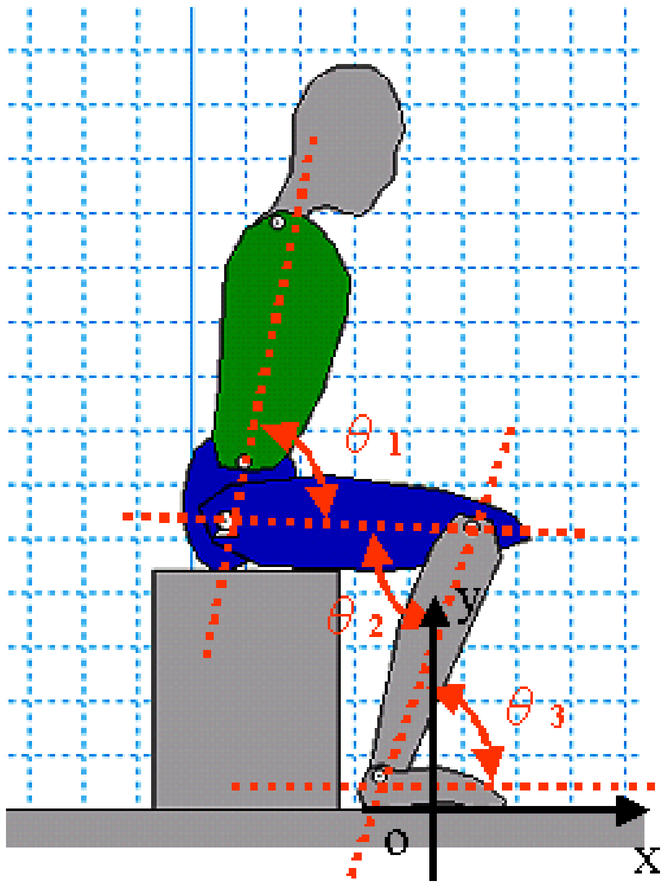
Support Pad

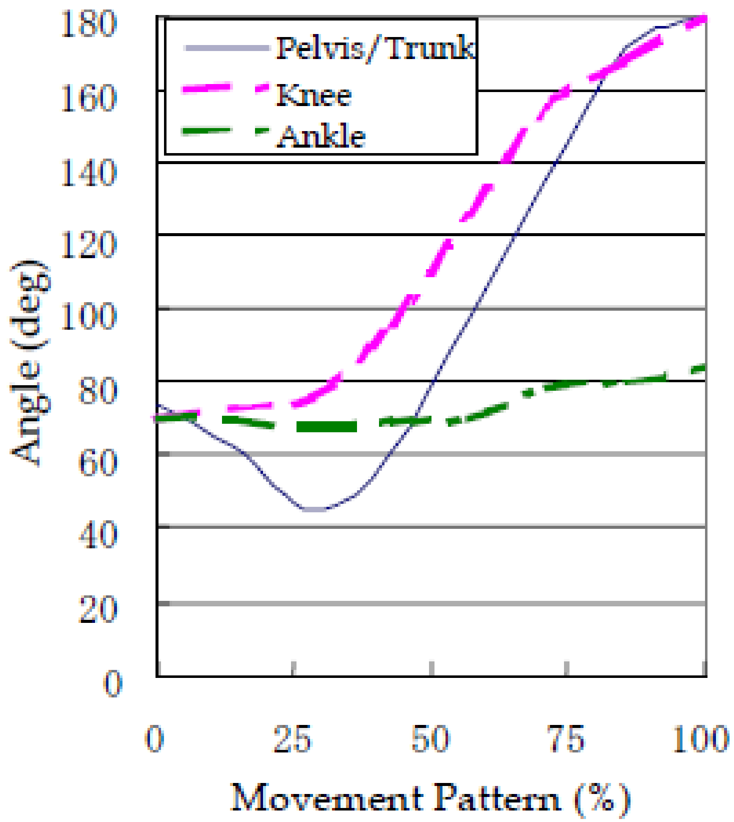
Assistance Posture



The kinematic model of developed system

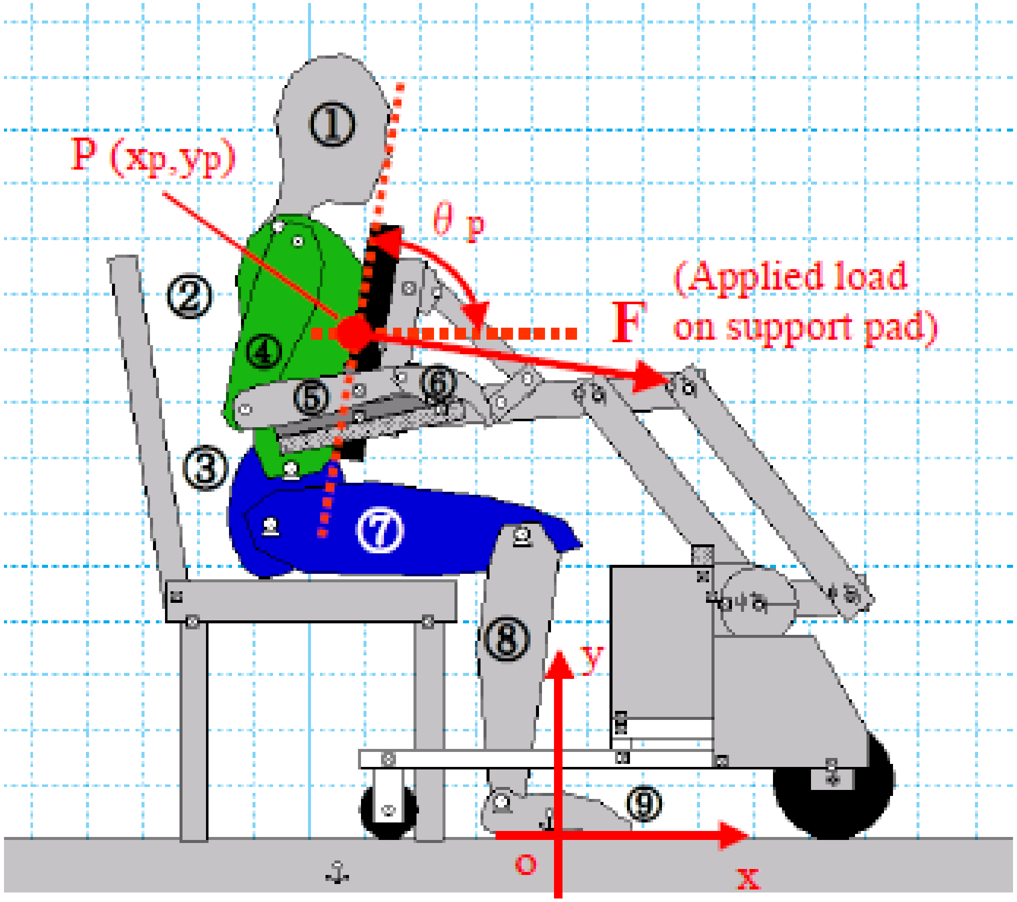

Aa lot of standing up motions for assistance are proposed. Kamiya (2005) proposed the standing up motion which uses remaining physical strength of the patients based on her experience as nursing specialist.



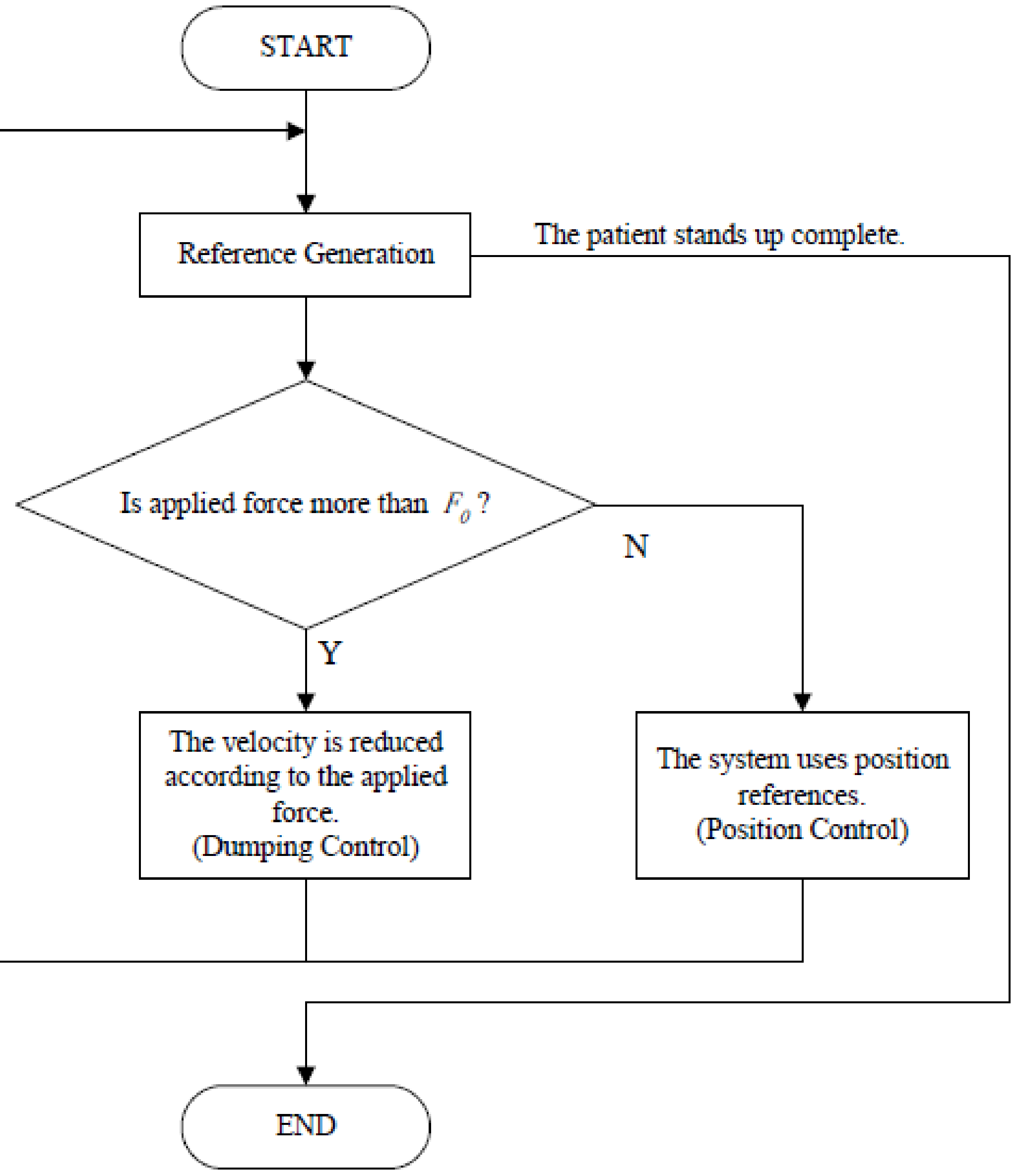


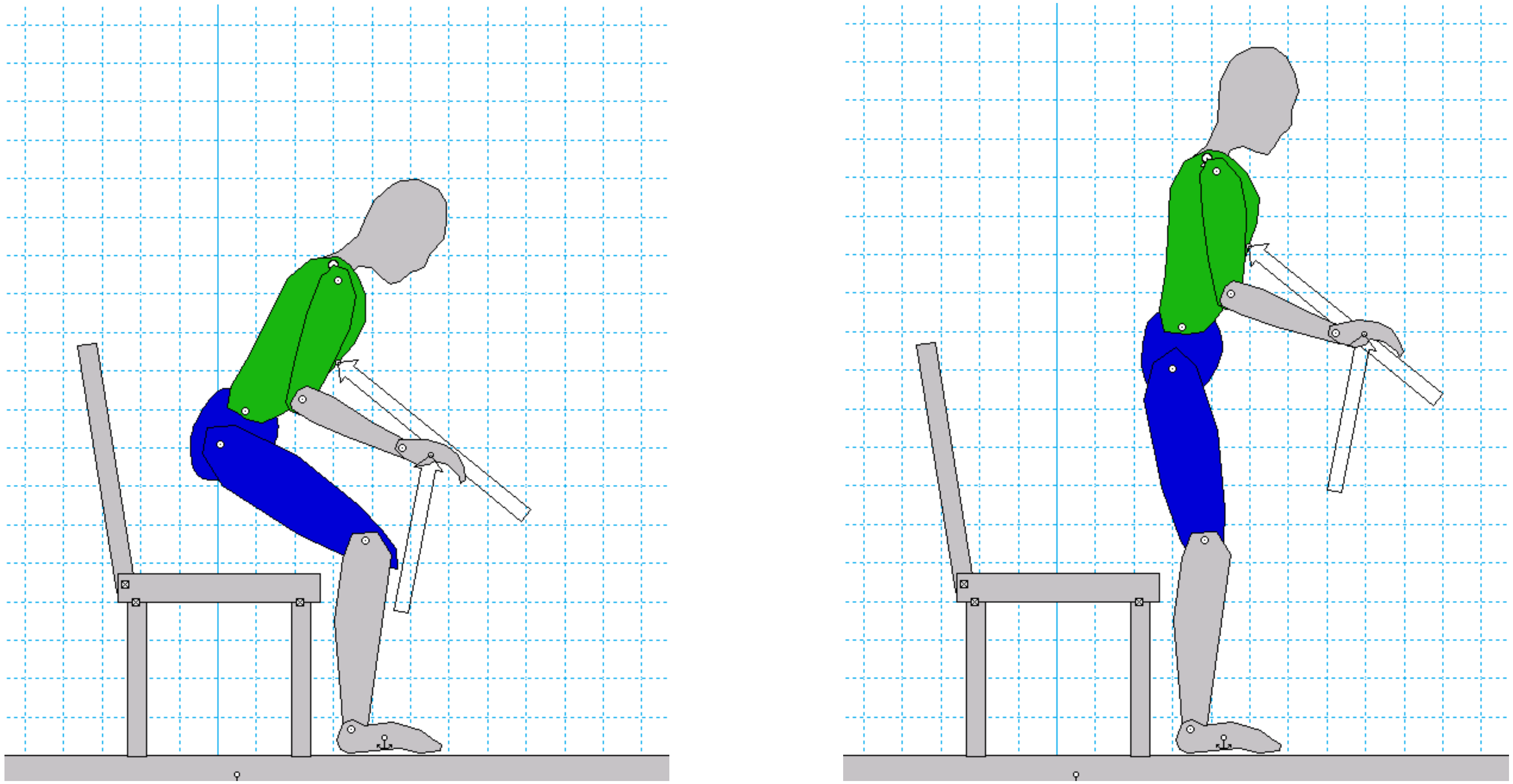
Standing-up motion with Kamiya scheme. ϑ_1 shows the angular of the pelvis and the trunk. ϑ_2 and ϑ_3 shows the angular of the knee and the ankle, respectively.

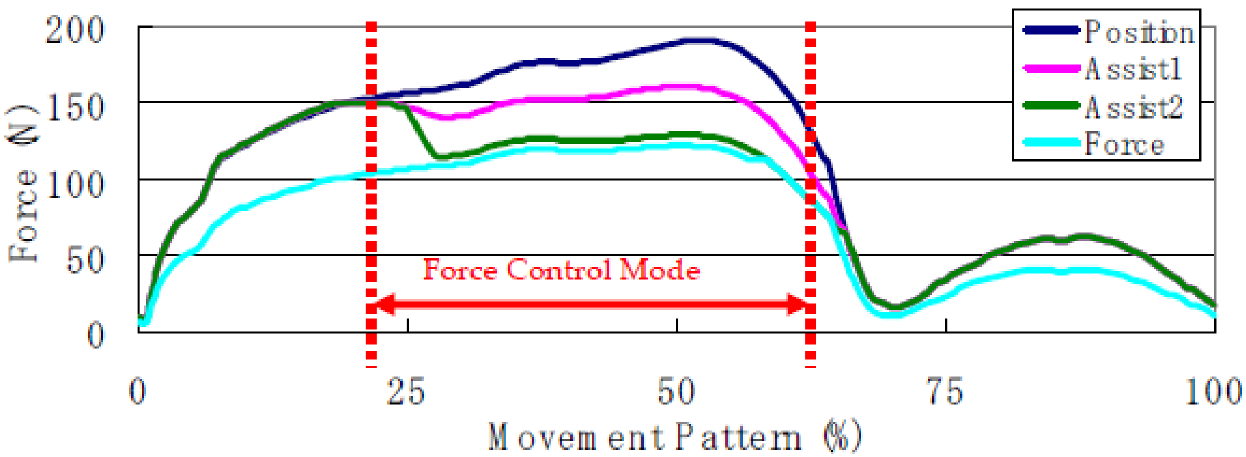
Simulation setup: Working Model 2D as a physical simulator and MATLAB as a controller



Force Control







Simulation result. Arrows show the assistance forces.