Research Techniques in Biomechanics

KIN 743

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KIN 743: Research Techniques in Biomechanics

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Course Description

Examination of some of the techniques used in biomechanical research for data collection, analysis and presentation. Emphasis on developing an understanding of experimental techniques, their capabilities and limitations. The lecture/discussion/lab sessions provide a historical and theoretical basis for each of the techniques examined. The major topics covered will be

- Analog to digital conversion
- Signal processing
- Kinematics (e.g., motion capture)
- Kinetics (i.e., force transducers)
- Electromyography

Textbooks

Required:	Instrumentation Handbook Research Methods in Biomechanics

Grading Elements

30% Projects	Projects will be assigned periodically and could include problems, discussion questions, movement analyses, library or research tasks, for example. Ten point deduction (of 100) per class for late assignments.
40% Semester Project	Each student will be responsible for proposing an experiment. The proposal will focus on appropriate methods.
30% Final Exam	The Final Exam will be comprehensive, with questions based on readings, lectures, projects, discussions.

Note

- Learning Enhancement Services (LES) houses Disability Services, Learning Strategies and Supplemental Instruction. If you have a documented disability that may require assistance, you will need to contact LES for coordination in your academic accommodations. LES is located in the Reynolds Student Services Complex, suite 137 (895-0866 or TDD 895-0652).

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Semester Project

The purpose of the semester project is to learn how to organize and propose an appropriate experiment. Successful organization of an experiment will require the student to thoroughly understand instrumentation necessary to answer a specific research question. A successful experiment proposal will require that the student be able to operate instrumentation as well as process data successfully. The semester project consists of the following elements:

1. Introduction (i.e., development of a research question/hypothesis) 10%
2. Methods 70%
   - description of subjects 5%
   - instrumentation 10%
   - procedures 10%
   - data reduction 10%
   - statistical analysis 5%
3. Results 10%
4. Discussion/conclusion 10%

Evaluation of experiment

A – Well thought out, organized, and information presented is complete and correct.
B – Details are reported in a straightforward fashion, but there is lack of overall understanding.
C – There are obvious errors reported and poor organization and/or missing information.
D – There are errors in reporting facts and obvious material is omitted.
F – If you fit into this category, don't bother handing in your work.

Tentative schedule

Week	*Topic*
1	Introduction
2	Kinematics (elgon, sampling theory, validity vs. reliability)
3	Motion Analysis
4	Motion Analysis
5	Smoothing
6	Accelerometry
7	Kinetics
8	Synchronization techniques
9	Joint Moments
10	Mass-Spring model
11	Open
12	Isokinetics
13	EMG
14	Impact tester
15	Class presentation

Projects

The purpose of the projects is to give you hands on experience in collecting and processing data. The material handed in will vary from presenting a working project (e.g., elgon) to graphs (e.g., smoothing), to a write up (e.g., bibliography). Specific details will be provided for each project upon beginning the project.

- Electrogoniometer
- Sampling theorem
- Digitize known motion using Motion Analysis & HuMan
- Smoothing routines
- Ground reaction force
- Joint moments during running, walking, and/or jump/landing
- Mass-spring modeling
- Shock attenuation, use of FFT
- Isokinetic testing
- Bibliography

Writing Methods

Journals may specify a format that the method section should follow. In many cases, the same information is simply presented in different organizations. The common elements of many journals are highlighted below. All reports should use this format unless a different format has been specified.

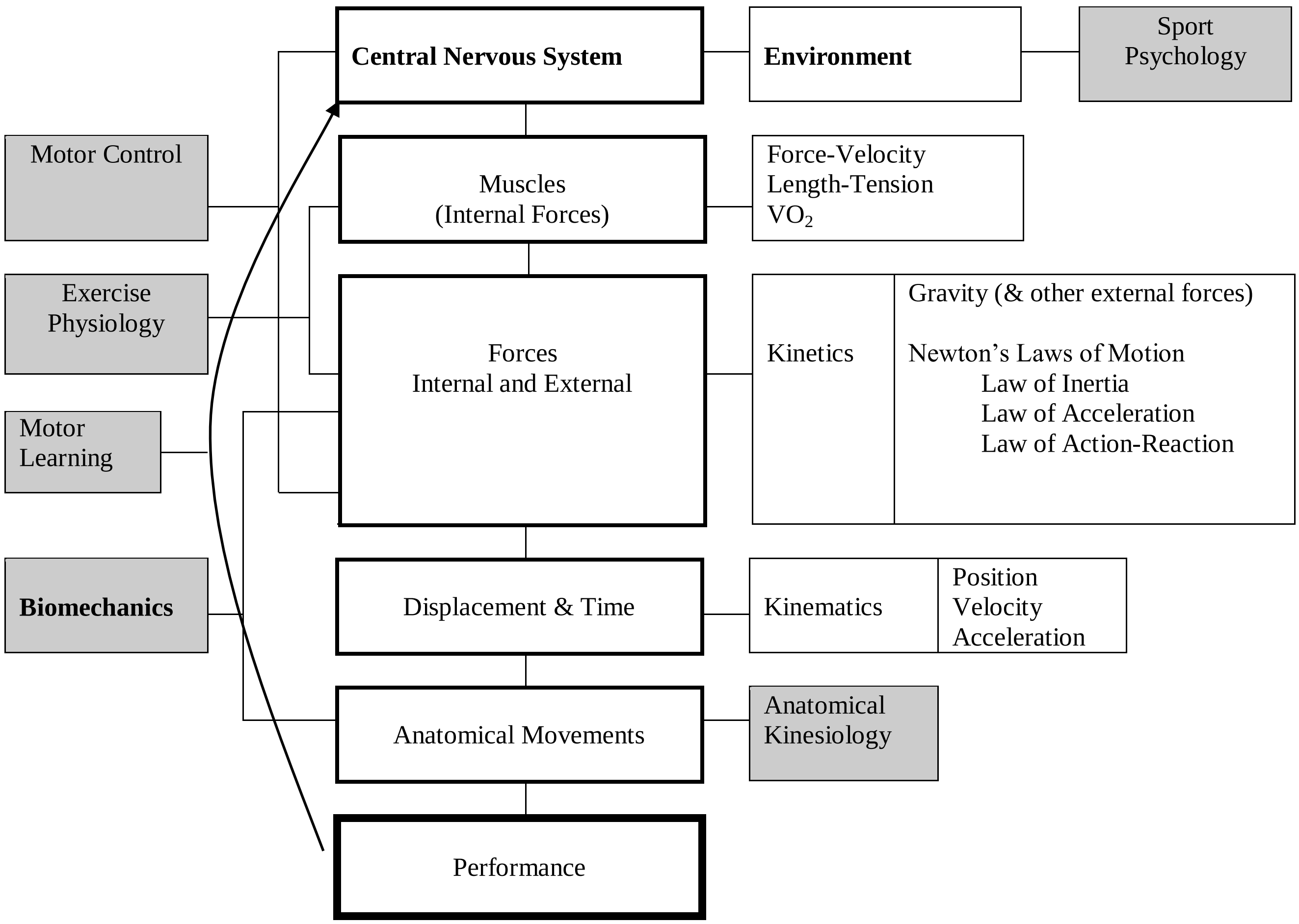
Participants *(or subjects)*	Describe population of subjects that were tested • Weight, height, age, gender • Experience in task • Injuries (or lack of) • …

Instrumentation	Describe the instruments used in the experiment
	• Model, manufacturer
	  • Force plate (Kistler model 8600B, 60 x 30 cm)
	  • Treadmill (Precor model 9.3)
	• A/D board type
	• (sometimes sample rate and period)

Protocol *(or experimental procedures)*	Describe the experiment conducted • Warm-up • Conditions • Order • Describe when data were collected (sometimes sample rate and period)
Data reduction *(or data analysis)*	Describe how data were processed • Calculations that were made • Specify values recorded • "Impact peak magnitude was recorded as the highest force within 50 ms of heel contact that was followed by a local force minimum."
Statistical analysis	Specify statistical design • Dependent variables • Independent variables • Statistical procedures used • Repeated measures ANOVA, follow-up tests…

Kinesiology

Kinesiology is ultimately the study of performance. For example, an exercise physiologist is interested in measuring aerobic performance as well as training an individual to perform better. A person involved in Motor Control is interested in how performance is controlled through the neuromuscular skeletal system. Someone interested in Motor Learning is interested in how a person learns to control movements to increase performance.



In order to understand the factors affecting performance, it is essential that you, the student of Kinesiology, integrate the information from all the courses offered in the Department of Kinesiology.

Terminology

Biomechanics

Kinematics
- Types of motion
- Displacement
- Distance
- Velocity
- Speed
- Acceleration
- Representation of angles
  - Absolute vs. Relative angles
- Angular displacement
- Angular velocity
- Angular speed
- Angular acceleration
- Relationship between linear and angular velocity and acceleration

Kinetics
- Linear Kinetics
  - Newton’s Laws of Motion
  - Force
  - Mass
  - Inertia
  - Momentum
  - Impulse
  - Gravity
  - Ground reaction force
  - Projectile motion (vertical and horizontal)
- Angular Kinetics
  - Torque
  - Moment
  - Axis of rotation
  - Line of application of a force
  - Center of mass/gravity
  - Moment of inertia
  - Moment arm

Mathematical skills
- Slope
- Trigonometric relationships (e.g., calculation of angels)
- Composition and resolution of vectors
- PVA models

Computing skills
- Excel (or some spreadsheet software)
  - Graphing
  - Formulas
  - Functions
- Matlab

Introduction

Topic	Parameter	Instrument
Anthropometrics	Joint center Segment masses Segment COM Segment moment of inertia	Table of norms regression equations models direct measurement
Kinematics	Time Displacement Velocity Acceleration Angular parameters Momentum	Timers Video recorder/TV Cinematography Accelerometers Electrogoniometers Computer simulation
Kinetics	Forces Impulse Pressure	Pressure transducers Force transducers ma modeling
Neuromuscular	Muscle onsets Contractile properties Muscle sequencing	EMG Indwelling EMG Surface EMG in vitro muscle testing

Common tools used in Biomechanics Research

Kinematics
- Electrogoniometer
- Auto (Motion Analysis) and Hand (HuMan) digitizing
- Cameras (e.g., Panasonic VHS cameras)
- Accelerometer

Kinetics
- Kistler force platform
- Isokinetic dynamometer
- Impact tester

Electromyography
- Surface EMG

Synchronization
- Elgon
- Magnetic switch
- Synch-box

Concepts commonly used in Biomechanics research
- Sampling theorem
- Mass-spring model
- Joint moments
- Smoothing

Variables and Units

Kinematic Parameter	**Symbol**	**Unit**
Time	t	s
Position		
Cartesian		
Horizontal	x	m
Vertical	y	m
Medial-lateral	z	m
Polar		
Radius	r	m
Angle	2	radians
Linear		
displacement	s	m
velocity	v	mAs^{-1}
acceleration	a	mAs^{-2}
Angular		
displacement	2	rad
velocity	T	radAs^{-1}
acceleration	∀	radAs^{-2}
Linear Momentum	H	kgAm/s
Angular Momentum	h	kgAm^2/s

Kinetic Parameter	**Symbol**	**Unit**
Force	N	Newton (kgAmAs^{-2})
Linear Impulse	J	Ns
Angular Impulse		NAmAs
Torque	τ	Nm
Pressure	Pa	Pascal (N/m^2)
Power	W	Watt (J/s)
Work	U	Joule
Energy	E	Joule

Other	**Symbol**	**Unit**
Mass	m	kg
Length	l	m
Time	t	s
Moment of inertia	I	kgAm^2
Density	Δ	kg/m^3

Recording data

Analog vs. Digital signals

Analog: continuous time function.

Digital: discrete time function.

A/D converter

- Transforms analog signals to digital format.
- Analog signal can be represented by a voltage (e.g., elgon).
- The voltage is converted to a digital form using an A/D converter.
- Range: A/D converters have a range of voltages that it can detect, usually ∀10V or ∀5V.
- Computers understand 0s and 1s, called a binary digit or bit.
- Bits are converted to decimal form in the following manner:

$111 = 2^2+2^1+2^0 = 4+2+1 = 7$
$110 = 2^2+2^1+0 = 4+2+0 = 6$
$101 = 2^2+0+2^0 = 4+0+1 = 5$
$100 = 2^2+0+0 = 4+0+0 = 4$
$011 = 0+2^1+2^0 = 0+2+1 = 3$
$010 = 0+2^1+0 = 0+2+0 = 2$
$001 = 0+0+2^0 = 0+0+1 = 1$
$000 = 0+0+0 = 0+0+0 = 0$

- The voltages are converted to binary digits and stored in the computer (e.g., RAM).
- **Resolution** is defined as the number of bits that the A/D converter uses to represent the analog signal. The higher the resolution, the greater the number of divisions of the voltage range can be made. This results in more discrete voltage values that can be used to represent the analog signal. The resolution of an A/D board is identified by the bit code. A 3-bit code has 8 codes (2^3) that can be used to represent a signal. An 8-bit A/D board has 2^8 or 256 codes; a 16-bit A/D converter has 65536 codes.
    - For example, consider a 10V range of detectable voltages (i.e., ∀5V). If you have a 3 bit A/D converter, the voltages that can be represented are:

Voltage	**Binary code**
0	000
1.43	001
2.86	010
4.29	011
5.71	100
7.14	101
8.57	110
10.00	111

- Therefore, a value of 4.9 V could not be represented accurately using a 3-Bit A/D converter (4.9 V would be rounded to either 5.71 or 4.29 V depending on the A/D converter).
- To calculate the voltage increment of the A/D converter, use the following formula:

  Voltage increment = (range/(2^{bits}-1)

Units

- A/D units are in voltages, which must be converted back to correct units (e.g., degrees, N, g)
- Relationship between voltage change and unit change must be linear.
- Conversion formula

  Units = (A/D voltage) * units/volt
- For example, an accelerometer may have a conversion factor of 10 g/V. Therefore, if 2.5 V are measured by the A/D board, an acceleration of 25g was recorded.

How to make an electrogoniometer.

An electrogoniometer (elgon) is used to quantify angular position. The elgon consists of a potentiometer hooked up to a 9 V battery. The variable resistor is also hooked up to a BNC connector, which allows for connecting the elgon to an A/D board (e.g. APAS). If done correctly, the voltage output from the BNC will vary depending on the position of the elgon arms. A conversion factor can be calculated to determine the voltage per degree. Although this elgon will allow for a good degree of hyperextension, the elgon should not be used for 360 degree revolutions, as you may damage the potentiometer.

Tools needed:

- Soldering iron
- Solder
- Clippers
- 9 V Battery
- Super Glue
- Silicon caulking
- Electric tape
- File
- Electric Drill
- Hacksaw

Equipment needed for elgon:

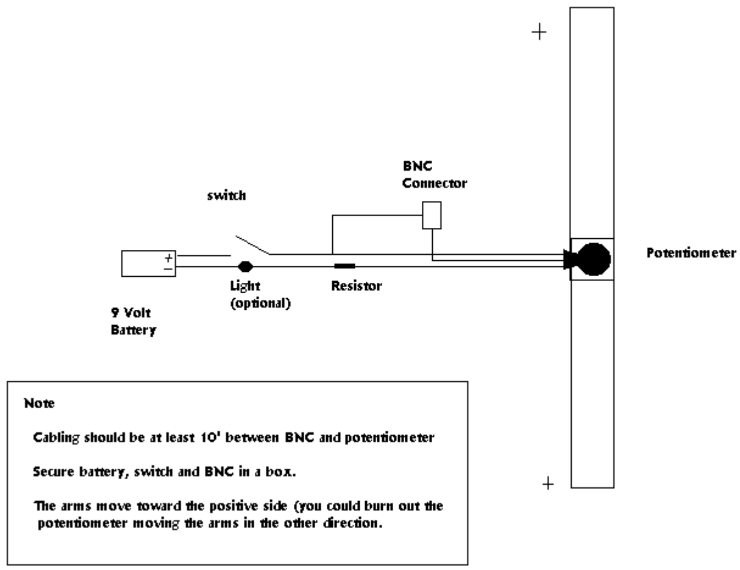
- Potentiometer ('pot')
- Resistor
- 10' stero-cable
- BNC male connector
- 9 V Battery clip
- On-off switch
- Project box
- 2 x goniometer arms (Plexiglass)
- light (optional)

Construction of electrogoniometer arms.

1. Purchase a sheet of plexiglass from a hardware store (cost is less than $10). Cut two straight pieces approximately 1" x 12" – or to the size that works best for your situation. File edges smooth.
2. Take a marker and mark 6/8" from the end of one arm. This point will be "Hole 1" and will be the axis of rotation of the goniometer.
3. Mark another point (Hole 2) 9/8" from the same end used in #2.
4. Drill a ¼ inch diameter hole for Hole 1 (big enough for potentiometer post).
5. Drill a 1/8" diameter hole for Hole 2.
6. Use the hacksaw and cut the post of the potentiometer flush with screw threads. Be careful not to damage the threads.
7. Remove cap from potentiometer by loosening the four tabs.
8. Fit the post through the drilled hole. Fit the metal tab in Hole 2 and secure the potentiometer with the washer and nut. The potentiometer posts should be on one side of the arm. This side will be the useable side of the goniometer.
9. Hold the elgon arm such that the moveable portion of the pot is topside (nut and washer on the down side). Position the large tab near the end of the elgon arm. Lay the 2nd elgon arm over the pot and mark where to cut openings for the two tabs.
10. Using the 1/8" drill bit, drill out marks for the circle and straight tabs (marked in #9).

At this point, you should have the pot secured between two arms. Use the super glue and fix the pot board to the metal casing (note that the cap usually holds the board and metal casing together, but we aren't using the cap!). Next, super glue the top arm to the pot.
The next steps are for wiring the pot.

1. Cut 2 x 10 foot section of the stero-cable. Split one 10’ section into two wires (you need only one of the two wires, so put the other wire into the toolbox!).
2. Drill holes for the BNC connector and switch in the box. Also drill a small hole to fit cabling through.
3. Plug in your solder iron and solder the components together as shown below.



- An option is to include a light to indicate whether the elgon is on. This is nice to have as an easy check to make sure the elgon is turned off when not in use.
- As a final touch, you can use the silicon caulking to secure some of the components within the box. When finished, screw on the bottom of the box.
- Test the elgon by hooking up a BNC cable with one end split. Use a multimeter to check voltage of the elgon in different positions. You should register a changing voltage from a high close to 9 V to a low close to 1 V. If you see any large deflections in the voltage readings, you may be moving the arms in the wrong direction! Remember, the elgon is for primarily one direction only (not for 360 degrees). There is probably about 270 degrees of range of motion of the elgon.

Sampling Rate

Sampling Rate

Frequency of sampling analog signal.

Purpose: Best representation of analog signal that is cost effective.

Cost effective:

- High speed data acquisition systems are expensive
  - 30 Hz vs. 200 Hz vs. 1000 Hz kinematic system
  - Computing equipment (e.g., storage of data)
  - Film, video, etc.
  - Analysis time increases (personnel cost)

"Best" representation

- Qualitatively similar digital and analog pattern (time domain analysis).
- Frequency representation of digital and analog signals is similar.

Frequency domain

- Sine wave basics
- Amplitude, frequency, period, cycle
- Superposition: Addition of sine waves
- Excell chart illustrating sine wave basics

Sampling theorem

- The analog signal can be reconstructed if the digital signal is sampled at twice the highest frequency present in the analog signal.
- Nyquist frequency: The frequency equal to twice the highest frequency present in the analog signal.
- Alaising error: False frequencies present in digital signal.
- Minimum rate defined by sampling theorem.
  - 1000 Hz for GRF data
  - 500 Hz for EMG data
  - 100 Hz for rear foot motion
  - 30-200 Hz for most human motion (depending on question)
- Maximum rate defined by experience.
- Aliasing example using MATLAB

Electric Circuit Basics

I = V/R

Types of circuits

Series: Current must flow through each component.

$R_t = R_1 + R_2 + R_3 + \ldots + R_n$

$V_t = V_1 + V_2 + V_3 + \ldots + V_n$

$I_t = I_1 = I_2 = I_3 = \ldots = I_n$

Parallel: Current can flow through one component without flowing through another.

$1/R_t = 1/R_1 + 1/R_2 + 1/R_3 + \ldots + 1/R_n$

$I_t = I_1 + I_2 + I_3 + \ldots + I_n$

$V_t = V_1 = V_2 = V_3 = \ldots = V_n$

Cathode: Negative terminal
Anode: Positive terminal

Circuit components
- Battery: Power source
- Resistor: limits current
- Variable resistors
  - Potentiometer
  - Photoresistor
- Light source
  - LED: narrow wavelength range
  - Incandescent: many wavelengths
- Switch
  - Pushbutton
    - Normally open
    - Normally closed
    - Temporary
  - Magnetic: also called a relay since it is closed due to electromagnetic field.
  - Mercury
  - Toggle
  - Other
- Diode: Permits flow in a specified direction
  - Permits flow only when threshold is reached
  - If current is excessive, the diode will burn out
  - Reverse voltages can burn a diode out

  - LED: Light emitting diode
    - Light is directly proportional to current (I = V/R)
      - Protect them with resistors in series
      - Rs = (supply voltage - LED voltage)/LED current
        - Where LED voltage and LED current are specified

    - The cathode is on the ‘flat’ side of the LED

The Camera

Speed of Light: 3×10^8 m/s in a vacuum. The actual speed is dependent on the material passing through. For example, in water, the speed of light is 2.25×10^8 m/s.

Refraction: The bending of light when passing from one media to another. When light rays pass into a media where the speed of light is reduced, light rays will bend toward the normal. When light rays pass from a media where the speed of light is lower than another media the light ray will bend away from the normal.

Lens

- Convex
- Concave
- Converging
- Diverging
- Focal point: The point where light rays converge.
- Focal Length: The distance the focal point is from the center of the lens.
  - Short focal lengths increase angle of view (e.g., wide angle lens, f=28 mm)
  - Normal, similar to eye (e.g., 50 mm lens)
  - Long focal lengths have a narrow angle of view and magnify the image size (e.g., telephoto lens, e.g., f=200 mm). Height of object is proportional to the image distance.
- Lens equations:

$$\frac{h_i}{h_o} = \frac{d_i}{d_o}$$

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

$$m = -\frac{h_i}{h_o} = -\frac{d_i}{d_o}$$

$$\begin{aligned}
&where \\
&h_i = image\ height \\
&h_o = object\ height \\
&d_i = image\ dis\tan ce \\
&d_o = object\ dis\tan ce \\
&f = focal\ length \\
&m = magnification
\end{aligned}$$

For example, consider an object 20 cm in height that is 2 m from the center of a f=50mm lens. What would be the image height?

Answer: 5 mm

Camera

- Focus ring: Moves the lens closer to or further away from film (i.e., adjusts di)
- Shutter-speed: The length of time the shutter is open (e.g., 1 s to 1/1000 s)
  - Faster movements require higher shutter speeds to prevent blurring of image.
- F-stop (a.k.a. aperture, iris): Regulates the amount of light that reaches the film.

$$f - stop = \frac{f}{D}$$

$$or$$

$$D = \frac{f}{f - stop}$$

$$f - stop = camera\ setting$$

$$f = focal\ length$$

$$D = diameter\ of\ opening$$

- For example, a 28 mm lens set at an f-stop of 2.8 has a diameter of 10 mm
- A 50 mm lens set at an f-stop of 2.8 has a diameter of 17.8 mm
- Sometimes the f-stop is referred to as the “speed” of the lens. The faster the lens, the greater the diameter of the aperture. The advantage of a fast lens is that lower light is required for a good picture. The disadvantage is that more light is passed through the thinner edges of the lens. The effect of imperfections of lenses will be more apparent in these thin regions.
- Circle of confusion: Some objects in focus, others are not. Focus either on close objects, far objects, or in between so that some close and some far objects are in focus.
- Depth of field: range in which circle of confusion is small (i.e., range in which objects are in focus).
  - A function of f-stop. The smaller the lens opening, the smaller the circles of confusion and the greater the depth of field.
  - Advantage of increasing depth of field: increased ‘in-focus’ range.
  - The disadvantage is that more light is needed since f-stop is small.

Video Camera

- CCD: Charge-Coupled Device. This is the transducer that changes light rays into electronic signals which are recorded on VHS tape. High-quality cameras will most likely incorporate multiple CCD.
- Pixels: picture elements. The CCD contains a specific array of pixels. The entire array is analogous to the film plate in a 35mm camera. Information is stored and read out line by line.
- There are two standards for scanning and displaying video signals: NTSC and ATSC.
- NTSC: National Television System Committee.
  - Primary standard in use
  - The video image contains frames and lines.
  - 30 frames per second
  - 525 lines per frame (actually, 480 are used, with 640 pixels per line)
  - Odd lines are scanned in 1/60 of a second
  - Even lines are scanned in 1/60 of a second
  - 1/60 + 1/60 = 1/30
  - Why?
    - In early days of TV, the glow of the phosphorescent material in TV would be lost easily.
    - Transmitting data in this way could be done in the 6 MHz bandwith assigned to TV stations.
- ATSC: Advanced Television System Committee
  - Developed standards for HDTV: High-definition TV
  - Our TV’s use an aspect ratio of 4:3, HDTV uses 16:9
  - Increased the number of lines to improve picture resolution (720 lines by 1280 pixels per line)
- Resolution: the amount of detail a camera can reproduce. Reported in horizontal resolution.
  - Single CCD camera: 250 lines of resolution

- Multiple CCD camera: 600 lines of resolution
- But, pictures will be produced at 525 lines.

Recorder

- VHS: Video Home System
- Records signal at 250-300 lines of resolution
- S-VHS (super VHS) increases resolution to 400 lines
- The video tape is used to record the video signal (no-duh.). This is done through ‘heads’ positioned on a drum. The heads are used to record the electrical signal onto the tape through a scanning process resulting in slanting tracks on the video tape.
- The tracks contain video information.
- Audio information is contained in an audio track located below the video tracks.
- Each track contains information for one field (i.e., 262.5 lines – odd or even).

Errors

- Perspective error: When an object moves out of the photographic plane.
- Parallax error: Error in location of object based on discrepancy of point of view.
- Digitizer error (e.g., selection of centroid)
- Camera movement
- Calibration errors (e.g., object size, location in photographic plane)
- Error in identifying anatomical landmarks

Types of Kinematic instrumentation:

- Video
- Film
- Optoelectric
- Electromagnetic
- Some systems have the capability to autodigitize, others (e.g., film) require hand digitizing.

Motion Analysis

Motion Analysis is a kinematic system which auto-digitizes reflective images. Kinematic digitization serves the same function as an A/D board – transform an analog signal to digital format. In this case, the digital format consists of (x,y) coordinates.

When using Motion Analysis, retro-reflective markers are typically used and placed on specific anatomical landmarks. Retro-reflective markers are used (instead of bike-reflectors) to minimize defraction of light off the reflective surface. The disadvantage of using retro-reflectors is that the light source needs to be placed in line with the camera. We will also experiment with using LED light sources instead of retro-reflectors due to laboratory lighting environment. Do not confuse our use of LEDs with active digitizing systems, which locate and track active markers (e.g., Selspot).

There are three major steps to digitizing using MA:

1. System setup (e.g., lighting, camera set up, calibration)
2. Collecting data (e.g., VP110, unlvgo.ev)
3. Processing data via QB4.5

1. System setup
    - Reflector Marker selection
        - Size of marker depends on image being digitized.
        - Typically, when digitizing the lower extremity during locomotion or jump-landing, markers should be no larger than a quarter.
    - Ample light to reflect markers without distorting markers
    - Set the camera back as far as possible and zoom in.
    - Set the f-stop to the largest number (i.e., smallest diameter).
    - Familiarize yourself with the VP110 processor controls.
    - Once you have a satisfactory setup, record the VP threshold. Then, working in DOS, change the directory that you are going to work in and type 'ev'. Prior to working in this directory, make sure you have the file 'unlvgo.ev' in the directory. For now, let's all work in the c:\KIN743 directory.

2. Collecting data
    - Two programs can be used to operate Motion Analysis: EV and MEV.

      EV: one camera mode
      MEV: two camera mode
    - The EV mode allows you to operate Motion Analysis through specific commands or through batch programs.
    - Unlvgo.ev is a specific EV program to collect digitized data. Note that when using MA, there is no video record, only digitized coordinates.
    - Upon successful collection, you should have a file *.bk1 that should be copied to disk.
    - For each camera setup (and each subject), you should collect a horizontal and vertical reference frame.

3. Processing digitized data
    - Each *.bk1 file contains x,y coordinates in pixels per path, with (0,0) set at the top left corner of the image.
    - The next step involves editing the *.bk1 file to delete errant paths and/or join fragmented paths. This is done through QuickBasic 4.5 program called UNLVedit.bat

Video analysis of motion

Introduction

- Why video tape?
  - hard copy of motion
  - allows quantifying motion
  - video games
- What should be video taped?
  - any motion you want to quantify
- What are the advantages of high speed video (>100Hz)?
  - smaller time increments/more information
  - discrete events can be better defined (ball contact - blurr)
- Conversion of Hz to time interval
  - Hz = frames/sec (sec = frames/Hz)

    ex: 30 Hz camera: each frame = 1/30th s

    200 Hz : each frame = 1/200 s

Subject set up

- reflective markers (assuming that the areas that we are marking are the actual joint center and that skin movement is negligible)
- same material as on bicycle, clothing, etc.; thus, cover up other reflective markers (ie shoe)
- size of marker and why this is important during digitizing
  - blending
  - size: optimize to reduce blending error but maximize accuracy
  - location of markers are points in space: x,y
  - each marker (for this lab) is a joint center/axis of rotation.
  - What markers will we need to analyze walking/running?
  - Markers needed to calculate joint angles:
    1. shoulder: greater tuberosity and acromium process
    2. greater trochanter
    3. knee: lateral epicondyle of femur and condyle of tibia
    4. heel (with shoe): calcaneus
    5. malleolus
    6. 5th metatarsal

Equipment orientation

- procedures for camera
- camera placed strategically to optimally view complete phase of motion.
- level camera in two planes, and check to make sure camera is perpendicular to field of motion.
- camera as far back using zoom in
  - reduces error: increases image size in center of lens

Possible problems with using video analysis:

- error in set up
  - image not large enough (data not able to be obtained)
  - image not centered in field of vision

    (some error will result due to image being refracted through outlying area of lens as well as viewing perspective error off outlying area of screen)
  - error due to reflective markers
    - validity of placement
    - reliability of placement
    - movement of marker due to skin, shoe, ?
    - blending of marker (two markers too close!)
    - bad marker (not circular)
    - excessive/poor lighting

Smoothing Data

Every data set analyzed contains noise. In general, the assumptions of noise are:

- The frequency content of noise is considered high.
- The amplitude of noise is low.

There are many techniques used to smooth data. Some of the techniques used include:

- Moving average. For a given data set, a new data set is created by calculating a moving average of the raw data. For example, a new data point (i) could be created as the average of n-1, n, n+1.

Frame	**time**	**x**	**vx**	**ax**	**3 point Smoothed**	**v**	**a**	**5 point smoothed**	**v**	**a**
73	0.067	2.946								
74	0.083	2.982	1.64		2.977					
75	0.100	3.001	1.42	-8.30	3.004	*1.48*		3.00		
76	0.117	3.029	1.37	-16.27	3.026	*1.22*	*-11.20*	3.02	*1.27*	
77	0.133	3.047	0.88	-9.01	3.045	*1.10*	*-2.77*	3.04	*1.23*	*0.0*
78	0.150	3.058	1.07	16.96	3.063	*1.13*	*8.24*	3.06	*1.28*	*1.1*
79	0.167	3.082	1.44	16.78	3.082	*1.38*	*10.32*	3.09	*1.27*	*2.5*
80	0.183	3.107	1.63	-2.77	3.108	*1.47*	*1.56*	3.11	*1.36*	*5.5*
81	0.200	3.137	1.35	-9.34	3.131	*1.43*	*-2.13*	3.13	*1.45*	
82	0.217	3.151	1.31	5.71	3.156	*1.40*		3.16		
83	0.233	3.180	1.54		3.178					
84	0.250	3.203								

- Fourier Smoothing. Signals can be represented by the summation of sine waves of varying
  - frequency: time to complete a cycle
  - amplitude: height of sine wave

  Steps to Fourier Smoothing include
  1. Completing a Fast Fourier Transformation (FFT). That is, calculating amplitudes of frequencies that estimate the raw signal.
  2. Identifying cutoff frequency.
  3. “resetting” amplitudes of unwanted frequencies (i.e. high) to zero.
  4. Calculating in inverse transformation.

- Band-pass. The amplitudes of a band of frequencies are unchanged. For example, it may be desired to have only frequencies between 3-10 Hz analyzed.

- Notch filter. The amplitudes of a band of frequencies are changed. For example, it may be desired to get rid of powerline (60 Hz) noise.

- High Pass. Frequencies above a specified cutoff frequency are passed through the filter (e.g. EMG).

- Low Pass. Frequencies below a specified cutoff frequency are passed through the filter (e.g. Kinematic data).

- Polynomial. Data can be fit with a polynomial function of degree n of the following form:

  $X(t) = a_0 + a_1t + a_2t^2 + a_3t^3 + \ldots + a_{n-1}t^{n-1} + a_nt^n$

  EXCELL users: select data series; ‘chart – add trendline – polynomial (2) – show equation’

  MATLAB users:
```
[p,s]=polyfit(x,y,n);
smooth_y=polyval(p,x);
%where       x = time
%            y = vertical displacement
%            n = polynomial degree (2nd for projectile motion)
```

- Digital Filtering. This is a form of moving average, but a system of sophisticated weights per row is used.

$T_n = f_c/f_s$

where T_n = cutoff to sample frequency ratio
f_c = cutoff frequency (Hz)
f_s = sample frequency (Hz)

[for MATLAB users: $T_n = 2(f_c/f_s)$]

$T_c=\tan(BT_n)$

where T_c = normalized cutoff frequency

$K_1 = T_c(2^{0.5})$ Butterworth filter
$K_1 = 2T_c$ Critically damped filter

$K_2 = T_c^{\,2}$
$a_0 = K_2/(1+K_1+K_2)$
$a_1 = 2a_o$
$a_2 = a_o$

$K_3 = 2a_0/K_2$
$b_1 = -2a_0+K_3$
$b_2 = 1-2a_0-K_3$

$\mathbf{x'}(i)= a_0\, x(i)+ a_1(x(i-1))+ a_2(x(i-2))+b_1(\mathbf{x'}(i-1))+b_2(\mathbf{x'}(i-2))$

EXCELL Example

	A	B	C
1	0.067	2.946	2.946
2	0.083	2.982	2.982
3	0.100	3.001	$= a_0B(3)+ a_1B(2)+ a_2B(1)+b_1C(2)+b_2C(1)$
4	0.117	3.029	
5	0.133	3.047	
6	0.150	3.058	
7	0.167	3.082	
8	0.183	3.107	
9	0.200	3.137	
10	0.217	3.151	
11	0.233	3.180	
12	0.250	3.203	

3D Calibration

The Problem: Calculate 3D coordinates from 2D image plane.

- Each point in space can be represented by a unique set of x,y,z coordinates.
- Each point on an image can be represented by a unique set of x,y coordinates.
- By combining multiple camera views of a point in space, 3D coordinates can be calculated.

The most common methods to transform 2D to 3D includes:

- DLT:	Abdel-Aziz & Karara (1971)
- MDLT:	Hatze (1988)
- DNLT:	Chen (1994)
- NLT:	Dapena (1982)

DLT: Uses a set of known spatial coordinates to determine internal and external camera parameters.

Internal Parameters:	lens distortion, camera distance from point
External Parameters:	Orientation of camera (relative to field of view and to each camera)

$x + \square x + \square x = (L_1X + L_2Y + L_3Z+ L_4)/(L_9X + L_{10}Y + L_{11}Z + 1)$

$y + \square y + \square y = (L_5X + L_6Y + L_7Z + L_8)/(L_9X + L_{10}Y + L_{11}Z + 1)$

x,y	image coordinates
X,Y,Z	spatial coordinates
$\square x, \square y$	random digitizing errors
$\square x, \square y$	non-linear systematic errors
L1-L11	camera parameters

Required: 6 control points (12 equations).
Recommended: 20-30 control points.
Advantages: accurate within calibration volume.
Disadvantages: accuracy suspect when extrapolating outside of calibration volume.

NLT: Uses reference frame to calculate internal parameters.
Uses control object of unknown shape, but with at least one known length, to calculate external parameters.

Note: Peak requires the user to select a camera - the camera internal parameters have been calculated by Peak, and therefore the correct camera must be selected.

Required: Reference frame, wand.
Advantages: Able to calibrate a large volume of space without the need of construction a large calibration cube.
If extrapolation of data outside the calibrated volume is required, the NLT is more accurate than the DLT.
Disadvantages: Less accurate within the calibrated space compared to the DLT.

For fun reading:

Chen, L., Armstrong, C.W., & Raftopoulos, D.D. (1994). JOB 27(4), 493-500.
Dapena, J., Harman, E.A., & Miller, J.A. (1982). JOB 15(1), 11-20.
Dapena, J. (1985). JOB 18(2), 163.
Hatze, H. (1988). JOB 21(7), 533-538.
Henrichs, R.N., & McLean, S.P. (1995). JOB 28(10), 1219-1224.
Kennedy, P.W., Wright, D.L., & Smith, G.A. (1989). IJSB 5(4), 457-460.
Miller, N.R., Shapiro, R., & McLaughlin, T.M. (1980). JOB 13(7), 535-548.

Joint Moments

Torque: The tendency of a force to cause rotation. $T=Fd_{\perp}$

Torque = Moment
    Units: Nm

Forward Dynamics: Given segment accelerations, position, velocity and joint moments can be calculated.
Inverse Dynamics: Given position vs. time data, accelerations and joint moments can be calculated.

To solve for joint moments, the following data are required:
    Anthropometrics
    Kinematics
    Kinetics

Anthropometrics
    Segment masses
    Segment COM
    Segment I_o

Kinetics
    Fy
    Fz
    COP

Kinematics
    α for foot, leg, thigh
    a_x for COM of each segment
    a_y for COM of each segment
    (x,y) coordinates for each joint

Assumptions of a rigid link segment model

- Mass and length of each segment are constant.
- COM is a fixed point within a segment.
- I_o is moment of inertia about COM and is fixed.

Steps to inverse dynamic approach

1. Record kinematic and kinetic data concurrently.
2. Record COP to identify location of GRF relative to foot.
3. Calculate segment accelerations in x and y directions.
4. Calculate segment angular velocities.
5. Calculate segment masses and moment of inertias
6. Use equations

Equations for inverse dynamics approach

$\Sigma F_x = ma_x$

$\Sigma F_y = ma_y$

$\Sigma T = I\alpha$

Moment of Inertia represents the resistance to change angular motion about the center of mass.

$I_o = m\rho^2$ units: kgm^2

ρ = Radius of Gyration = (coefficient)A(segment length)

I_o = moment of inertia about segment COM

l = segment length in meters

Segment	**defined**	**Weight %BW**	**COM %l**	**ρ/l**
Head-Arms-Trunk	Greater-Trochanter to Glenohurmeral joint	0.678	0.626	0.496
Head and neck	C7-T1 to Ear canal	0.081	1.000	0.495
Upper Arm	Glenohumeral axis to Elbow axis	0.028	0.436	0.322
Forearm	Glenohumeral axis to Ulnar Styloid	0.016	0.430	0.303
Hand	Wrist axis to Knuckle middle finger	0.006	0.506	0.297
Trunk	Greater Trochanter to Glenohumeral joint	0.497	0.500	
Thigh	Greater Trochanter to Knee joint approximation	0.100	0.433	0.323
Leg	Knee joint appox. To Lateral malleolus	0.0465	0.433	0.302
Foot	Lat. Malleolus to Head of 5^{th} metatarsal	0.0145	0.50	0.475

General Equations (Courtesy of Dr. Tim Derrick, Iowa State)

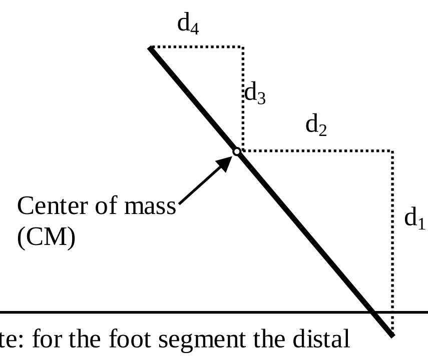
Proximal Reaction Force (x) (R_{dx} for the foot is the horizontal GRF)
$R_{px} = ma_x - R_{dx}$

Proximal Reaction Force (y) (R_{dy} for the foot is the vertical GRF)
$R_{py} = ma_y - R_{dy} - mg$

Proximal Moment (M_d for the foot is zero)
$M_p = I□ - M_d - (R_{dx}*d_1) - (R_{dy}*d_2) - (R_{px}*d_3) - (R_{py}*d_4)$

$d_1 = CM_y - d_y$
$d_2 = d_x - CM_x$
$d_3 = CM_y - p_y$
$d_4 = p_x - CM_x$

proximal moment	$\mathbf{M_p}$	
proximal force x	$\mathbf{R_{px}}$	**unknowns**
proximal force y	$\mathbf{R_{py}}$	
distal moment	M_d	
distal force x	R_{dx}	
distal force y	R_{dy}	
CM acceleration x	a_x	
CM acceleration y	a_y	
angular acceleration	□	
mass	m	
moment of inertia	I	
proximal joint x	p_x	
proximal joint y	p_y	
CM x	CM_x	
CM y	CM_y	
distal joint x	d_x	
distal joint y	d_y	
gravity	g = -9.81	



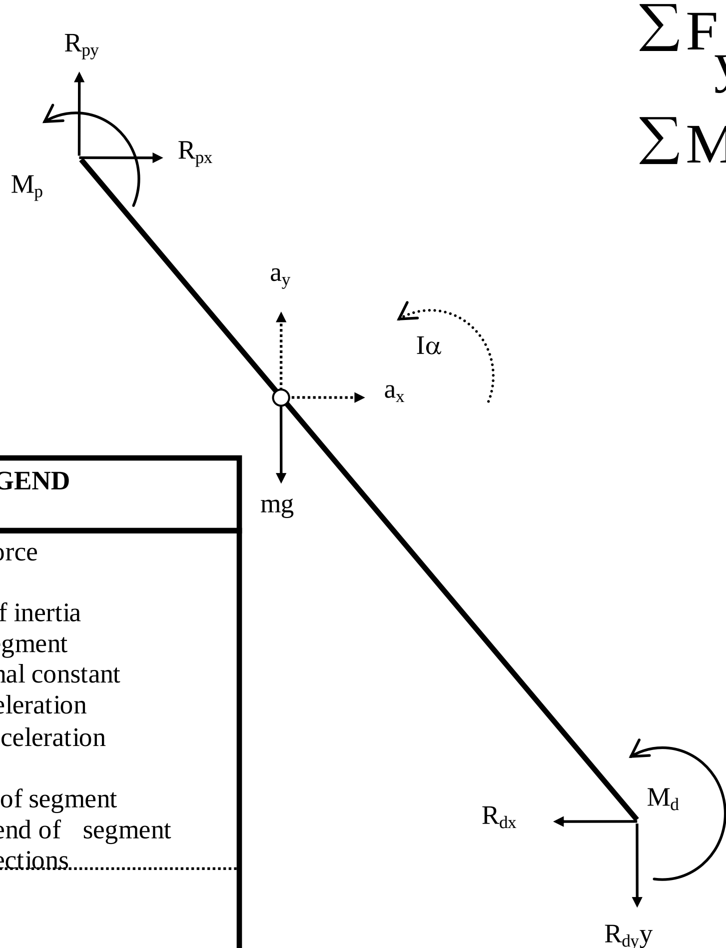
Note: for the foot segment the distal moment (M_d) is 0, the distal forces (R_{dx} and R_{dy}) are the ground reaction forces and the distal joint location (d_x and d_y) is at the center of pressure.

Free Body Diagram

$$\sum F_x = m \cdot a_x$$

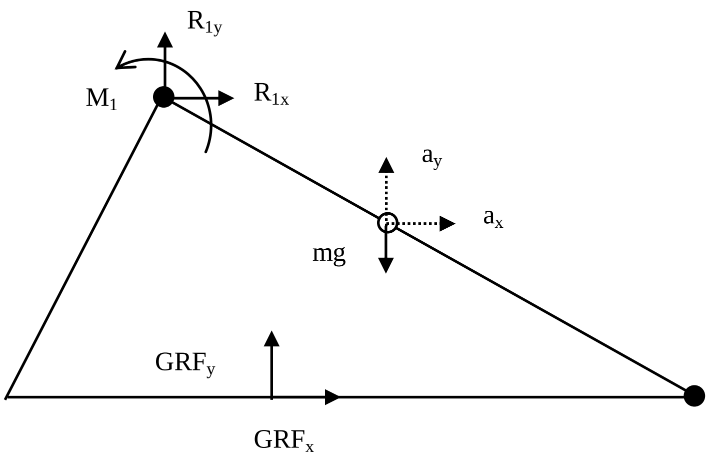
$$\sum F_y = m \cdot a_y$$

$$\sum M = I \cdot \alpha$$



LEGEND	
R	reaction force
M	moment
I	moment of inertia
m	mass of segment
g	gravitational constant
a	linear acceleration
α	angular acceleration
d	distal end of segment
p	proximal end of segment
x,y	vector directions

Sample Joint Moment Calculations
Frame 11 – Ankle joint moment



$GRF_x = -149.96$ N
$GRF_y = 878.73$ N
$a_x = -0.9$ m•s^{-2}
$a_y = 2.25$ m•s^{-2}
$\alpha = 12.18$ rad•s^{-2}
m = 1.16 kg
$I_{cm} = .009684$ kg•m^2

	x	y
ankle	.849	.110
cm	.930	.061
COP	.8563	0

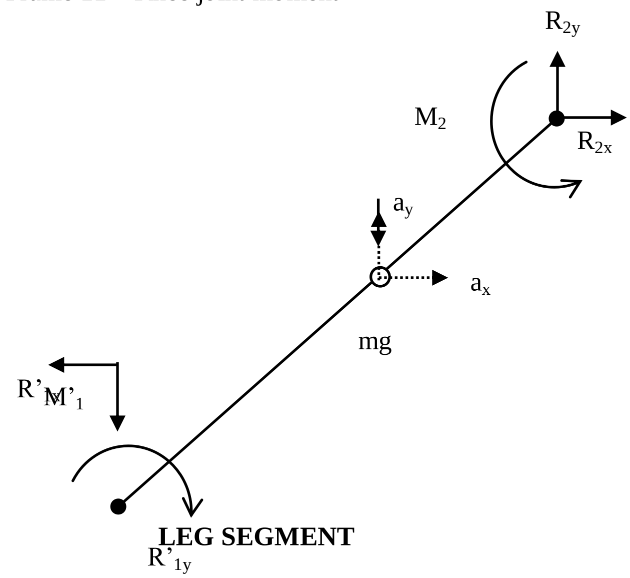
$R1_x + GRF_x = ma_x$
$R1_x = ma_x - GRF_x$
$R1_x = 1.16kg * -.90m•s^{-2} - (-149.96N)$
$R1_x = 148.92N$

$R1_y + GRF_y + mg = ma_y$
$R1_y = ma_y - GRF_y - mg$
$R1_y = (1.16kg * 2.25m•s^{-2}) - 878.73N - (1.16kg * -9.81m•s^{-2})$
$R1_y = -864.74N$

$M_1 + M(R1_x) + M(R1_y) + M(GRF_x) + M(GRF_y) = I\alpha$
$M_1 = I\alpha - M(GRF_x) - M(GRF_y) - M(R1_x) - M(R1_y)$
$M1 = (.009684kg•m^2 * 12.18rad•s^{-2}) - (-149.96N * .061m) - (878.73N * -.0737m) - (148.92N*-.049m) - (-864.74N *-.081m)$
$M1 = .12N•m + 9.15N•m + 64.76N•m + 7.30N•m – 70.04N•m$
$M_1 = 11.29N•m$

- M_1 is positive indicating a CCW moment

Frame 11 – Knee joint moment



M_1 = -11.29 N•m
R_{1x} = -148.92 N
R_{1y} = 864.74 N
a_x = -4.47 m•s^{-2}
a_y = -0.63 m•s^{-2}
α = 14.01 rad•s^{-2}
m = 3.72 kg
I_{cm} = .0664 kg•m^2

	x	y
knee	.876	.549
cm	.864	.359
ankle	.849	.110

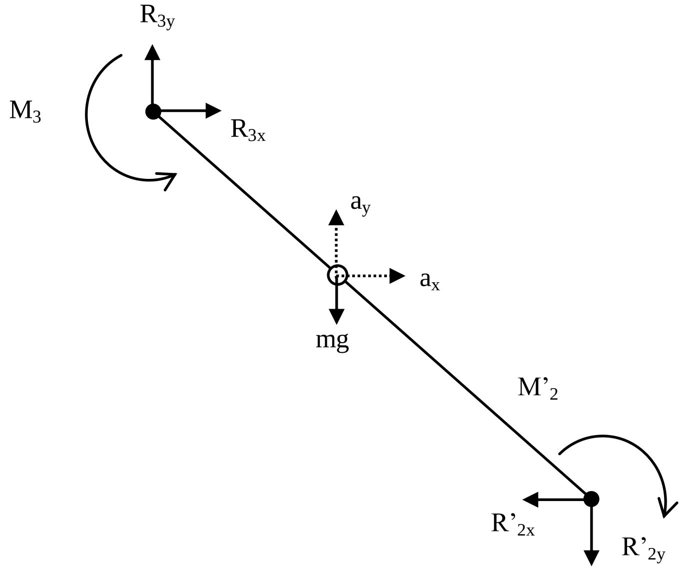
$R2_x + R1_x = ma_x$
$R2_x = ma_x - Rl_x$
$R2_x$ = (3.72kg * -4.47m•s^{-2}) – (-148.92N)
$R2_x$ = 132.29N

$R2_y + Rl_y + mg = ma_y$
$R2_y = ma_y - Rl_y - mg$
$R2_y$ = (3.72kg * -.63m•s^{-2}) - (864.74N) - (3.72kg * -9.81m•s^{-2})
$R2_y$ = -830.59N

$M_2 + M_1 + M(R1_x) + M(R1_y) + M(R2_x) + M(R2_y) = I\alpha$
$M_2 = I\alpha - M_1 - M(R1_x) - M(R1_y) - M(R2_x) - M(R2_y)$
M_2 = (.0664kg•m^2 * 14.01rad•s^{-2}) – (-11.29N•m) - (-148.92N * .249m)
- (864.74N * -.015m) - (132.29N * -.19m) - (-830.59N * .012m)
M_2 = .93N•m + 11.29N•m + 37.08N•m + 12.97N•m + 25.14N•m + 9.97N•m
M_2 = 97.37N•m

- M_2 is positive indicating a CCW

Frame 11 – Hip joint moment



M_2 = -97.37 N•m
R_{2x} = -132.29 N
R_{2y} = 830.59 N
a_x = -4.648 m•s^{-2}
a_y = -0.269 m•s^{-2}
α = -16.08 rad•s^{-2}
m = 8.00 kg
I_{cm} = .141 kg•m^2

	x	y
hip	.743	.932
cm	.801	.766
knee	.876	.549

THIGH SEGMENT

$R3_x + R2_x = ma_x$
$R3_x = ma_x - R2_x$
$R3_x = (8.0kg * -4.648m•s^{-2}) – (-132.29N)$
$\mathbf{R3_x = 95.11N}$

$R3_y + R2_y + mg = ma_y$
$R3_y = ma_y - R2_y - mg$
$R3_y = (8.0kg * -.269m•s^{-2}) - (830.59N) - (8.0kg * -9.81m•s^{-2})$
$\mathbf{R3_y = -754.27N}$

$M_3 + M_2 + M(R2_x) + M(R2_y) + M(R3_x) + M(R3_y) = I\alpha$
$M3 = I\alpha - M_2 - M(R2_x) - M(R2_y) - M(R3_x) - M(R3_y)$
$M3 = (.141kg•m^2 * -16.08rad•s^{-2}) – (-97.37N•m) - (-132.29N * .217m) - (830.59N * .075m) - (95.09N * -.166m) -$
$(-754.27N * -.058m)$
$M3 = -2.27N•m + 97.37N•m + 28.71N•m - 62.29N•m + 15.78N•m – 43.74N•m$
$\mathbf{M3 = 33.55N•m}$

- M3 is positive indicating a CCW moment

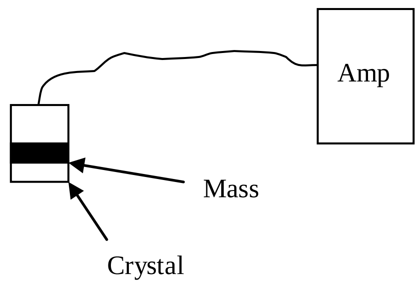
Accelerometers

Acceleration:

- Rate of change of velocity.
- Direction of acceleration indicates the slope of the velocity vs. time plot.
- Whether velocity is speeding-up or slowing-down depends on initial velocity.
- Direction of motion is given through velocity information.

Techniques to measure acceleration:

- Video analysis
    - Record position vs. time, calculate 2^{nd} derivative.
- Force plate
    - Newton's 2^{nd} law: F=ma
- Accelerometer



Accelerometers

- Consists of:
    - Mass
    - Transducer material
        - Piezoelectric crystal material
        - Strain gauges
        - Ceramics
    - Amplifier

- Piezoelectric crystal
  This material is sensitive to forces placed upon it. When a force acts on the crystal, the material changes its electric properties. The Kistler force plate also uses piezoelectric crystals. Most accelerometers do not measure constant acceleration conditions – like freefall or standing weight. This information is found in accelerometer specifications that identify frequency response of accelerometers. If the frequency response includes zero, then it measures constant acceleration.

- Sensitivity
    - 100 mV/g = 1 g/100 mV = 0.01 g/V
    - 1000 mV/g = 1 g/1000 mV = 0.001 g/V

- Accelerometer sensitive axis
    - Uniaxial
    - Triaxial
    - Compression vs. shear

- Using accelerometers in human movements
    - Surface mounted accelerometers
    - Bone mounted accelerometers

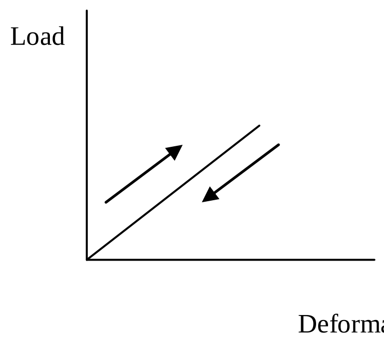
- Factors affecting surface mounted acceleration
    - Rate of change of velocity.
    - Accelerometer mass (not mass component *per se*, but total accelerometer mass).
    - Soft tissue between accelerometer and bone.
    - Orientation of sensitive axis relative to gravity.
    - Angular motion (Centripetal acceleration = $v_T^2/r = rT^2$).

Advantages of Accelerometry	**Disadvantages**
Can record accelerations at high sample rates.	An accelerometer is needed for each segment of interest.
Accelerations can be continuously recorded.	Sensitive to attachment procedures.
Suitable for testing impact magnitudes.	Attachment procedures could affect human performance (e.g., too tight attachment).
Representation of segment accelerations.	Single sensitive axis changing relative to gravity.
	Integration is possible only if v_i is known.

Impact Testing and Springs

Biomechanic analyses often involve quantifying elastic behavior of a material, object, or person during some activity. Testing elastic behavior of an object or material often involves impact testing, while testing elastic behavior of a person during a task involves recording kinetic and kinematic data concurrently.

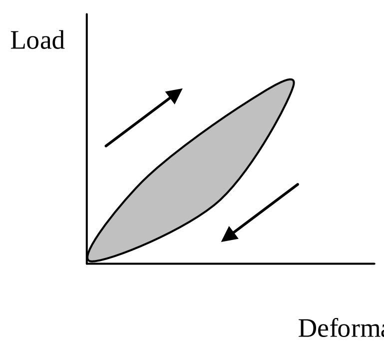
Elastic*: The ability to return to original position.*



Pure elastic behavior in not dependent on time, or loading rate. However, the elastic behavior of most materials (e.g., surfaces, bone, tendon) is dependent on time.

Viscoelastic: The elastic response is dependent on loading rate.
Viscosity: fluid property, a measure of resistance to flow.
Elasticity: material property, a measure of the ability to return to original shape.

A technique used to test viscoelastic properties of an object is to impact test it via impact tester. An impact missile is dropped on the test surface and recordings of force and displacement are made.



Hysteresis: Same path not taken during loading and unloading.
Hysteresis loop: Represents the energy lost in the collision; or, the energy not returned by the object (dissipated as heat).

Energy: The capacity to do work.
Potential Energy of position: mgh
Kinetic Energy: $\frac{1}{2} mv^2$
Potential Energy of a spring: $\frac{1}{2} kx^2$
Conservation of Energy: Energy can neither be created nor destroyed. It may only change from one form to another.
During collisions, energy pre-collision = energy post-collision
$E_{pre} = E_{post}$

$PE_i + KE_i = PE_f + KE_f + Q$

At impact:	$E = KE_i$
At max deformation:	$E = PE_{spring}$
At point of missile takeoff:	$E = KE_f$
Important:	$KE_i \neq KE_f$ (i.e., energy is dissipated)
	$KE_i = KE_f + Q$

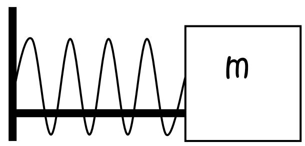
Q: Represents the non-mechanical energy (e.g., heat).
Area of Hysteresis loop = Q: The energy not returned by the material during a collision.

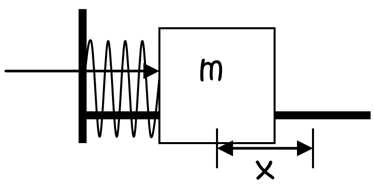
Mass-Spring Model

- The amount of deformation of a spring determines the amount of force exerted back by a spring.

  $F = -kx$

- The negative sign indicates that the force is always directed back to the equilibrium position of the spring.
- To calculate k of an object, apply a force to it and measure the deformation.





- How would you calculate lower extremity stiffness while hopping?

In-class Experiments:
1. Calculate the spring stiffness of one of a rubber band.
2. Impact test different materials and calculate the spring stiffness of each material.

Modeling the human body as a spring

Pros
- A mass-spring model can be used to predict human movement (e.g., GRF).
- A simple model can be used to understand human movements (e.g., hopping, running)

Cons
- The human body is not a spring since deformation can occur with no recoil necessary.
- The stiffness of the lower extremity stiffness can vary within a cycle (e.g., during the landing phase during running).

Electromyography

- Electromyography (EMG): The study of the electrical signal associated with muscle contraction.
- A powerful tool to understand human movement. A very powerful tool when used in conjunction with some other kinematic instrumentation (e.g., elgon).

1. What is being measured?
2. How do you measure EMG?
3. How do you process EMG?
4. What does it mean?

Muscle contraction occurs as a result of:

- CNS signal
- Transmission of signal to motor end plate via α motor neurons
- Upon reaching post-synaptic membrane threshold, signal is transmitted throughout muscle fibers of a motor unit (α motor neuron and all innervated muscle fibers).
- EMG measures the electrical depolarization-repolarization cycle of muscle activation.

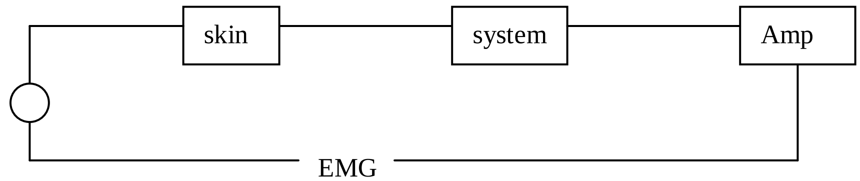
Terminology

- Motor unit
- Muscle fiber action potential
- Motor unit action potential (muap)
- Synchronization: tendency for different motor units to fire simultaneously.
- Motor point: location where smallest external stimulus is needed for muscle contraction (i.e., innervation zone).

How to measure:

- Goal: quantify muscle activity.
  - Piezoelectric Contact Sensors
  - Microphones
  - Accelerometers
  - Optical methods
  - Pressure transducers
  - Electromyography

- The problem: The electrical activity of muscle contraction is small and generally motor units fire asynchronously. For surface EMGs, the electrical activity must be recorded through subcutaneous fat, connective tissue (e.g., tendon sheath), skin, electrolyte gel, lead material, wire, amplifier, and finally computer.
- The EMG system must take into account all these factors (and more) when generating the resulting 'raw' signal.

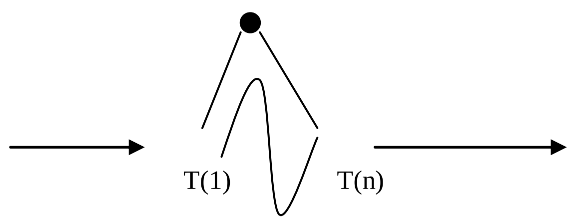


- Skin resistance: reduce by shaving, abrading, cleaning.
- Electrode, electrolyte transition: resistance is a function of material. Electrodes come in all different styles and materials. The Noraxon system uses a lead that connects to a 'patch' that contains electrolyte gel. If this gel is not good, the lead is no good.
- The wires act as antennae (part of 'system') that record electrical wilderness signals and may tug on electrodes and cause movement artifacts.

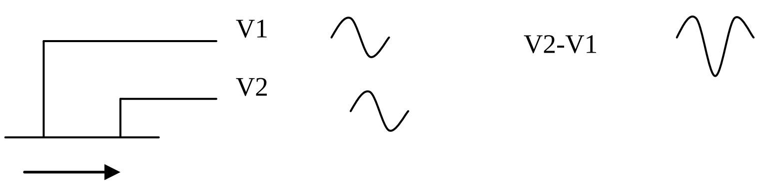
- Amplifier: This system amplifies the input signal – which may contain noise. Good amplifiers amplify all frequencies equally, meaning that noise is amplified. Some ways to reduce amplification of noise:
    - Analog filters (booo for you if you do not know)
        - CMRR (discussed below).
        - High pass filters – removes movement artifacts
        - Low pass filters – removes high-frequency noise
        - Other analog filters (these are boo for me)
    - Locate amp as close to muscle surface as practically possible (sometimes boo, sometimes not).
    - Some EMG systems include an amp on the electrode (true 'pre-amp' systems). Others, such as the Noraxon have the amp located between the electrode and computer.

EMG basics:

- One lead system:



- Most EMG systems use a two electrode system to record muscle activity:



- Most EMG systems use a third lead as a reference lead to identify noise common to both leads. This lead is typically placed on an inactive site (e.g., bony landmark).
- Common-Mode Rejection
  The signal common to both leads is removed through difference between leads (see EMG.xls). This procedure is referred to as CMR and is completed in the amplifier (i.e., differential amplifier).

  $A = (b+N) – (c+N) = (b-c)$

  Therefore, common noise is removed from the signal. Usually, the amplifier's ability to remove noise from the signal is reported as the common-mode rejection ratio (CMRR). This value represents the ratio of noise removed relative to signal amplitude. For example, if the CMRR is 2000:1, then all but 1/2000 of the noise is removed from the signal. Usually, the CMRR is reported in decibels using the following calculation:

  $\text{CMRR (dB)} = 20\log_{10}(\text{ratio})$

  Therefore, for a 2000:1 CMRR, the dB would be: $20\log_{10}(2000) = 66$ dB
  What is the CMRR of the Noraxon amplifier?

Processing EMG

- Remove DC bias. Calculate mean of all data, subtract mean from each data point.
- Rectify:
    - Full wave rectification: absolute value of all EMG values (recommended).
    - Half wave rectification: analyze positive data only.

- Lot's of options at this point
  - Smooth
    - Butterworth
    - Moving window average (recommended)
    - Used to quantify EMG pattern.
  - Integrate
    - IEMG = $\Sigma x(t)/fs$ (Rectangular integrator)
    - IEMG = $\Sigma(x(n)+x(n+1))/2fs$
    - Units: mVs
    - Over a time period (recommended).
    - Reset after some specified time period (e.g., 50 ms). This is similar to a moving average.
    - Reset after some specified voltage value (e.g., 50 mV). The number of resets are recorded for analysis, more resets = more active muscle.
    - IEMG used to quantify activity of muscle.
  - Average EMG
    - Units: mV
    - Across some time specified period
    - Used to quantify activity of muscle, normalized to time.
  - Linear Envelope
    - Common EMG phrase used to describe the following process:
      - DC bias removed
      - Full wave rectification
      - Low pass filter
- Normalization
  - Since there are a lot of variables that determine magnitude of EMG for a given person, EMG data are typically normalized to some baseline value. This baseline measure could be:
    - Maximal voluntary contraction
    - Quiet record of EMG
    - Some baseline condition. For example, when comparing EMG across three running speeds, magnitudes could be normalized to the slowest speed EMG magnitude.

Interpreting EMG
Carlo J. De Luca, 1997. The use of surface electromyography in Biomechanics. Journal of Applied Biomechanics, 13, 135-163.

Electromyography is a seductive muse because it provides easy access to physiological processes that cause the muscle to generate force, produce movement, and accomplish the countless functions that allow us to interact with the world around us. The current state of surface electromyography is enigmatic. It provides many important and useful applications, but it has many limitations that must be understood, considered, and eventually removed so that the discipline is more scientifically based and less reliant on the art of use. To its detriment, electromyography is too easy to use and consequently too easy to abuse.

Recommendations
- Have subject warm-up prior to instrumenting.
- Minimal sample rate = 500 Hz.
- Know the software and hardware specifications.
- Identify appropriate site. For our lab, that means locate the belly of the muscle and be able to identify fiber orientation. If you can quantify motor point (i.e., innervation zone), do NOT put leads over this area. Rather put the leads proximal to the motor point.
- Prepare site appropriately. Shave, abrade, clean, repeat. Even if someone presents shaved, abrade and clean. Reduce skin resistance.
- Use 'good' leads and/or gel. Do not let gel communicate between leads. Watch for sweat contaminating the leads.
- Place lead centers about 2 cm apart, in line with muscle fibers.
- Fix connectors and wire to minimize movement artifact.
- Locate and clean site for common ground.

- In methods, identify clearly processing steps.
- Prior to collecting data, know what you are going to do with EMG data (e.g., analyze iEMG, average EMG, patterns, …).
- Avoid between subject comparisons (use within-subjects design).
- Avoid between muscle comparisons of magnitude.
- Avoid between day comparisons.
- Report amplifier specs (gain, CMRR, any filtering, differential lead).
- Report processing steps (DC bias, full-wave rectification, …).
- Use appropriate units (iEMG = mVs, average EMG = mV).

Isokinetic Dynamometer

An Isokinetic Dynamometer is a fancy word identifying an instrument that allows for measuring forces during same speed movements. Remember the different types of contractions from your Exercise Physiology studies:

Isokinetic: Contractions where angular speed is constant.
Isometric: Contraction where distance is constant.
Concentric: Contraction where muscle shortens.
Eccentric: Contraction where muscle lengthens (but it's trying to shorten!)

There are several manufacturers of Isokinetic Dynamometers:

KinCom (our lab has one)
Cybex Orthotron
BioDex

Each of the instruments allows for measuring force exerted by the user against a pad. Some of the machines report the user in Torque, others in Force. We'll discuss the difference between torque and force during the section on Angular Kinetics.

The tester sets a specific angular velocity for the user to use during exercise. The interesting aspect of this type of machine is that no matter how hard the user pushes against the pad, the angular velocity will not exceed the angular velocity set by the tester (i.e. isokinetic exercise).

Can you figure out how long it would take to complete a single knee extension exercise through 90 degrees (i.e. angular displacement) with the machine set to 30 degrees/second?

In the lab setting, we use this machine to quantify muscle contractile properties over a range of speeds.

When using the machine, it is important to line up the machine axis of rotation with the anatomical axis of rotation. That is, if you are setting up a user for knee extension exercise, it is important to line up the knee joint axis with the machine axis. If you do not appropriately line up the two axes, the user will be rather uncomfortable and at risk of injury.

Here's some things to try:
Can you exert the same magnitude of force across a range of angular velocities?
During knee extension exercise, can you exert the same amount of force while sitting vs. lying on your back?
What angular velocity would you need to select in order to test an isometric contraction?
Is there a difference in how much force you can exert near the ends of ROM compared to the midrange of ROM?

Energy

Energy: The ability to do work.

Work:

- The transfer of energy from one object to another.
- The product of the magnitude of force and the distance through which the force acts.
- Used to describe what is accomplished by a force.
- W = Fd Units: Nm or Joule

Energy cannot be created or destroyed. It may only change from one form to another.

$E_1 = E_2$

Energy has to come from somewhere and go somewhere.

- Energy is needed to get an object moving
- Energy is needs to be dissipated to slow an object down.

Mechanical Energy:

- PE: Potential Energy
  - Position: PE = mgh
  - Spring: $PE = \frac{1}{2} kx^2$
- KE: Kinetic Energy
- Units: Joule

Power:

- The rate at which energy is transformed from one form to another.
- The rate at which work is done.
- Unit: Work/time = J/s or Watt

Power vs. Energy

- What a person can do is not limited only by the total energy required but also the rate at which the energy is used.

P = W/t = Fd/t = Fv
Angular parameter: $P = T\omega$

Since power is a measure of the rate of energy being transformed (maybe to heat or some other non-mechanical form) it is used to calculate 'Energy Absorbed' and 'Energy Generated' parameters.

- Energy Absorbed: T and ω have the opposite directions.
- Energy Generated: T and ω have the same directions.

- Quadriceps eccentric contraction: T is an extensor moment (i.e., negative) ω is flexion (i.e., positive).

Matlab: MATrix LABoratory

MATLAB is a computer program that allows you to:

- Perform basic and advanced mathematical calculations.
- Read in data files.
- Plot data for visual inspection.
- Create routines to allow user to interact with plots via mouse.
- Identify and calculate discrete variables.
- Save data.

MATLAB terminology:

- Variable: any name representing some quantity. Spaces <u>cannot</u> be included in a variable name. Examples of variable names:
- average_force
- this_is_a_good_variable_name
- Scalar: any variable that is represented by a single value.
- Vector: a variable that is represented by more than one value (i.e. magnitude and direction). When using MATLAB, vectors can also be thought of as ARRAYS. However, you need to be very careful when using math functions with vector variables.
- Command line: specific command to run at the MATLAB prompt
- Script file: a file that contains a sequence of command lines. To run script files as a program within MATLAB, script files need to end in '*.m'.
- Comment: Good script files include a comment or remark preceding or in conjunction with a command in order to explain your thought process.

MATLAB rules:

- Prior to creating a new variable, check to see if it is a 'm' file by typing 'help [variable name]' at the MATLAB prompt.
- Since multiple users will be writing script files, include your initials as part of your script file name.
- When saving data to a file, be sure to check what directory you are working in to prevent overwriting another user's file.
- DO NOT modify any of the MATLAB routines or any other user routines. You can always copy command lines into a new script file for your specific use.

Good programming habits:

- Each script file should start with an extensive description of the program.
- Comments should be used throughout program.
- Indent sections within 'for' loops and 'if' statements.
- Hand-check your results for selected files using EXCELL.
- Use GLOBAL variables sparingly.
- Keep script files small. If you find yourself using the same sequence of commands within script files, consider writing another script file or function.

Introduction

Explore the on-line help files:
>>help help

Explore the demonstration files:
>>demo

Learn how to create variables.
>>a=10
>>b=5
>>c=a*b

Learn how to use the ‘;’ by repeating the above statements with a ‘;’ at the end of each statement.
More uses of the ‘;’:
>>d=[1,2,3;4,5,6;7,8,9]
>>e=[2,2,2;3,3,3;4,4,4]

Be careful when multiplying vectors. Try these:
>>f=d*e
>>g=e*d

Did you get the same answer? No?! That’s because MATLAB is written to perform vector mathematics for arrays – so be careful!

Create some strings:
>>A=[‘a string’]
>>B=[‘another string’]
>>C=[A B]

It is easy to combine string variables in MATLAB. Now, check out how many variables you have created:
>>whos

The ‘whos’ command is a useful command when debugging a program. Clear the screen from all the work:
>>clc

Note, if you hit ‘page-up’ the work is still there.
Let’s change what A represents, use the ‘up-arrow’ key to find the A=[‘a string’] and change the command:
>>A=[‘a different string’]

The up-arrow key can be a short cut to redo commands.
Now, lets clear all the variables that you have created and start over:
>>clear

Check to make sure you have no variables
>>whos

Also, try ‘help clear’ to see what options you have when using the ‘clear’ function.

Use MATLAB to solve the following problems:

1. What is the hypotenuse of a right triangle that has sides A=6.5 and B=8.8?
2. If a runner ran 5 miles on Monday, 6.2 on Tuesday, 4 on Wednesday, and 10 on Saturday, what was the total weekly mileage?
3. For the runner in #2, what was the average miles per day ran?
4. If a diver completed 2.5 revolutions in 1.1 seconds, what was the average angular speed?
5. Convert 5 miles per hour to m/s.
6. Convert 10 m/s to mph.

More on matrices

You can create column and row vectors using the ':'
>>a=1:10
>>b=0:20

By default, the increment between positions is '1', but you can change that:
>>d=0:0.01:1
>>e=0:0.001:1
>>f=1:2:20

Check out the size of your variables
>>whos

Note that the 'size' is listed as 'rows x columns'
You can change any position within the array
>>a(1)=0
>>a(5)=0
>>a(10)=0

Note that the notation 'a(1)' refers to a particular position in a vector whereas the notation 'a1' would be a valid variable name.

You can multiple the entire vector by any scalar (i.e., a single number)
>>c=a*2

You can also change a vector value by reassigning itself
>>a=a*10

You can make a 'row-vector' into a 'column-vector' by transposing
>>a=a'

Now, clear your workspace and create the following vectors
>>clear
>>a=1:10
>>b=11:20

Now, combine them into one vector, with 'a' in row 1, 'b' in row 2:
>>c=[a;b]

Do the same thing, but change 'a' and 'b' to column vectors and put 'a' in column 1, 'b' in column 2
>>a=a'
>>b=b'
>>c=[a b]

You can change any element in 'c' by c(row position, column position)
>>c(6,2)=0
>>c(5,1)=0

Watch what happens if you assign a position that does not currently exist:
>>c(20,2)=1

You can also access an entire column by using the ':'
>>b=c(:,1)

This means is: 'access all the rows in column 1. You can also access only part of all the rows or columns:
>>b=c(1:5,2)

You can also do some neat math using the array notation
>>c(:,3)=c(:,1)*2
Watch your math expressions. When multiplying vectors, MATLAB performs vector math. In most cases, you will be doing math element by element. That is, you may want to multiply the first element in a vector by the first element in some other vector. To do this, you use the '.*' notation.
>>a=1:5;
>>b=2:6;
>>c=a.*b

Note that the expression 'a.*b' multiplies corresponding elements in 'a' and 'b' and gives a different answer than 'a*b'.

Some times you may want to either know how long a vector is or access the entire vector without the knowledge of the length of the vector. To do this, use the 'length' function (or, alternatively 'size').
>>help length
>>d=a(2:length(a)
>>e=a(2:length(a)-1);

Explore some commonly used functions:
>>help mean
>>help sum
>>help std
>>help min
>>help max
>>help find

Try these problems.

1. Create a vector of the even whole numbers between 21 and 51.
2. Given the vector x=[5 3 2 10 7 4]
   a. add 10 to each element
   b. add 10 to only the odd elements
   c. Multiply the even elements by 2
3. Given the vectors x1=[1 2 3 4 5] and x2=[2 3 4 5 6]
   a. add the vectors, element by element (i.e., x1(1)+x2(1)…
   b. multiply each element in x1 by the corresponding element in x2
   c. divide each element in x1 by the corresponding element in x2
4. Given a vector x=[1 2 3;4 5 6; 7 8 9], write commands to
   a. Assign the first row to variable x1, 2^{nd} row to x2 and 3^{rd} row to x3
   b. Assign the last two columns to a variable called 'x4'.
   c. Compute sum of all the elements in the first column.
   d. Compute the mean value of each column.
5. Given a vector x=[1 3 2 3 1 7 3 2 1 0 3 5]
   a. Use a function to identify the maximum value within the vector
   b. Calculate the mean of the vector
   c. Find all the positions that contain the value '3'
   d. Find all the positions that are greater than '3'

Plots

Plotting data is easy using the 'plot' function.
>>help plot

You have a lot of options available to you when plotting. Let's start with some basics.
>>plot(a,b)

This is simply plot(x values, y values). Note, the x and y vectors need to be the same dimensions.
Try changing the color
>>plot(a,b,'r')
>>plot(a,b,'ro')

Add a title and axes labels
>>title('my first plot')
>>ylabel('y-axis')
>>xlabel('x-axis')

Sometimes you want to have more than one line per plot, use the 'hold on' function
>>d=b*2;
>>hold on
>>plot(a,d,'y')
>>plot(a(4),d(3),'ro')

When you have finished plotting everything on, be sure you turn off the hold.
>>hold off

Sometimes you want to create multiple plots on one graph. In that case, use the 'subplot' function
>>subplot(2,1,1)
>>plot(a,b)
>>subplot(2,1,2)
>>plot(a,d)

The subplot function reads, (number of rows of plots, number of columns of plots, plot number to work with). You can use all the same plot functions (e.g., title, ylabel,…) with the subplot function.

Now, try these problems

1. Create a straight line (y1) with a slope of 10, y-intercept of 5. Create the line over a time of 0 to 1 seconds at 1/100 of an interval.
2. Plot the above line.
3. Create a parabola ($y2=ax^2+bx+c$), with a=-10; b=5; c=0
4. Plot the parabola
5. Add the straight line and parabola lines together; y3=y1+y2 and plot y3.
6. Using the subplot function, plot y1, y2 and y3 on separate plots.
7. On the y1 plot, add a single point plot(time(20),y1(20),'ro'
8. On the y2 plot, plot the 50th point as a red circle
9. Create a variable 'total' in which column 1 is time, column 2 is y1, column 3 is y2, column 4 is y3.

Comparisons

Often it is necessary to compare two parameters.

```
>>help if
```

Start by clearing the work space and then creating two variables.

```
>>clear
>>clc
>>a=10;
>>b=10;
```

Now, compare ‘a’ and ‘b’, if they are equal, let c=1; if not, don’t do anything to ‘c’.

```
>>if a==b
c=1
end
```

Note that when working in the command window, MATLAB waits until the ‘end’ statement before evaluating the comparison and performing any commands.

IMPORTANT: Note that the comparison notation is ‘==’ while the assignment notation is ‘=’ BE CAREFUL – if you type ‘if a=b’ the value of ‘a’ is reassigned and the comparison will not work.

Change ‘b’ value and compare ‘a’ and ‘b’ for equality. If they are equal, let c=1, if not, c=0.

```
>>b=15
>>if a==b
c=1
else
c=0
end
```

You can also add in other ‘if’ statements within a comparison.

```
>>b=15
>>if b<10
c=1
elseif b<13
c=2
elseif b<20
c=3
end
```

Check out the other possible comparisons you can make

```
>>help !
```

The ones you will use are:

==	equality
>	Greater than
<	Less than
~=	Not equal

Try these problems

1. Given the vectors x1=[1 4 3 5 1 3 5 2 6 9] and x2=[1 1 1 2 9 9 5 2 1 1], explain the following expressions
   a. x1==x2
   b. x1>x2
   c. x1<x2
   d. x1~=x2
2. Given the vector x=[3 11 13 1 0 –5 –1 9 2 0], write commands that will
   a. double the values that are less than zero.
   b. Assign all values that are greater than 1 to a new variable x2
   c. Assign all values beyond the first instance where x is greater than 12 to a new variable x3
   d. Subtract the mean value from each element
3. Given a=10, b=20 write commands that make c=1 if
   a. both ‘a’ and ‘b’ are greater than 5
   b. either ‘a’ or ‘b’ are greater than 15
   c. only if a<b and b>20
   d. either a==b or a<b
4. Given the vectors x1=[1 2 3 4 5] and x2=[1 1 1 4 1 1 1], write commands that let c=1 if
   a. the length of x1<x2
   b. the sum of x1>x2
   c. the third element in x2 is less than x1
   d. the sum of the odd elements in x1 plus the sum of the even elements in x2 is greater than 15

Loops

Many times you may want to run a series of commands. To do this, you will need to use the 'for' command.

```
>>help for
```

The 'for' loop requires that you specify how many times the loop should repeat. When doing this, you create a new variable within the 'for' function. Good programming skills include using unique variables for the 'for' loop.

Create a loop that repeats 5 times. Within the loop, add 1 to a variable for each loop. Start by clearing the workspace.

```
>>clear
>>a=1;
>>for n=1:5
>>a=a+1
>>end
```

You can also place loops within loops. This can be a useful programming skill. Create two loops, let the inner loop repeat 5 times, the outer loop 2 times. Add 1 to a variable each time the inner loop repeats, reset the variable each time the outer loop repeats.

```
>>a=1;
>>for n1=1:2
>>for n2=1:5
>>a=a+1;
>>end    %this is the end the inner loop
>>a=1;
>>end    %this ends the outer loop
```

Note: the '%' indicates a comment. MATLAB does not process anything written after the '%' symbol.

You can also use the 'while' function for loops. This loop will continue to repeat while a particular statement is true.

```
>>help while
>>a=0;
>>while a<10
a=a+1
end
```

Try these problems.

1. Write commands that prints character arrays from 's1c1t1' to 's3c5t3' the screen (this will take three loops).
2. Using loops, write commands that result in the following array:

   $$\text{Total} = \begin{matrix} 1 & 2 & 3 & 6 \\ 2 & 3 & 4 & 7 \\ 3 & 4 & 5 & 8 \end{matrix}$$

   The outer loop repeats three times and controls row values. The inner loop repeats four times and controls column number.
3. Create two vectors:
   A = [1 2 3 4 5 6 7 8 9 0];
   B = [2 2 3 3 5 5 6 6 9 0];

   Using loops, compare A and B position by position and identify the position number that A and B are equal. Save the position numbers in a variable called 'equalvalue'. The final value of equalvalue should be: [2 3 5 9 10].

4. Use the ‘rand’ function to calculate the following
    a. The number of random numbers between 0 and 1 that are needed to add up to 20 (or more).
    b. The number of random numbers observed until a number between 0.2 and 0.5 is observed.
5. Use the ‘input’ function and generate a loop in which the user is asked to enter a speed in mph and the program returns the speed in m/s. The loop should continue until the user enters the value ‘0’. Use the ‘fprintf(1,’message’) to print specific messages to the user (e.g., ‘enter 0 to exit’, ‘m/s’).

Script files

There are many times when you may want to run a series of commands, to do this, you can write script files. A script file is referred to as a m-file since all MATLAB script files need to end in '.m' in order to work in MATLAB.

When creating m-files, you should do the following preliminary steps:

1. After determining the name of the m-file (e.g., mymean.m) type: 'help mymean' to see if it already exists.
2. Identify the directory that the m-file must be saved in by typing 'path' – MATLAB will look for m-files only in the specified directories.

You create the m-file by using the MATLAB editor. Open the MATLAB editor and start a new m-file. Within the m-file, you can use any series of MATLAB commands. Start the m-file with a series of comments explaining what the program does.

```
%mph2mps
%
%This program converts velocity units from mph to m/s.
%The user is asked to enter a velocity value in mph, the program returns
%velocity in m/s.  The program will continue until the user enters '0'
%
```

Save the m-file as 'mph2mps.m' in an appropriate directory (i.e., check 'path'). By including comments at the beginning of the m-file, you create on-line help.

```
>>help mph2mps
```

If you included comments at the beginning of the file, the comments are shown in the command window. This can be very helpful when you are writing m-files which call other m-files.

Continue with the script file, writing the commands necessary to convert mph to m/s as many times as the user wants.

```
%========================

%it is a good idea to clear the workspace before beginning a new program
clear
clc

%tell the user what is going on.  Note, the '\n' notation results in a carriage return.
fprintf(1,'This program will convert mph to m/s.\nEnter a speed in mph, when you are finished, enter 0.\n\n')

%initialize the value that will be manipulated
speed = 1;

%create the loop which will continue to loop until speed is 0
while speed~=0

        %use indentations wisely – it helps to follow the flow of control
        %use comment wisely – you should write a comment for every logical group of commands.

        %Ask the user to input a speed value.  Assign the input to the 'speed' variable.
        speed = input('Enter a speed in mph (0 to exit):  ');

        %convert mph to m/s
        speedms = speed*.447;

        %Tell the user what the conversion is:
        %start by converting the integer to a string in order to print a character array to the screen.
```

```
        spd1 = sprintf('\n   %4.2f', speed);
        spd2 = sprintf(' mph = %4.2f', speedms);
        spdans = [spd1, spd2, ' m/s\n'];

        %print the conversion to the screen
        fprintf(1, spdans);

end     %end of while loop – continue until 0 is entered.

%let the user know the program has finished running
fprintf(1,’\n\nDone processing mph2mps\n’)

%=====================================
```