Some Notes on Kinematics Calculations in ANZ

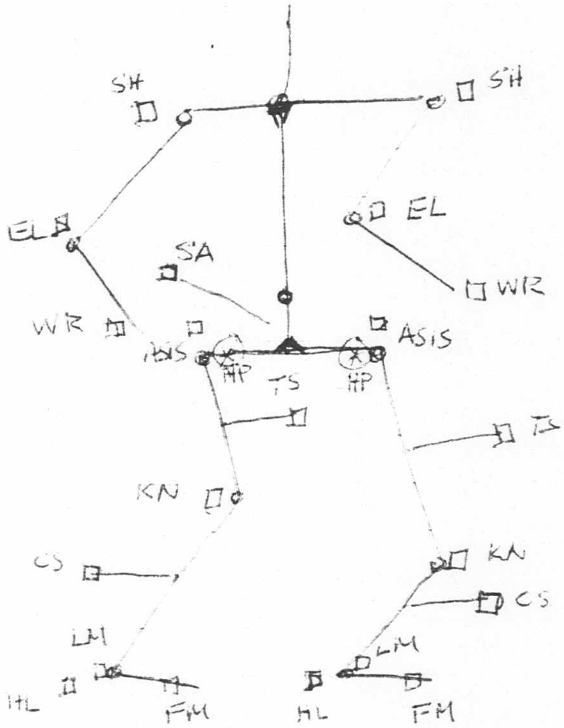
Position/Orientation calculation

The transformation from a time series of marker positions to a time series of segment positions and orientations is carried out in a simple manner in ANZ. Various combinations of three markers is used to calculate these segment kinematics. There are notes describing the vector cross product order and other operations used to do these calculations. The result of doing the transformations in this manner is that the locating of the segment local coordinate systems is very dependent upon the placement of the markers. In addition, since only three markers per segment is used, the calculations are not as accurate as they could be if redundant markers were placed on the segments. Algorithms to take advantage of such marker sets, such as the Spoor & Veldpaus or the modified Schut algorithm used by Antonsson, are not implemented in ANZ. I am working on a more general spatial kinematics package, written in C, which incorporates four different algorithms to do this calculation (so that they can be used to cross check one another). This will not be done for a while however. In the meantime, the calculations used here are adequate for clinical locomotion studies, but they should not be applied to detailed kinematic evaluations such as spatial kinematics of a joint like the knee. The methods used here are very similar to those used in Helen Hayes marker set as well as those incorporated into Motion Analysis Corporation's Orthotrak software package.

Rotational and translational velocity and acceleration

The rotational and translational velocities and accelerations are computed using spatial kinematic formulations. Translational vel/accel is a simple matter. The computation of the rotational vel/accel is another matter. Three different algorithms have been programmed to allow cross checking of the rotational vel/accel calculations. The three methods are: 1) Direct differentiation of the rotation matrix elements, 2) differentiation of the segment euler angles, 3) differentiation of the marker trajectories. The first two methods have notes about their derivation in the ANZ documentation, although both are common approaches described in kinematics texts. The marker based approach is based upon a paper by Verstraete. In all cases the differentiation of quantities is usually carried out using the GCVSPL routine of Herman Woltring although it can be overridden and finite difference used instead for comparison purposes.

OSU/Boston Marker Set



HP locations are computed from ASIS & KN markers using the method published by Tylkowski & Simon (See comments in the source code for the AdjustMarkerData routin in marker.for)

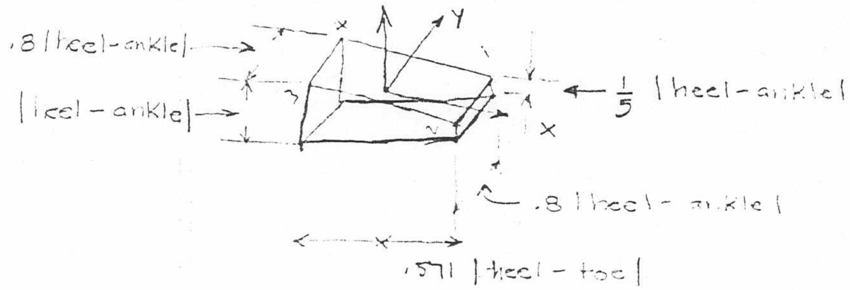
□ HL - heel
LM - lateral malleolous (adjusted)
FM - First metatarsal
CS - Calf stick
KN - Knee (lateral) (adjusted)
TS - Thigh stick
AS - ASIS
SA - Sacral
EL - elbow
SH - shoulder
WR - wrist

⊛ HP - hip (computed)

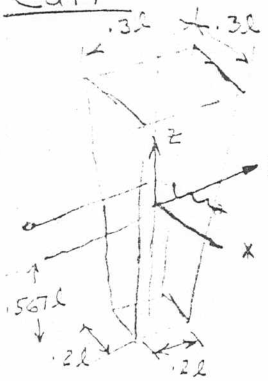
Sizing of segment parallelapipeds
- based upon my measurements
- expressed as ratio of length of long axis of segment

(These are used only for making Show3d views)

Foot



Calf

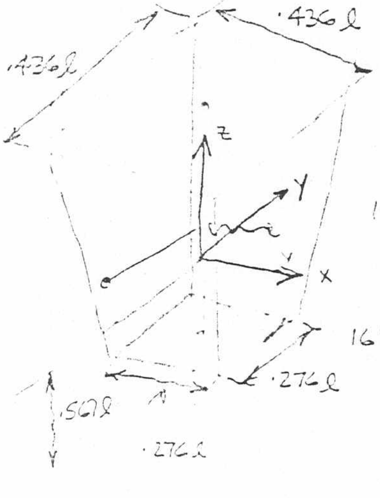


$15\frac{1}{2}" = 2\pi r_k$ $d_k = 5.252$ $K_k = .309$

17"

$11" = 2\pi r_a$ $d_a = 3.501$ $K_a = .206$

Thigh

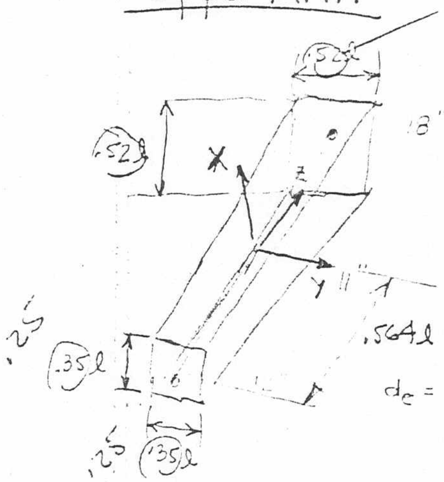


26" $d_h = 5.276$ $K_h = .436$

19"

$16\frac{1}{2}"$ $d_k = 5.252$ $K_k = .276$

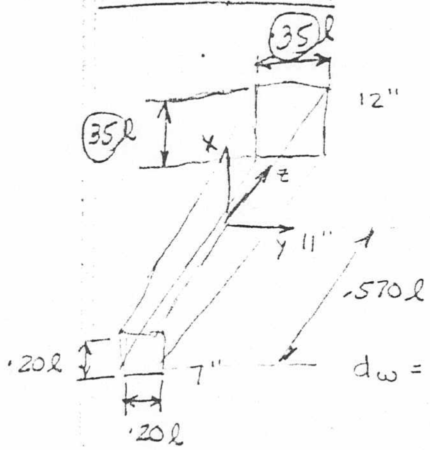
Upper Arm



18" $d_s = 5.780$ $K_s = .520$

$d_e = 3.820$ $K_e = .350$

Lower Arm

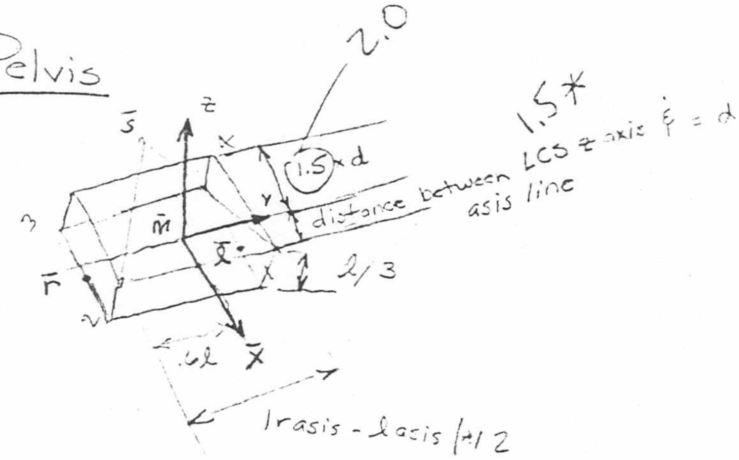


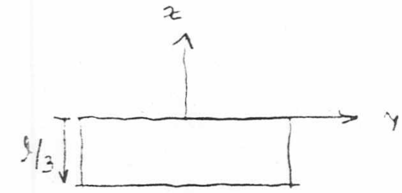
12" $d_e = 3.820$ $K_e = .350$

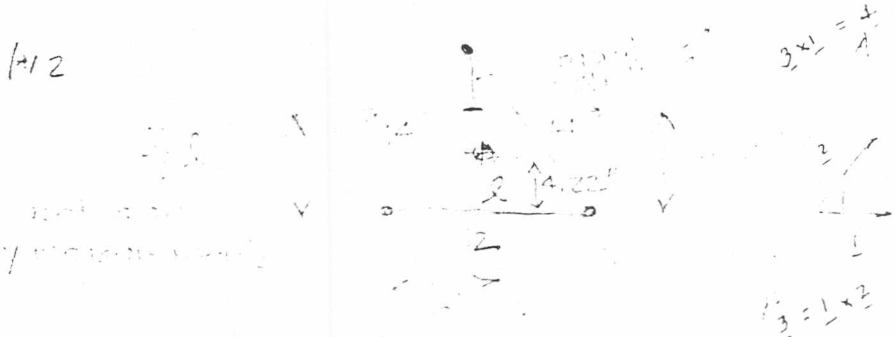
$d_w = 2.228$ $K_w = .200$

$$\bar{m} = \frac{\frac{\bar{r}+\bar{l}}{2} + (\bar{s} + L\bar{x})}{2}$$

Pelvis

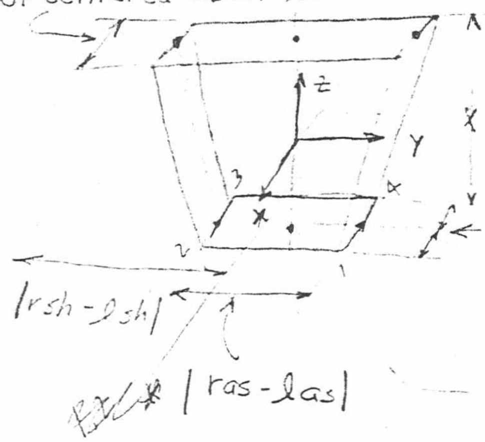






Trunk

Same width as at pelvis
but centered about lsh-rsh line



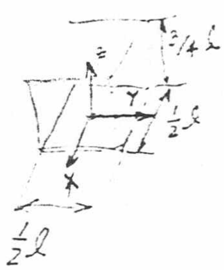
(alt. - distance between shldr line & y axis)
distance from shldr pt to LCS along z axis

(alt. - distance between asis line & y axis)
distance from asis pt to LCS along z axis

Same distances as pelvis except now relative to trunk coord system.

Locations at which line between rsh - lsh comes closest rasis - lasis (least ⊥ distance) to trunk LCS z axis

Head



$l = |rsh - lsh|$

1-24-84

Connectivity of Body in Analyze

Angle (Joint) #	Name	Seg. 1 #	Name	Seg. 2 #	Name
1	rtak	1	~~rtft~~	2	rtcf
2	rtkn	2	rtcf	3	rtth
3	rthp	3	rtth	7	pelv
4	lfak	4	lfft	5	lfcf
5	lfkn	5	lfcf	6	lfth
6	lfhp	6	lfth	7	pelv
7	pvlb	7	pelv	0	lab
8	pvtk	8	trnk	7	pelv
9	rtel	10	rtla	9	rtua
10	rtsh	9	rtua	8	trnk
11	lfel	12	Lfla	11	Lfua
12	lfsh	11	Lfua	8	trnk
13	neck	13	head	8	trnk
14	rtwr	14	rthd	10	rtla
15	lfwr	15	lfhd	12	Lfla

Angles are defined as Seg. 1 moving relative to Seg. 2

This data is in the array jnt-seg-num (

Connectivity of body for various combinations of ground contact conditions

Data specified in each case:

#of jnts
jnt load calculation order
Seg. LCS in which jnt load calc's are performed
#of jnts connected to seg whose jnt load is being calc'd
jnts #'s connected to Seg.
#ext. loads applied to Seg. — Provision for extra externally applied loads - such as a cane!
ext. load id #'s

No Ground Reaction Known, Swing phase -TOP DOWN

Rt. stance leg JNT_TD(rt)

12

neck	rtel	rtsh	lfel	lfsh	trnk/plv	lfak	lfkn	lfhp	rthp	rtkn	rtak
head	rtla	rtua	lfla	lfua	trnk	lfft	lfcf	lfth	plv	rtth	rtcf
0	0	1	0	1	3	0	1	1	2	1	1
—	—	rtel	—	lfel	neck rtsh lfsh	—	lfak	lfkn	lfhp trnk/plv	rthp	rtkn

0 ⟶

⟶

Lf stance leg JNT_TD(lf)

12

neck	rtel	rtsh	lfel	lfsh	pvtk	rtak	rtkn	rthp	lfhp	lfkn	lfak
head	rtla	rtua	lfla	lfua	trnk	rtft	rtcf	rtth	pelv	lfth	lfcf
0	0	1	0	1	3	0	1	1	2	1	1
—	—	rtel	—	lfel	neck rtsh lfsh	—	rtak	rtkn	rthp pvtk	lfhp	lfk

0 ⟶

0 ⟶

Ground Reaction Known – ~~S~~Swing Phase – BOTTOM UP

Rt. Stance Leg JNT_BU(rt)

nt	12											
-order	neck	rtel	rtsh	lfel	lfsh	prtk	lfak	lf Kn	lfhp	rtak	rtKn	rthp
seg LCS	head	rtla	rtua	lfla	lfua	trnk	lfft	lfcf	lfth	rtft	rtcf	rtth
t-seg	0	0	1	0	1	3	0	1	1	0	1	1
t#'s	—	—	rtel	—	lfel	neck rtsh lfsh	—	lfak	lfKn	—	rtak	rtKn
t load	0	0	0	0	0	0	0	0	0	1	0	0
load #	0	0	0	0	0	0	0	0	0	1	0	0

Lf. Stance Leg JNT_BU(lf)

Same as above except for ext loads

ext load	0	0	0	0	0	0	1	0	0	0	0	0
t load #	0	0	0	0	0	0	2	0	0	0	0	0

Ground Reaction Known Both feet – Double Stance

JNT_DBL(3)

Same as above except for ext loads

ext load	0	0	0	0	0	0	1	0	0	1	0	0
t load #	0	0	0	0	0	0	2	0	0	1	0	0

Ground Known for one foot - Double Stance

Rt. foot Known   JNT_DBL(rt)

#jnt	12											
nt-order	neck	rtel	rtsh	lfel	lfsh	pvtk	~~rtfk~~ rtak	rtkn	rthp	lfhp	lfkn	lfak
nt seg LCS	head	rtla	rtua	lfla	lfua	trnk	rtft	rtcf	rtth	pelv	lfth	lfcf
t-seg	0	0	1	0	1	3	0	1	1	2	1	1
nt #'s	—	—	rtel	—	lfel	neck rtsh lfsh	—	rtak	rtkn	pvtk rthp	lfhp	lfkn
xt loads	0	0	0	0	0	0	1	0	0	0	0	0
f load #	0	0	0	0	0	0	1	0	0	0	0	0

Lf foot Known   JNT_DBL(lf)

12

neck	rtel	rtsh	lfel	lfsh	pvtk	lfak	lfkn	lfhp	rthp	rtkn	rtak
head	rtla	rtua	lfla	lfua	trnk	lfft	lfcf	lfth	pelv	rtth	rtcf
0	0	1	0	1	3	0	1	1	2	1	1
—	—	rtel	—	lfel	neck rtsh lfsh	—	lfak	lfkn	lfhp pelv	rthp	rtkn
0	0	0	0	0	0	1	0	0	0	0	0
0	0	0	0	0	0	2	0	0	0	0	0

Ground Reaction Unknown - Double Stance

JNT_DBL(4)

6

neck	rtel	rtsh	lfel	lfsh	pvtk
head	rtla	rtua	lfla	lfua	trnk
0	0	1	0	1	3
—	—	rtel	—	lfel	neck rtsh lfsh

0 →

0 →

NOTE: JNT_DBL (5) & (6) Added 11/21/89

rt. only but don't eval. lf leg

lf. only but don't eval. rt leg

Floating Axis Euler Angles (JCS)

Order $\theta - \phi - \psi$ ← flexion - abduction - internal

$$R = R_Y(\theta)\, R_X(\phi)\, R_Z(\psi)$$

Same conventional as Grood & Suntay, Chao, etc...

$y' = -x s\theta, y c\theta$

$x' = x c\theta, y s\theta$

$\begin{Bmatrix} x' \\ y' \end{Bmatrix} =$

$$= \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\phi & -s\phi \\ 0 & s\phi & c\phi \end{bmatrix} \begin{bmatrix} c\psi & -s\psi & 0 \\ s\psi & c\psi & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$= \begin{bmatrix} c\theta & 0 & s\theta \\ 0 & 1 & 0 \\ -s\theta & 0 & c\theta \end{bmatrix} \begin{bmatrix} c\psi & -s\psi & 0 \\ c\phi s\psi & c\phi s\psi & -s\phi \\ s\phi s\psi & s\phi c\psi & c\phi \end{bmatrix}$$

$$= \begin{bmatrix} c\theta c\psi + s\theta s\phi s\psi & -c\theta s\psi + s\theta s\phi c\psi & s\theta c\phi \\ c\phi s\psi & c\phi c\psi & -s\phi \\ -s\theta c\psi + c\theta s\phi s\psi & s\theta s\psi + c\theta s\phi c\psi & c\theta c\phi \end{bmatrix}$$

$$c\phi = \sqrt{r_{21}^2 + r_{22}^2}$$

$$\theta = \mathrm{ATAN2}(r_{13}/c\phi,\ r_{33}/c\phi)$$

$$\psi = \mathrm{ATAN2}(r_{21}/c\phi,\ r_{22}/c\phi)$$

$$\phi = \mathrm{ATAN2}(-r_{23},\ c\phi)$$

if $c\phi = 0$ (or error)

if $r_{23} < 0$

$\phi = 90°$ $\psi = 0°$ $\theta = \mathrm{ATAN2}(r_{12}, r_{11})$

$$\begin{bmatrix} c\theta & s\theta & 0 \\ 0 & 0 & -1 \\ -s\theta & c\theta & 0 \end{bmatrix}$$

else if $r_{23} > 0$

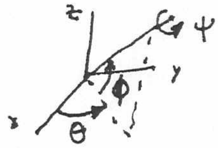
$\phi = -90°$ $\psi = 0°$ $\theta = \mathrm{ATAN2}(-r_{12}, r_{11})$

$$\begin{bmatrix} c\theta & -s\theta & 0 \\ 0 & 0 & 1 \\ -s\theta & -c\theta & \end{bmatrix}$$

Used with (Shoulder) in upper body marker set..

Polar (Z Y Z) Euler Angles

Azimuth - Inclination - Twist



$$R = R_z(\theta)\, R_y(\phi)\, R_z(\psi)$$

$$= \begin{bmatrix} c\theta c\phi c\psi - s\theta s\psi & -c\theta c\phi s\psi - s\theta c\psi & c\theta s\phi \\ s\theta c\phi c\psi + c\theta s\psi & -s\theta c\phi s\psi + c\theta c\psi & s\theta s\phi \\ -s\phi c\psi & s\phi s\psi & c\phi \end{bmatrix}$$

$$s\phi = \sqrt{r_{13}^2 + r_{23}^2}$$

$$\theta = \mathrm{ATAN2}\left(r_{23}/s\phi,\ r_{13}/s\phi\right)$$

$$\psi = \mathrm{ATAN2}\left(r_{32}/s\phi,\ -r_{31}/s\phi\right)$$

$$\phi = \mathrm{ATAN2}\left(s\phi,\ r_{33}\right)$$

if $s\phi = 0 \longrightarrow$ (or error)

if $r_{33} > 0$ then

$$\begin{bmatrix} c\theta & -s\theta & 0 \\ s\theta & c\theta & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$\phi = 0°$

$\psi = 0°$

$\theta = \mathrm{ATAN2}(-r_{12}, r_{11})$

else if $r_{33} < 0$ then

$$\begin{bmatrix} -c\theta & -s\theta & 0 \\ -s\theta & c\theta & 0 \\ 0 & 0 & -1 \end{bmatrix}$$

$\phi = 180°$

$\psi = 0°$

$\theta = \mathrm{ATAN2}(-r_{12}, r_{11})$

...

Fixed Euler Angles - Roll, Pitch, Yaw

order $\gamma - \beta - \alpha$

Old method used to compute joint angles at Boston Children's Gait Lab - not used normally in ANZ. Included for compatibility only!

$$R = R_Z(\alpha)\, R_X(\beta)\, R_Y(\gamma)$$

$$= \begin{bmatrix} c\alpha & -s\alpha & 0 \\ s\alpha & c\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & 0 & 0 \\ 0 & c\beta & -s\beta \\ 0 & s\beta & c\beta \end{bmatrix} \begin{bmatrix} c\gamma & 0 & s\gamma \\ 0 & 1 & 0 \\ -s\gamma & 0 & c\gamma \end{bmatrix}$$

$$= \begin{bmatrix} c\alpha & -s\alpha & 0 \\ s\alpha & c\alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} c\gamma & 0 & s\gamma \\ s\beta s\gamma & c\beta & -s\beta c\gamma \\ -c\beta s\gamma & s\beta & c\beta c\gamma \end{bmatrix}$$

$$= \begin{bmatrix} c\alpha c\gamma - s\alpha s\beta s\gamma & -s\alpha c\beta & c\alpha s\gamma + s\alpha s\beta c\gamma \\ s\alpha c\gamma + c\alpha s\beta s\gamma & c\alpha c\beta & s\alpha s\gamma - c\alpha s\beta c\gamma \\ -c\beta s\gamma & s\beta & c\beta c\gamma \end{bmatrix}$$

$$c\beta = \sqrt{r_{12}^2 + r_{22}}$$

$$\alpha = \mathrm{ATAN2}(-r_{12}/c\beta,\ r_{22}/c\beta)$$

$$\beta = \mathrm{ATAN2}(r_{32},\ c\beta)$$

$$\gamma = \mathrm{ATAN2}(-r_{31}/c\beta,\ r_{33}/c\beta)$$

if $c\beta = 0$ or (error)

if $r_{32} > 0$

$\beta = 90°$

$\alpha = 0°$

$$\begin{bmatrix} c\gamma & 0 & s\gamma \\ s\gamma & 0 & -c\gamma \\ 0 & 1 & 0 \end{bmatrix}$$

$\gamma = \mathrm{ATAN2}(r_{13}, r_{11})$

else if $r_{32} < 0$

$\beta = -90°$

$$\begin{bmatrix} c\gamma & 0 & s\gamma \\ -s\gamma & 0 & c\gamma \\ 0 & -1 & 0 \end{bmatrix}$$

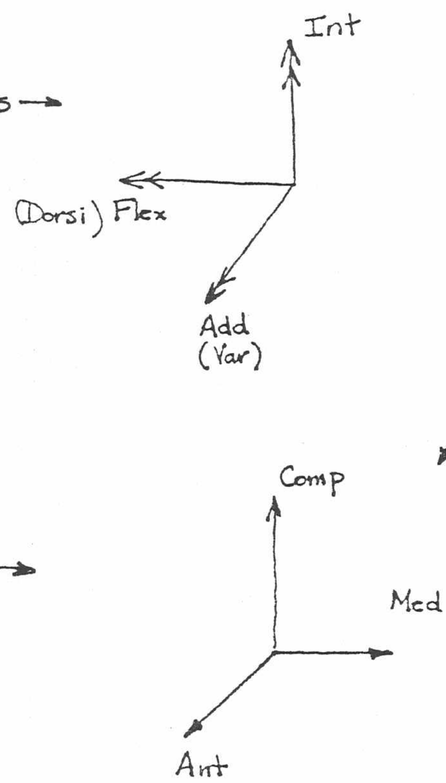
$\alpha = 0°$ $\gamma = \mathrm{ATAN2}(r_{..}, r_{..})$

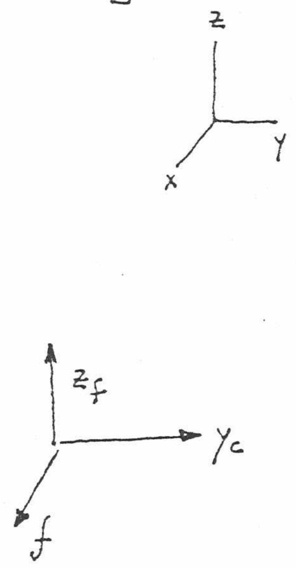
JCS Axis Definitions for all joints
(Arrow shown is positive direction)
Primarily to compute Joint Loads along JCS axes

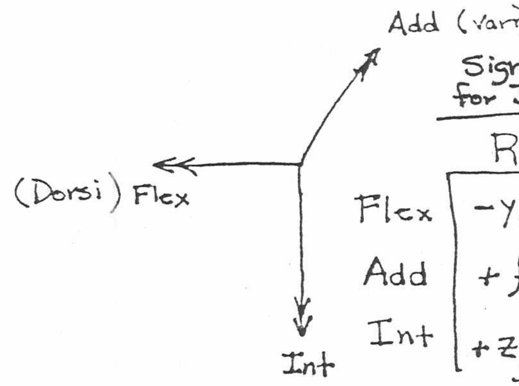
Right — Left

Ankle

Moments →



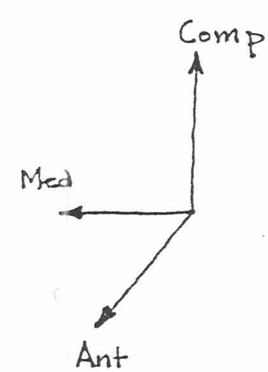




Sign correction for Joint Loads

	Rt	Lf
Flex	$-y_c$	$-y_c$
Add	$+f$	$-f$
Int	$+z_f$	$-z_f$

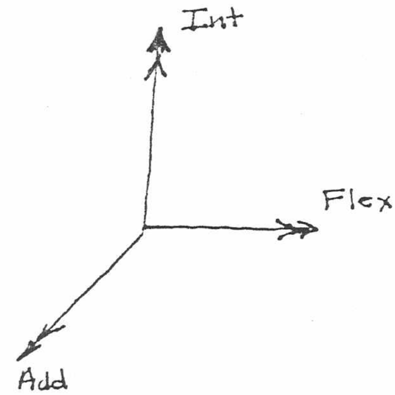
Forces →

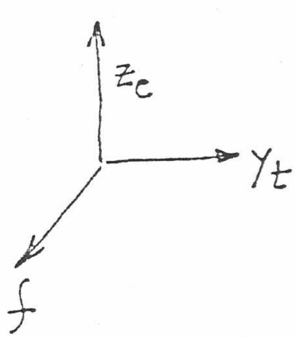


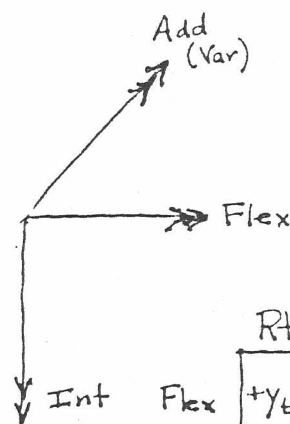
	Rt	Lf
Med	$+y_c$	$-y_c$
Ant	$+f$	$+f$
Comp	$+z_f$	$+z_f$

Knee

Moments →

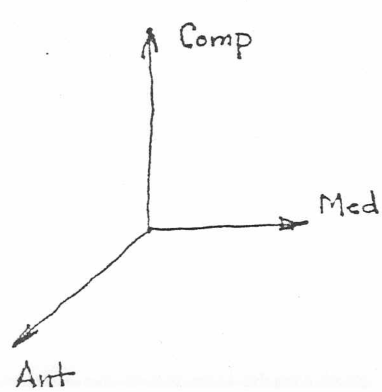


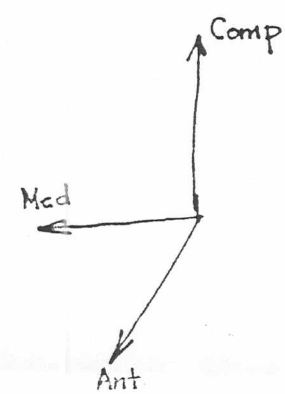




	Rt	Lf
Flex	$+y_t$	$+y_t$
Add	$+f$	$-f$
Int	$+z_c$	$-z_c$

Forces →



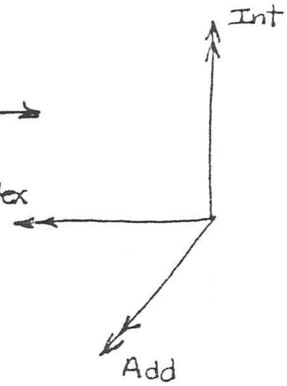


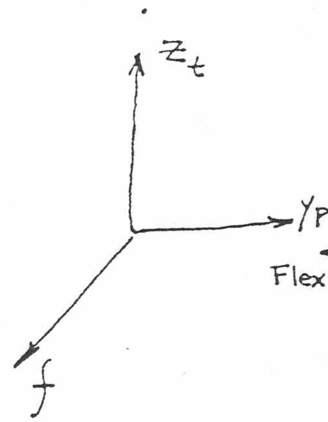
	Rt	Lf
Med	$+y_t$	$-y_t$
Ant	$+f$	$+f$
Comp	$+z$ [illegible]	$+z$ [illegible]

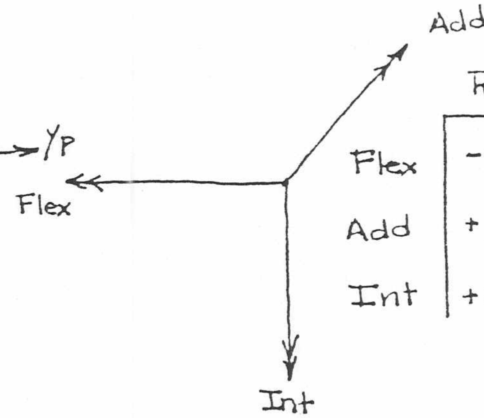
Right — Left

ip

Moments →

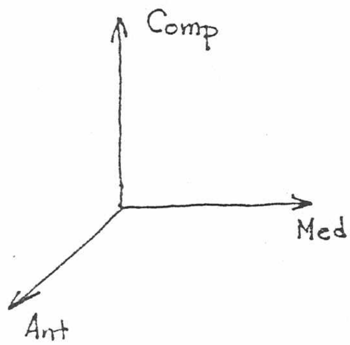


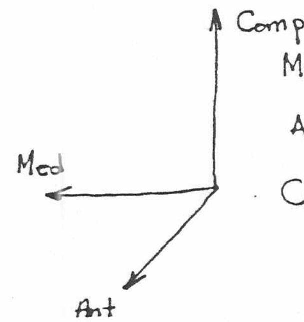




	Rt	Lf
Flex	$-Y_P$	$-Y_P$
Add	$+f$	$-f$
Int	$+Z_t$	$-Z_t$

Forces →

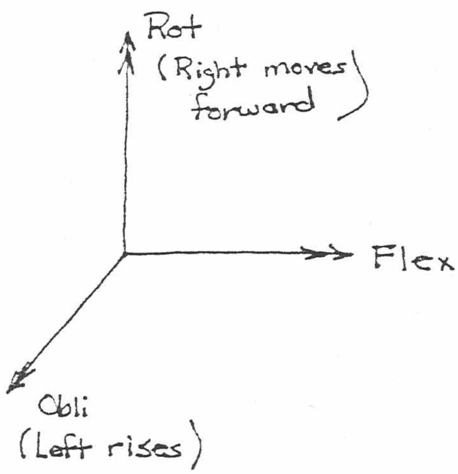




	Rt	Lf
Med	$+Y_P$	$-Y_P$
Ant	$+f$	$+f$
Comp	$+Z_t$	$+Z_t$

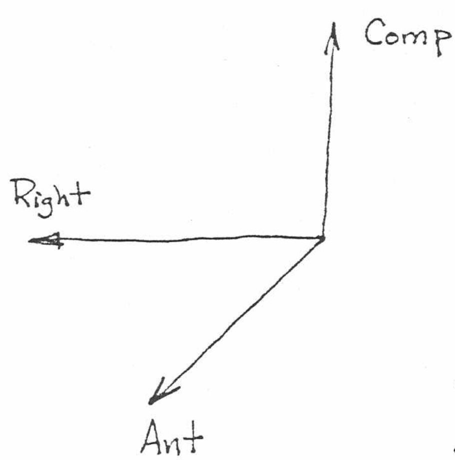
vis/Lab

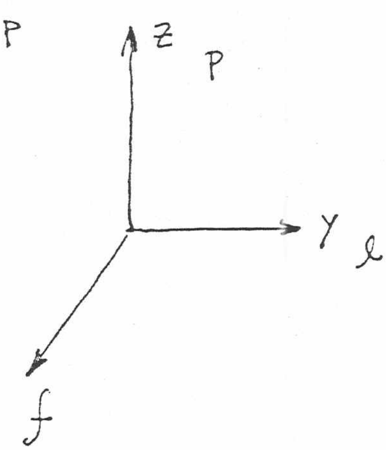
Moments →



Flex	$+Y_\ell$
Obli	$+f$
Rot	$+Z_P$

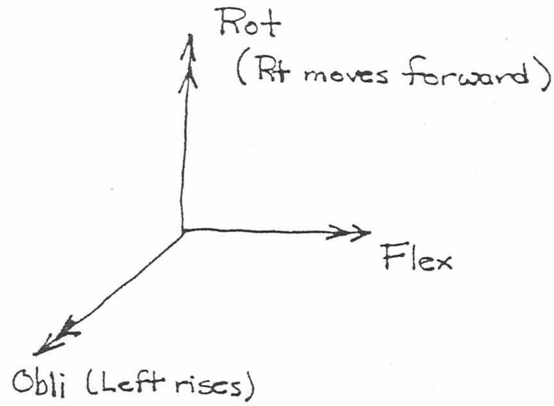
Forces →



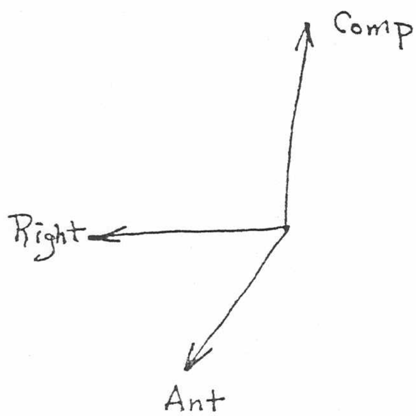


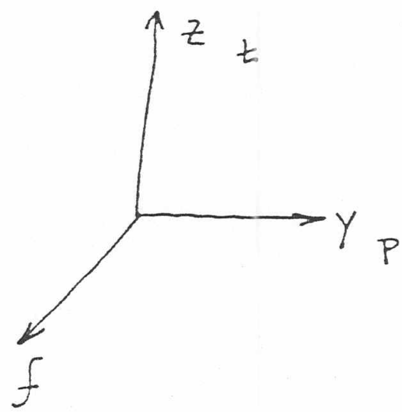
Right/Left	$-Y_\ell$
Ant	$+f$
Comp	$+Z_P$

nK/Pelvis



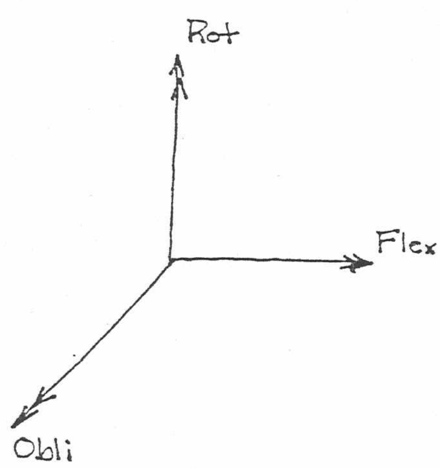
Flex	$+Y_p$
Obli	$+f$
Rot	$+Z_t$





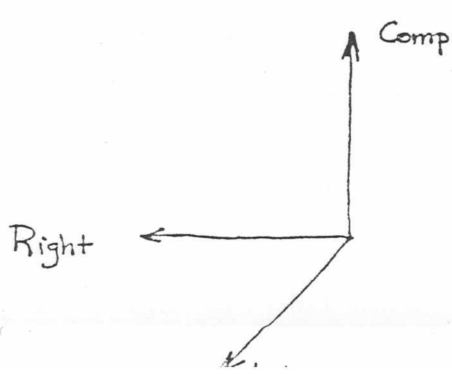
Right	$-Y_p$
Ant	$+f$
Comp	$+Z_t$

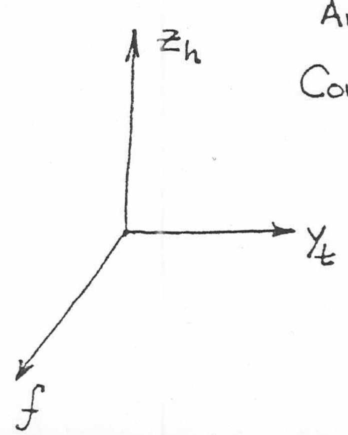
Neck



Flex	$+Y_t$
Obli	$+f$
Rot	$+Z_h$

Right	$-Y_t$
Ant	$+f$
Comp	$+Z_h$

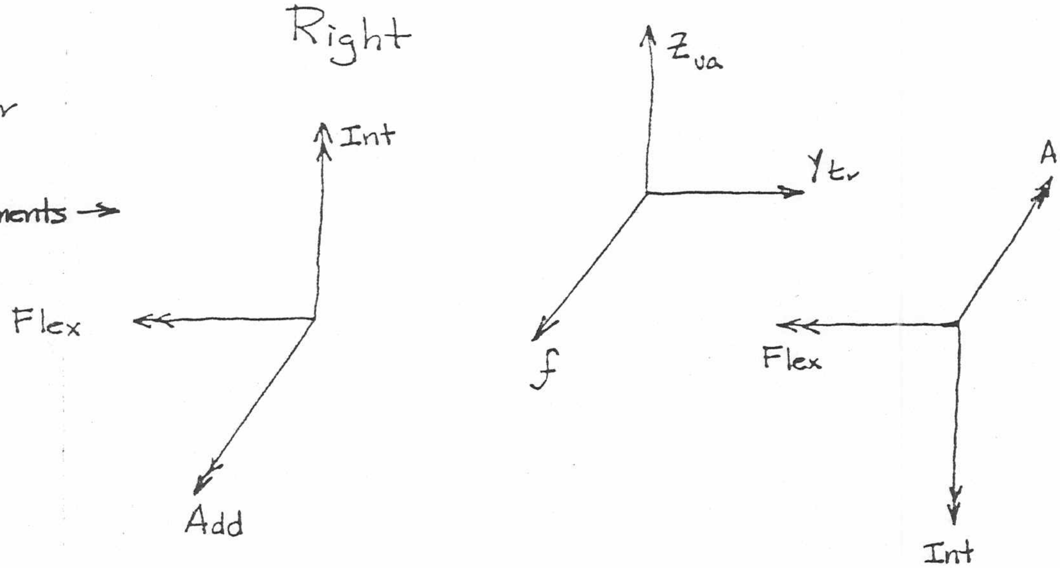




Right | Left

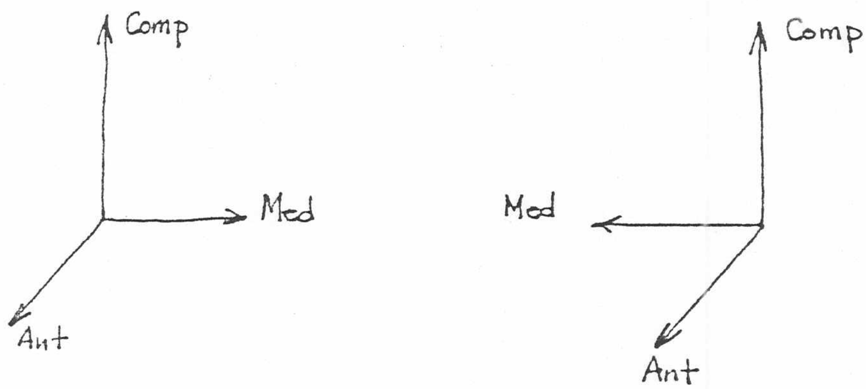
ulder

Moments →



	Rt	Lf
Flex	$-Y_{tr}$	$-Y_{tr}$
Add	$+f$	$-f$
Int	$+Z_{ua}$	$-Z_{ua}$

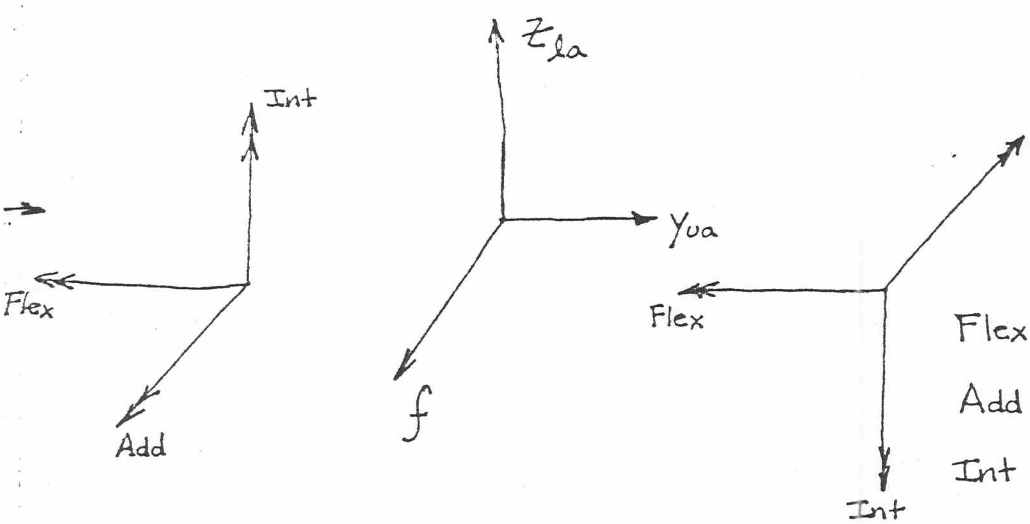
Forces →



	Rt	Lf
Med	$+Y_{tr}$	$-Y_{tr}$
Ant	$+f$	$+f$
Comp	$+Z_{ua}$	$+Z_{ua}$

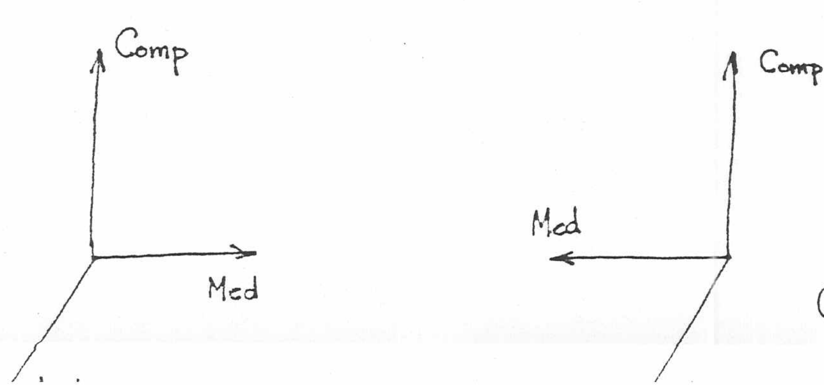
ow

Moments →



	Rt	Lf
Flex	$-Y_{ua}$	$-Y_{ua}$
Add	$+f$	$+f$
Int	$+Z_{la}$	$-Z_{la}$

Forces →



	Rt	Lf
Med	$+Y_{ua}$	$-Y_{ua}$
Ant	$+f$	$+f$
Comp	$+Z_{la}$	$+Z_{la}$

Reconstruction of Ground Reaction Load

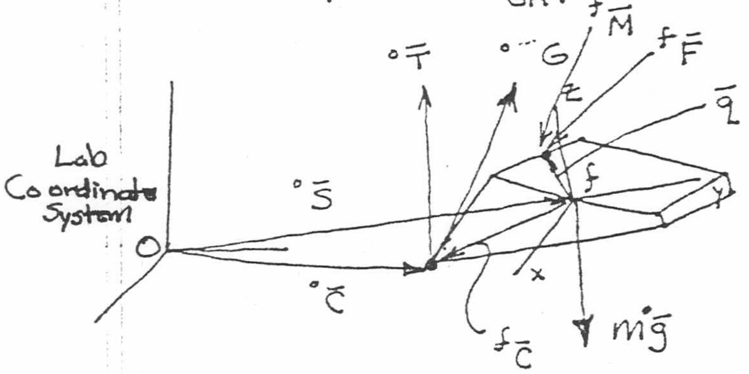
[To be used as a check when a leg's joint loads in double support are computed from top down because foot is not on a force plate & opposite foot is on a plate or in the case of single support but no force data]

Known: Ankle Resultant load & its position relative foot LCS

Foot, mass, inertia, velocity, acceleration
expressed in foot's CS

Find: $^{o}\bar{G} = {}^{o}\begin{Bmatrix} G_x \\ G_y \\ G_z \end{Bmatrix}$; $^{o}\bar{T} = {}^{o}\begin{Bmatrix} 0 \\ 0 \\ T_z \end{Bmatrix}$, $^{o}\bar{c} = {}^{o}\begin{Bmatrix} C_x \\ C_y \\ C_z \end{Bmatrix}$ all expressed in Global CS

GRF GRT Contact Point



$^{f}\bar{G} = {}^{o}_{f}R^{T}\,{}^{o}\bar{G}$

$^{f}\bar{T} = {}^{o}_{f}R^{T}\,{}^{o}\bar{T}$

$^{f}\bar{g} = {}^{o}_{f}R^{T}\,{}^{o}\bar{g}$

Force Equilibrium

$$m\,{}^{f}\bar{g} + {}^{f}\bar{G} + {}^{f}\bar{F} = m\begin{Bmatrix} a_x + V_z\omega_y - V_y\omega_z \\ a_y + V_x\omega_z - V_z\omega_x \\ a_z + V_y\omega_x - V_x\omega_y \end{Bmatrix} = \begin{Bmatrix} A_x \\ A_y \\ A_z \end{Bmatrix}$$

$$^{f}\bar{G} = {}^{o}_{f}R^{T}\,{}^{o}\bar{G} = \bar{A} - {}^{f}\bar{F} - m\,{}^{f}\bar{g}$$

$$\boxed{{}^{o}\bar{G} = {}^{o}_{f}R\,{}^{f}\bar{G}}$$

Moment Equilibrium (about f)

$$\underset{\uparrow}{{}^{f}\bar{T}} + \underset{\uparrow}{{}^{f}\bar{c}} \times {}^{f}\bar{G} + {}^{f}\bar{M} + {}^{f}\bar{q} \times {}^{f}\bar{F} = \begin{Bmatrix} I_x\alpha_x + (I_z - I_y)\omega_y\omega_z \\ I_y\alpha_y + (I_x - I_z)\omega_x\omega_z \\ I_z\alpha_z + (I_y - I_x)\omega_x\omega_y \end{Bmatrix} = \begin{Bmatrix} B_x \\ B_y \\ B_z \end{Bmatrix}$$

Find these ...

Note that $^{o}c_z = \phi$ since foot must touch floor

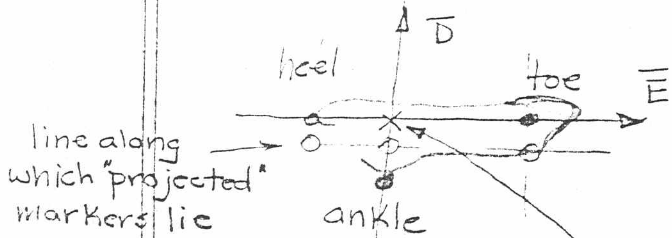
$$^{o}_{f}R^{T}\left({}^{o}\bar{T} + {}^{o}\bar{c} \times {}^{o}\bar{G}\right) + {}^{f}\bar{M} + {}^{f}\bar{q} \times {}^{f}\bar{F} = \bar{B}$$

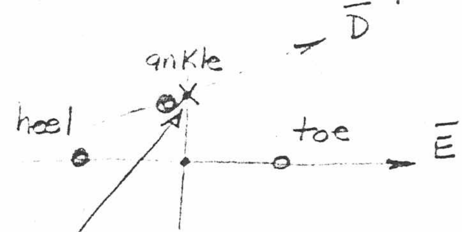
$$^{o}\bar{T} + {}^{o}\bar{c} \times {}^{o}\bar{G} = {}^{o}_{f}R\left(\bar{B} - {}^{f}\bar{M} + {}^{f}\bar{q} \times {}^{f}\bar{F}\right) = \bar{D}$$

$$\begin{Bmatrix} 0 \\ 0 \\ {}^{\circ}T_z \end{Bmatrix} + \begin{vmatrix} {}^{\circ}C_x & {}^{\circ}C_y & 0 \\ g_x & g_y & g_z \end{vmatrix} = \begin{Bmatrix} D_x \\ D_y \\ D_z \end{Bmatrix}$$

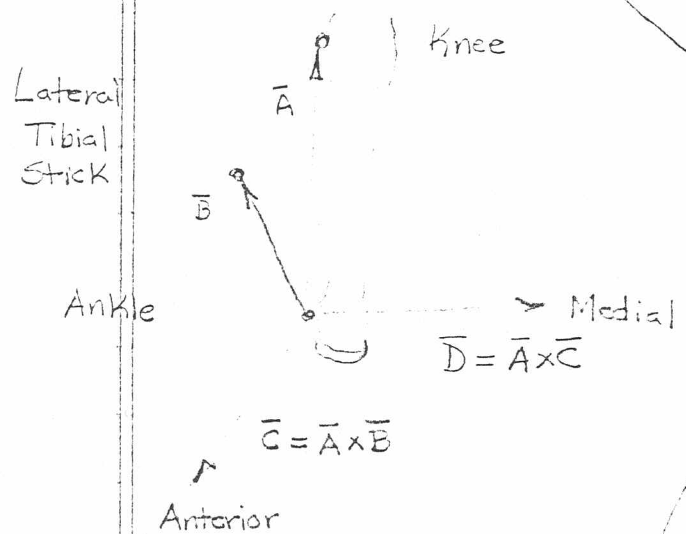
$$\begin{array}{rl} {}^{\circ}C_y\, g_z = D_x \Rightarrow & \\ -{}^{\circ}C_x\, g_z = D_y \Rightarrow & \\ {}^{\circ}T_z + {}^{\circ}C_x g_y - {}^{\circ}C_y g_x = D_z \Rightarrow & \end{array} \boxed{\begin{aligned} {}^{\circ}C_y &= D_x / g_z \\ {}^{\circ}C_x &= -D_y / g_z \\ {}^{\circ}T_z &= D_z + \frac{D_y}{g_z} g_y + \frac{D_x}{g_z} g_x \end{aligned}}$$

Correction of toe, ankle & heel marker position





Using the standard Boston/OSU bilateral marker set



Compute crossing point $\overset{\times}{\vee}$ on $\bar{D}$ of line having the minimum distance between $\bar{D}$ & $\bar{E}$.

Place ankle marker along $\bar{D}$, midway between original ankle marker & point x. Place heel & toe markers 1/2 that distance laterally along the direction defined by $\bar{D}$.

Not actually used, instead

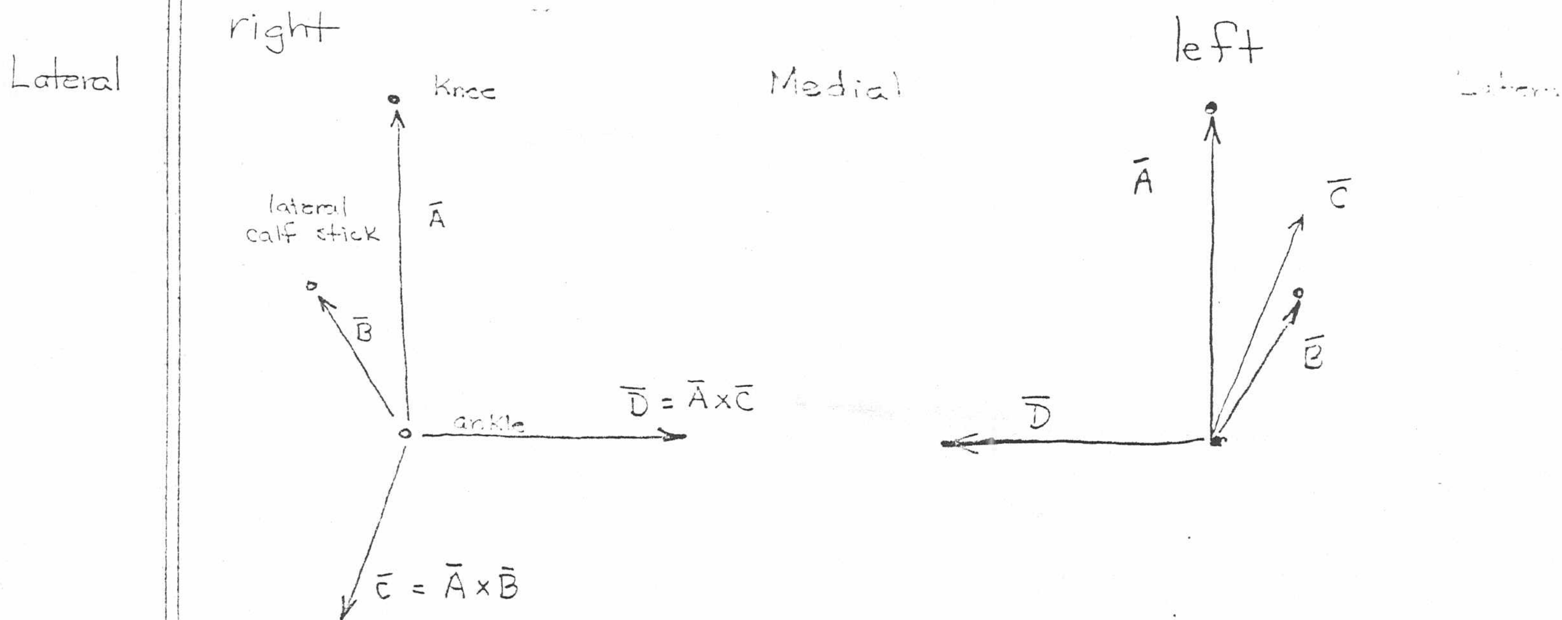
Place ankle marker along $\bar{D}$ at X & leave toe & heel in the same positions.

(See Source Code in AdjustMarkerDat routine in Marker.for)

Correction is used to make markers at knee & ankle more "centered" in the joint.

Ankle &

Knee marker position correction



Based upon my calf dimensions (Dwight)

$$\text{Knee ratio} = \frac{5.25}{42.0}$$

$$\text{Ankle ratio} = \frac{3.5}{42.0}$$

$$\text{Projection distance vector} = \text{ratio} * \frac{\bar{D}}{\|\bar{D}\|}$$

Marker #'s to Segment Correspondence

Rft (1)	rt. toe (9)	rt. akl (8)	rt. heel (20)		

lengths: 3
toe-heel
toe-ankle
ankle-heel

Rcf (2)	rt. akl (8)	rt. tib. stk (24)	rt. Knee (7)		

lengths: 3
ankle-Knee
ankle-tib. stk
Knee-tib. stk

Rth (3)	rt. Knee (7)	rt. th. stk (22)	rt. hip (4)		

lengths: 3
Knee-hip
Knee-th. stk
hip-th. stk

Lft (4)	lf. toe (12)	lf. akl (11)	lf. heel (21)		
Lcf (5)	lf. akl (11)	lf. tib. stk (25)	lf. Knee (10)		
Lth (6)	lf. Knee (10)	lf. th. stk (23)	lf. hip (5)		
Pelvis (7)	rt. asis (1)	sacral stk (2)	lf asis (3)	r hip (4)	l hip (5)

lengths: 3
rt asis - sac. stk
rt. asis - lf. asis
lf. asis - sac. stk

Trunk (8)	rt. asis (1)	lf. asis (3)	rt. sh (14)	lf. sh (17)

lengths: 6
rt asis – lf. asis
rt. asis – rt. sh
rt. asis – lf. sh
lf. asis – lf. sh
lf. asis – rt. sh
rt. sh – lf. sh

R. ua (9)	rt. sh. (14)	rt. el (15)

length 1 rt. sh. – rt. el.

R. la (10)	rt. el. (15)	rt. wr. (16)

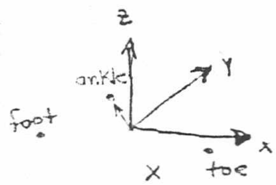
length 1 rt. el. – rt. wr.

L. ua (11)	lf. sh (17)	lf. el (18)
L. la (12)	lf. el (18)	lf. wr (19)

Head ———

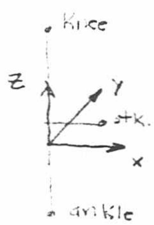
Location of segment ends relative to segment LCS

Foot



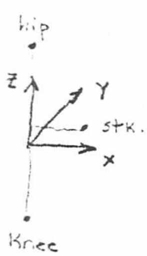
- force plate position contained in individual foot center of pressu data previously calculated in GCS.
- use LCS transform to get force load position in term of LCS
- " " " " " ankle point in terms of LCS
  - This position is fixed for all frames - use still data
- This position changes from frame to frame

Calf



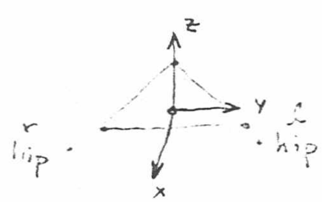
- use LCS transform to get ankle & knee position in terms of LCS
  - average LCS trans. from still data
  - " knee, anke markers " " "

Thigh



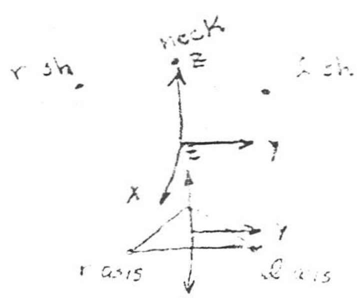
- use LCS transform to get knee & hip position in terms of LCS

Pelvis



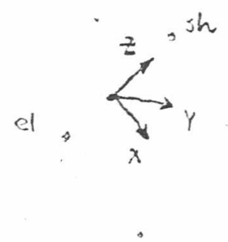
- use LCS transform to get both hips in terms of LCS
- mid section resultant located at LCS center.

Trunk



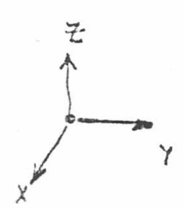
- use LCS transform on r sh, l sh, neck & center of pelvis LCS

Up arm — locate elbow, shoulder in LCS using LCS transform



Lower Arm — locate elbow, wrist in LCS using LCS transform.

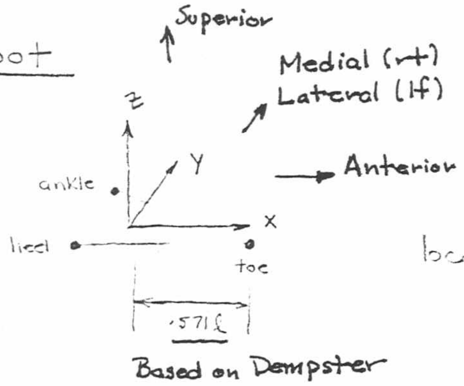
Head — located at LCS center



Location of Segment Coord Systems

Directions marked are for standing position to provide some reference

Foot



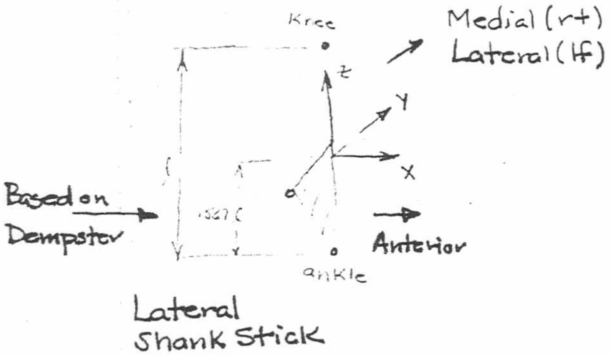
x ll to line from heel to toe

y ⊥ to plane formed by heel, ankle & toe

z mutually ⊥ to x & y

located at geometric center Δ

Calf

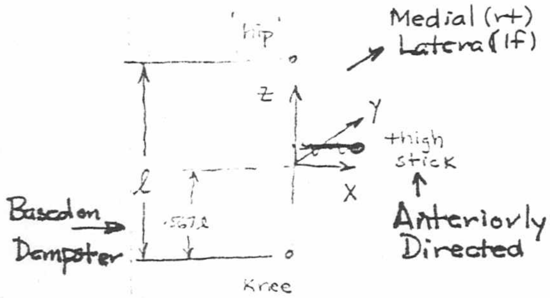


z from ankle to knee

X ⊥ z & ankle-shank-knee plane

Y mutually ⊥ to x & z

Thigh

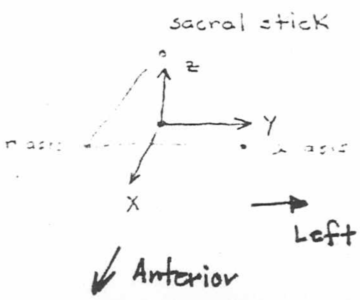


z from knee to hip

y ⊥ z & knee-thigh-hip plane

x mutually ⊥ to y & z

Pelvis



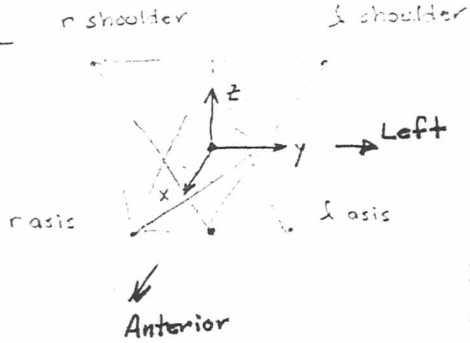
located at the geometric center Δ formed by r asis, sacral stick, & l asis

y from r asis to l asis

z ⊥ to plane of Δ

x mutually ⊥ to y & z

Trunk



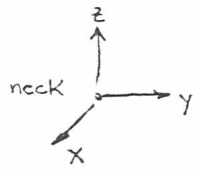
located at the average of the geometric centers of Δ's formed by r,l shoulder & average of r,l asis & r,l asis & average of r,l shoulder

y ∥ to line from r to l shoulder

x ⊥ plane of r,l shoulder & average of r,l asis

z: mutually ⊥ to x & y

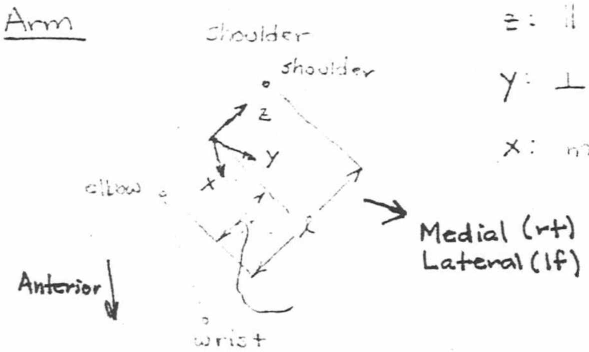
Head



located at neck marker

∥ to lab coord system

Upper Arm

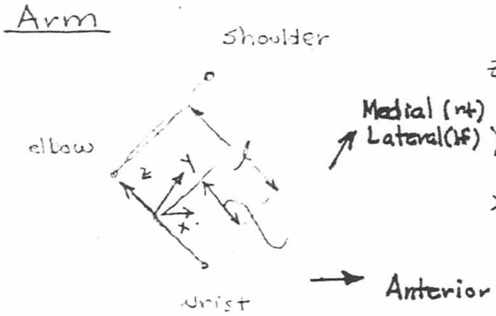


z: ∥ to line from elbow to shoulder

y: ⊥ to plane of shoulder, elbow, wrist

x: mutually ⊥ to x & z

Lower Arm



z. ∥ to line from wrist to elbow

y: ⊥ to plane of shoulder, elbow, wrist

x: mutually ⊥ to x & z

Numerical Integration of experimental Data

For numerical integration of experimentally acquired data, there are two different types required.

1) Moving integration window of selectable width
   - Used with EMG processing
   - Use extended trapezoidal rule (Num. Recipes, p. 107, 111)

$$\int_{t-\tau/2}^{t+\tau/2} f(x)\,dx = h\left[\frac{1}{2} f_{i-\frac{N}{2}} + f_{i+1-\frac{N}{2}} + f_{i+2-\frac{N}{2}} + \dots + f_{i-1+\frac{N}{2}} + \frac{1}{2} f_{i+\frac{N}{2}}\right]$$

where t = center point or time at which integration takes place.

Sample i corresponds to t.

h is the sample interval (sec)

N is the number of samples in the window

τ is the window width (sec)

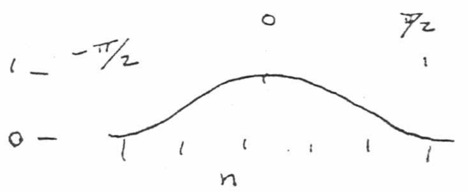
$$N = \mathrm{Int}\left(\frac{\tau}{h}\right)$$

1st pt   last pt

$$f_i' = \sum_{j=i-\frac{N}{2}+1}^{i+\frac{N}{2}-1} f_j + \frac{1}{2}\left(f_{i-\frac{N}{2}} + f_{i+\frac{N}{2}}\right)$$

for any i where $i+1-\frac{N}{2} < j < i$ is less than 1, set $f_i' = 0$

for any i where $i < j < i-1+\frac{N}{2}$ is greater than N, set $f_i' = 0$



$$\cos\left(-\frac{\pi}{2} + \pi\,\frac{i-1}{n-1}\right)$$

2) Standard Summation integration which continually adds the previous intervals

$f_1' = \quad 0$

$f_2' = \frac{h}{2}[f_1 + f_2]$

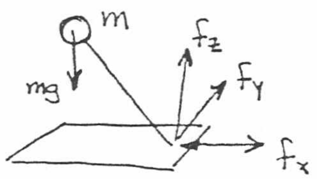
$f_3' = h\left[\frac{1}{2}f_1 + f_2 + \frac{1}{2}f_3\right]$

$f_4' = h[\frac{1}{2}f_1 + f_2 + f_3 + \frac{1}{2}f_4]$

$\Rightarrow \quad f_i' = f_{i-1}' + \frac{h}{2}[f_{i-1} + f_i]$ Nice & Simple...

Determination of Center of Mass of Body based upon force plate data...

Assume body is a single lumped mass attached to a massless stick striking the force plate



Since the force plate reference frame is stationary (as opposed for instance to the foot LCS which is used for calculating the ankle loads), Then,

$$+m\bar{g} + \bar{F} = m\bar{a}$$

Note that $\bar{F}$ is the force of the plate upon the body whereas usually the body on the plate is what is measured.

$$\begin{Bmatrix} f_x \\ f_y \\ f_z \end{Bmatrix} = m \begin{Bmatrix} a_x \\ a_y \\ a_z - g \end{Bmatrix}, \quad \bar{F}(t) \ \& \ \bar{a}(t)$$

$$\bar{a} = \ddot{\bar{p}} = \frac{\bar{F}}{m} + \bar{g}$$

$$\ddot{x} = \frac{1}{m} f_x$$

$$\dot{x} = \frac{1}{m} \int f_x \, dt + V_{x_0}$$

$$x = \frac{1}{m} \int_0^T \left(\int_0^T f_x \, dt \right) dt + V_{x_0} T + x_0$$

Ant/Post position of force

$$\ddot{y} = \frac{1}{m} f_y$$

$$\dot{y} = \frac{1}{m} \int_0^T f_y \, dt + V_{y_0}$$

$$y = \frac{1}{m} \int_0^T \left(\int_0^T f_y \, dt \right) dt + V_{y_0} T + y_0$$

med/lat position of force

$$\ddot{z} = \frac{1}{m}(f_z - g)$$
$$\dot{z} = \frac{1}{m}\int_0^T f_z\,dt - \frac{gT}{m} + V_{z_0}$$
$$z = \frac{1}{m}\int_0^T\left(\int_0^T f_z\,dt\right)dt - \frac{1}{2}\frac{gT^2}{m} + V_{z_0}T + z_0$$

Now if x_0, y_0, z_0 & $V_{x_0}, V_{y_0}, V_{z_0}$ are not Known at $t=0$ but rather, at $t = t_1$, then ?....

$$x = \frac{1}{m}\int_0^T\left(\int_0^T f_x\,dt\right)dt + V_{x_0}(T-t_1) + x_0$$
$$y = \frac{1}{m}\int_0^T\left(\int_0^T f_y\,dt\right)dt + V_{y_0}(T-t_1) + y_0$$

where $x = x(T)$, $T = 0, h, 2h, \ldots$

h = time increment

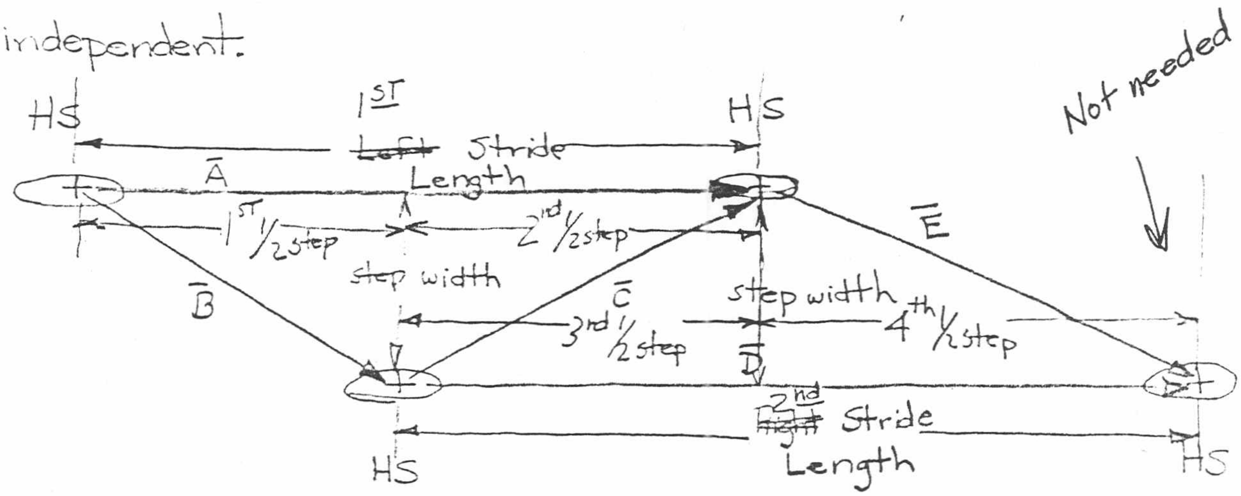
$$\dot{z} = \frac{1}{m}\int_0^T f_z\,dt - \frac{g(T-t_1)}{m} + V_{z_0}$$
$$z = \frac{1}{m}\int_0^T\left(\int_0^T f_z\,dt\right)dt - \frac{1}{2}\frac{g(T-t_1)^2}{m} + V_{z_0}(T-t_1) + z_0$$

Integrals must be evaluated for each time step to get the CM position at all time steps.

See Notes on integration

Stride Parameters

- Center of foot (i.e. foot local coordinate system center) is used in calculations. This makes calculations marker set independent.



If information is available on successive pair of heel strikes from both sides, then $\bar{D}$ & $\bar{E}$ are calculated.

1^{ST} stride length = $\|\bar{A}\|$

2^{nd} stride length = $\|\bar{D}\|$

Side_Stride_Ratio = Stride_Length(1ST) / Stride_Length(2nd)

$N_A = \dfrac{\bar{A}}{\|\bar{A}\|}$, $N_D = \dfrac{\bar{D}}{\|\bar{D}\|}$

1ST stride:

1^{ST} HS to 2^{nd} HS step width = $\sqrt{\|\bar{B}\|^2 - F^2}$

1^{ST} HS to 2^{nd} HS step length = $\bar{B}\cdot\bar{N}_A = F$

2^{nd} HS to 3^{rd} HS step width = $\sqrt{\|\bar{C}\|^2 - G^2}$

2^{nd} HS to 3^{rd} HS step length = $\bar{C}\cdot\bar{N}_A = G$

These will be the same size since they are the same ⊥ bisector of △ABC.

2nd stride (Optional):

2^{nd} HS to 3^{rd} HS step length = $\bar{C}\cdot\bar{N}_D = H$

2^{nd} HS to 3^{rd} HS step width = $\sqrt{\|\bar{C}\|^2 - H^2}$

3^{rd} HS to 4^{th} HS step length = $\bar{E}\cdot\bar{N}_D = I$

3^{rd} HS to 4^{th} HS step width = $\sqrt{\|\bar{E}\|^2 - I^2}$

(Opt) Side_width_ratio = Step_width(1ST) / Step_width(2nd)

(Opt) Step_width_avg =

These are the same length. (same reason as above)

Cycle_Time (1ST) (sec) = (Frame# 1ST HS - Frame# 3rd HS) * Camera_Speed

(Opt) Cycle_Time(2nd) = (Frame# 2nd HS - Frame# 4th HS) * Camera_Speed

(Opt) Side_Time_Ratio = Cycle_Time (1ST) / Cycle_Time (2nd)

$$\text{Cadence} = \left(1.0/\ \text{Cycle-Time}(1^{ST})\right) * 2 * 60\ \text{sec}/\text{min} \quad (\text{step}/\text{min})$$

or

(opt) $$\text{Cadence} = 1.0/\left(\text{Cycle-Time}(1^{ST}) + \text{Cycle-Time}(2^{nd})\right) * 60$$

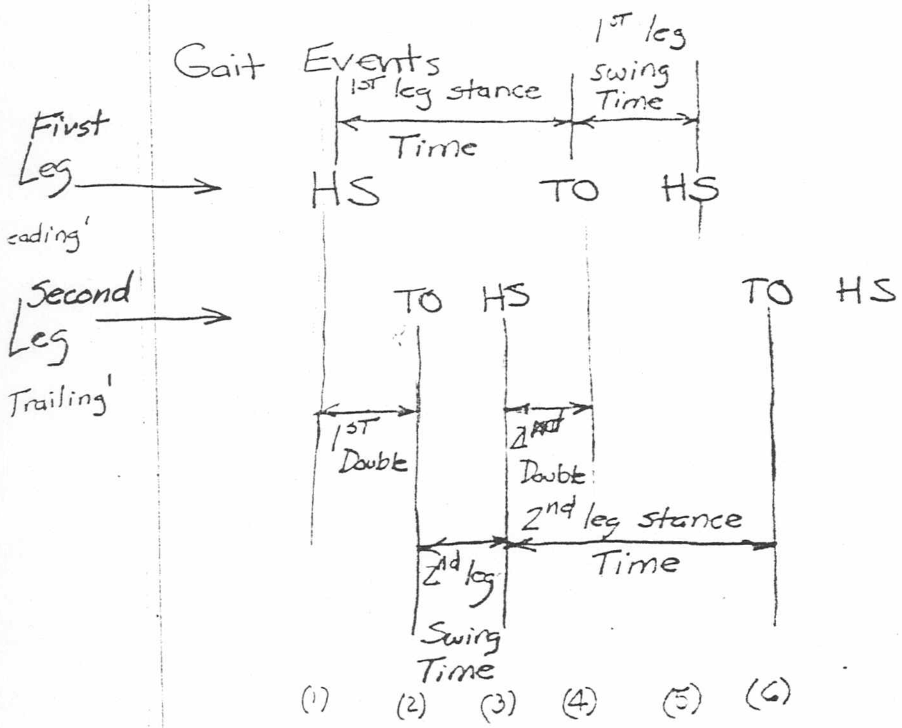
$$\text{Velocity}^{(1^{ST})} = \text{Stride-Length}(1^{ST}) / \text{Cycle-Time}(1^{ST})$$

(opt) $$\text{Velocity}^{(2^{nd})} = \text{Stride-Length}(2^{nd}) / \text{Cycle-Time}(2^{nd})$$

(opt) $$\text{Velocity-Avg} = \left(\text{Velocity}(1^{ST}) + \text{Velocity}(2^{nd})\right)/2$$

(opt) $$\text{Side-Velocity-Ratio} = \text{Velocity}(1^{ST}) / \text{Velocity}(2^{nd})$$

Gait Events



$$\text{Stance-Time}(1^{ST}) = (4) - (1)$$

$$\text{Swing-Time}(1^{ST}) = (5) - (4)$$

(Optional) $$\text{Stance-Time}(2^{nd}) = (6) - (3)$$

$$\text{Swing-Time}(2^{nd}) = (3) - (2)$$

$$\text{Double-Time}(1^{ST}) = (2) - (1)$$

$$\text{Double-Time}(2^{nd}) = (4) - (3)$$

To make % of cycle, divde these quantities by Cycle-Time_Avg

NOTE: Additional Equations are included in softwa for women and children (references in code comments

Position of CM based upon segment length
Dempster (1955)

	length ratio			
foot	.571	from distal joint	Up arm	.564
shank	.567		Lw arm	.570
thigh	.567			

Segment mass - use predictive equations of McConville (1980) along with density data of ~~Dempster~~ (1955)

foot $m = 1.10 * d_\omega * (9.31 * Ht + 1.87 * Wt - 994)$

shank $m = 1.09 * d_\omega * (26.72 * Ht + 11.84 * Wt - 2912)$

thigh $m = 1.05 * d_\omega * (35.19 * Ht + 45.30 * Wt - 4083)$

d_ω = density of water, Kg/cm^3

Ht = total hieght, cm

Wt = body weight, lbs

m = mass, Kg

Segment inertia - use predictive equations of McConville (1980)
(principal moments of inertia)

foot
a-p $I_X = 110 * Ht + 30 * Wt - 16550$
m-l $I_Y = 948 * Ht + 71 * Wt - 137353$
$I_Z = 954 * Ht + 86 * Wt - 138369$

shank
a-p $I_X = 12323 * Ht + 1702 * Wt - 1907428$
m-l $I_Y = 12429 * Ht + 1230 * Wt - 1922497$
$I_Z = 291 * Ht + 477 * Wt - 66811$

thigh
a-p $I_X = 28839 * Ht + 6407 * Wt - 4659953$
m-l $I_Y = 28559 * Ht + 7298 * Wt - 4679995$
$I_Z = -1587 * Ht + 4537 * Wt - 72496$

$gm \cdot cm^2 \; \frac{Kg}{1000 gm} \; \frac{m^2}{10000 cm^2}$

I = principal moment of inertia, $gm \cdot cm^2$

Segment Mass - Trunk & Arms

Pelvis $m = 1.01 * dw * (-68.97 * Ht + 98.98 \times wt + 6765)$ (p.41)

Thorax/Abdomen $m = 0.92 * dw * (-22.71 * Ht + 163.68 * wt + 524)$ (p 37) (1.09783)

$+ 1.01 * dw * (-23.05 * Ht + 19.42 * wt + 3121)$ (p.39)

(-25.30) (21.32) (3426

Head/neck $m = 1.01 * dw * (6.84 * Ht + 2.05 * wt + 2806)$ (p.33)

$+ 1.11 * dw * (-5.50 * Ht + 6.32 * wt + 943)$ (p.35)

Up arm $m = 1.07 * dw * (-2.14 * Ht + 13.25 * wt + 76)$ (p.43)

Lw arm $m = 1.13 * dw * (-.36 * Ht + 10.01 * wt + 267)$ (p.71)

Segment Moment of inertia

Pelvis $I_Y = -10851 * Ht + 13750 * wt + 492711$

$I_X = -10283 * Ht + 14215 * wt + 396174$ (p.41)

$I_Z = -14684 * Ht + 17498 * wt + 772875$

Thorax $I_Y = 3738 * Ht + 36636 * wt - 4768961$ (p.37)

$I_X = 8183 * Ht + 47484 * wt - 3393924$

$I_Z = -14325 * Ht + 36254 * wt - 675725$

Head $I_Y = 1097 * Ht + 103 * wt + 36972$

$I_X = 859 * Ht + 86 * wt + 20735$ (p.33)

$I_Z = 216 * Ht + 168 * wt + 83847$

Up arm $I_Y = 934 * Ht + 1094 * wt - 224626$

$I_X = 627 * Ht + 1304 * wt - 198020$ (p.43)

$I_Z = -338 * Ht + 391 * wt + 19102$

Lw arm $I_Y = 4086 * Ht + 1316 * wt - 645877$

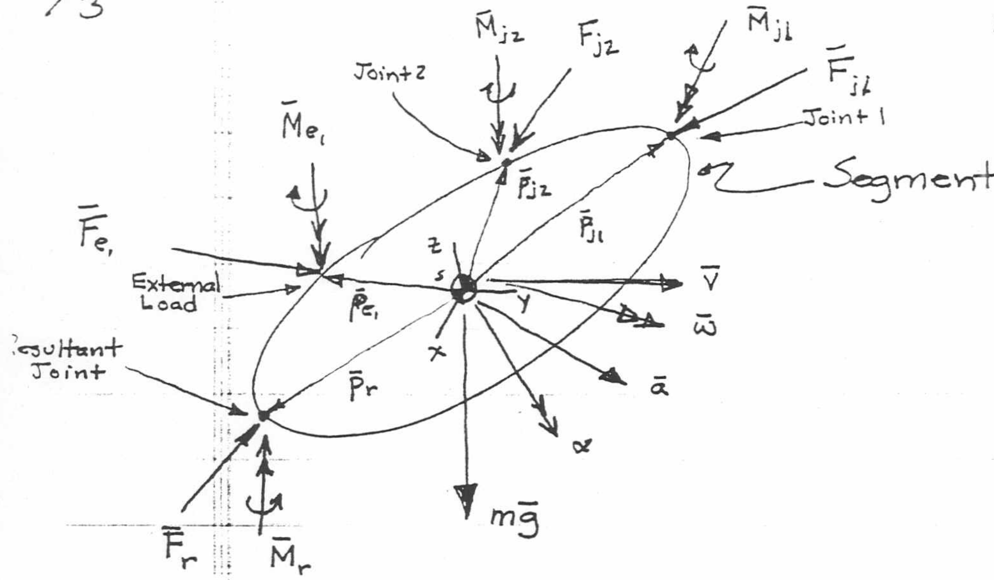
$I_X = 4058 * Ht + 1316 * wt - 642117$ (p.71)

$I_Z = -139 * Ht + 200 * wt + 7973$

Description of Net Joint Resultant load calculations

ANZ carries sequential calculations ~~from~~ from segment to segment the evaluate the net resultant joint loads. The actual sequence may vary depending upon what GRL data is known but the calculation of the joint loads for an individual segment is the same in all case — with one minor correction. A number of sequences are described in other descriptions of body/joint connectivity. The correction mentioned is whether the calculation of the net joint load is done in a sequence progressing from distal-to-proximal or proximal-to-distal. The normal sequence is distal-to-proximal so whenever the other order occurs the sign of the joint resultant load (JRL) must be negated. In the program, the JRL's are calculated relative to the segment local coordinate System (LCS) in terms of proximal segment acting upon distal segment. Following this, the JRL is transformed into 3 other forms relative to the proximal segment LCS, the global CS and the non orthogonal Joint CS derived from the euler angle sequence (Flexion/Ext. – Ab/Adduction – In/External).

The following segment illustrates the basic situation being evaluated along with the equations used in this evaluation:



All loads, positions, velocities, & accelerations are relative to segment LCS!

$\bar{F}_{ji}, \bar{M}_{ji}$ - i^{th} joint load

$\bar{F}ei, \bar{M}ei$ - i^{th} external load

$\bar{F}r, \bar{M}r$ - Resultant Joint load

$\bar{p}ji$ - location of joint load i

$\bar{p}ei$ - " " external load i

$\bar{p}r$ - " " resultant joint lo

$\bar{g}$ - gravity vector

There may be multiple joints affecting the segment whose net JRL ($\bar{F}_j$ - force, $\bar{M}_j$ - moment) have already been computed in a previous evaluation of the sequence, n_j - number of joints. Also, there maybe multiple external loads (ground reaction load) (n_e) applied to the segment although in practice usually only a single GRL is applied to the foot segment only. The locations of all joints & external loads are known through either definition or calculation. (An Assumption)

$\bar{v}$ - translational velocity of segment

$\bar{\omega}$ - rotational " " "

$\bar{a}$ - translational acceleration " "

$\bar{\alpha}$ - rotational " " "

m - mass

I_x, I_y, I_z - Prinicipal Inertias

Another Assumption - Segment LCS & principal inertial axes are aligned with one another & LCS is located at the center of mass. This is estimated using anthropometric equations (see other notes).

Since the dynamics equations are evaluated relative to the segment LCS which is rotating & translating, the following equations apply: (about the segment LCS)

Σ Forces : $\bar{E} = m\bar{g} + \sum_{i=1}^{n_j} \bar{F}_{ji} + \sum_{i=1}^{n_e} \bar{F}_{ei} + \bar{F}_r$

Σ Moments : $\bar{J} = \sum_{i=1}^{n_j} \bar{M}_{ji} + \sum_{i=1}^{n_j} \bar{p}_{ji} \times \bar{F}_{ji} + \sum_{i=1}^{n_e} \bar{M}_{ei} + \sum_{i=1}^{n_e} \bar{p}_{ei} \times \bar{F}_{ei} + \bar{p}_r \times \bar{F}_r$

where $\bar{E} = m \begin{Bmatrix} a_x + v_z\omega_y - v_y\omega_z \\ a_y + v_x\omega_z - v_z\omega_x \\ a_z + v_y\omega_x - v_x\omega_y \end{Bmatrix}$

$$\bar{J} = \begin{Bmatrix} I_x\alpha_x + (I_z - I_y)\,\omega_y\omega_z \\ I_y\alpha_y + (I_x - I_z)\,\omega_x\omega_z \\ I_z\alpha_z + (I_y - I_x)\,\omega_x\omega_y \end{Bmatrix}$$

The derivation of quantities $\bar{E}$ & $\bar{J}$ can be found in most any Advanced Dynamics ~~textbook~~. For example,

Advanced Dynamics: Modeling & Analysis by A. Frank D'Souza & Vijay K. Garg Prentice-Hall, 1984. (see p. 96-97, in particular Eq. 4.44 & 4.47)

To find the resultant joint loads, first compute $\bar{F}_r$

$$\bar{F}_r = \bar{E} - m\bar{g} \quad \sum_{i=1}^{n_j} F_{ji} \quad \sum_{i=1}^{n_e} F_{ei}$$

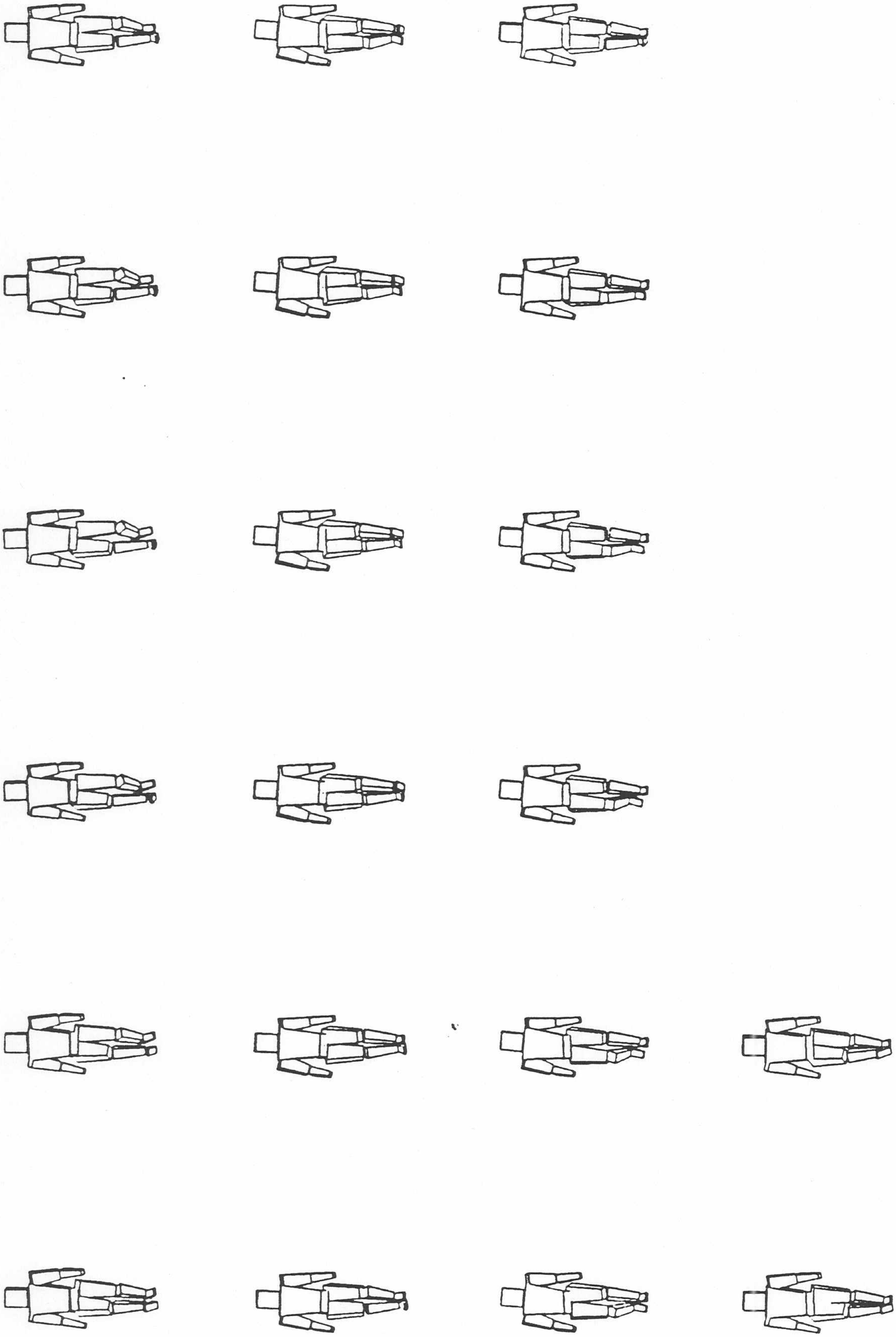
Then solve for $\bar{M}_r$ now that $\bar{F}_r$ is known

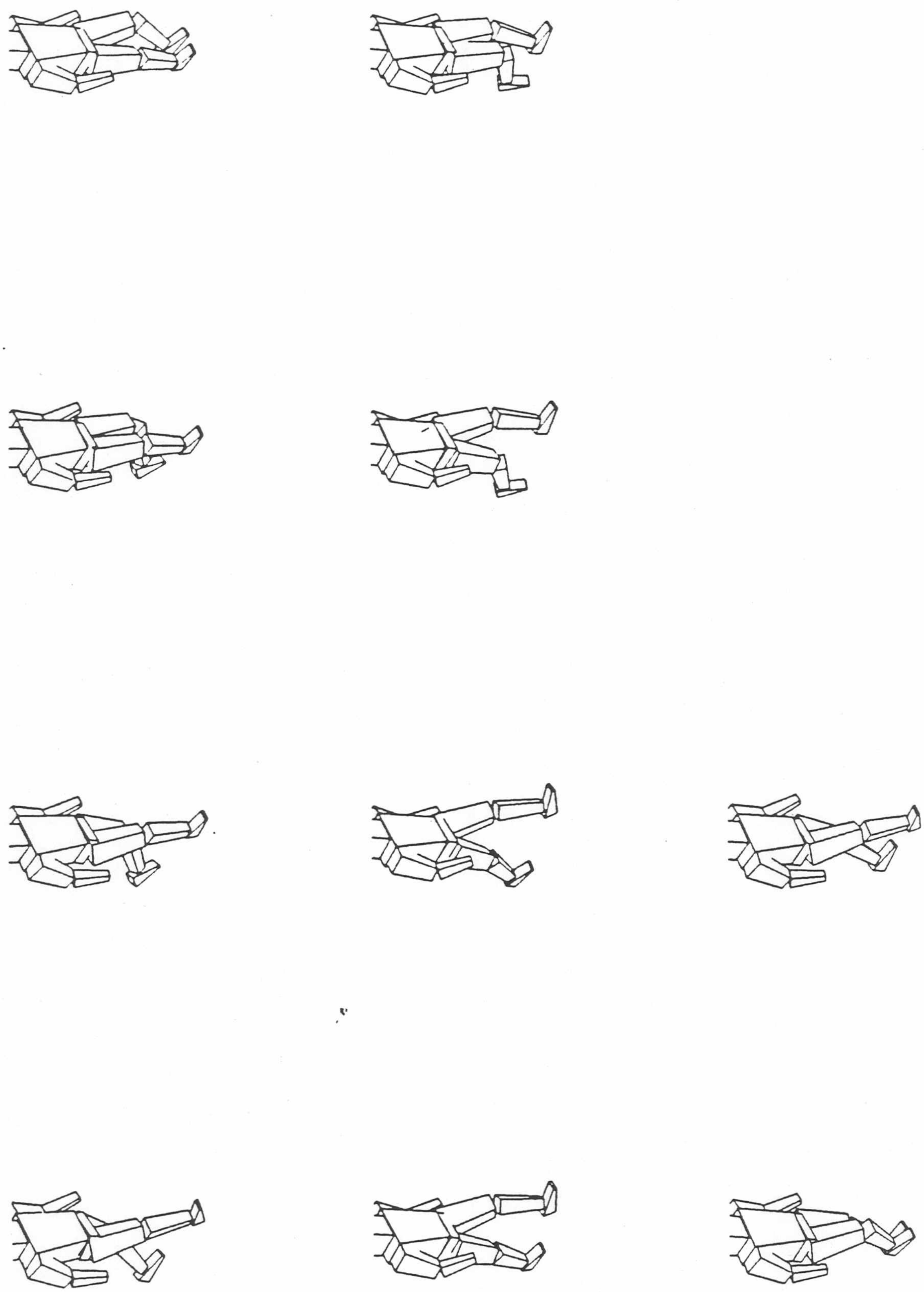
$$\bar{M}_r = \bar{J} - \sum_{i=1}^{n_j} M_{ji} - \sum_{i=1}^{n_j} \bar{p}_{ji} \times \bar{F}_{ji} - \sum_{i=1}^{n_e} M_{ei} - \sum_{i=1}^{n_e} \bar{p}_{ei} \times \bar{F}_{ei} - \bar{p}_r \times \bar{F}_r$$

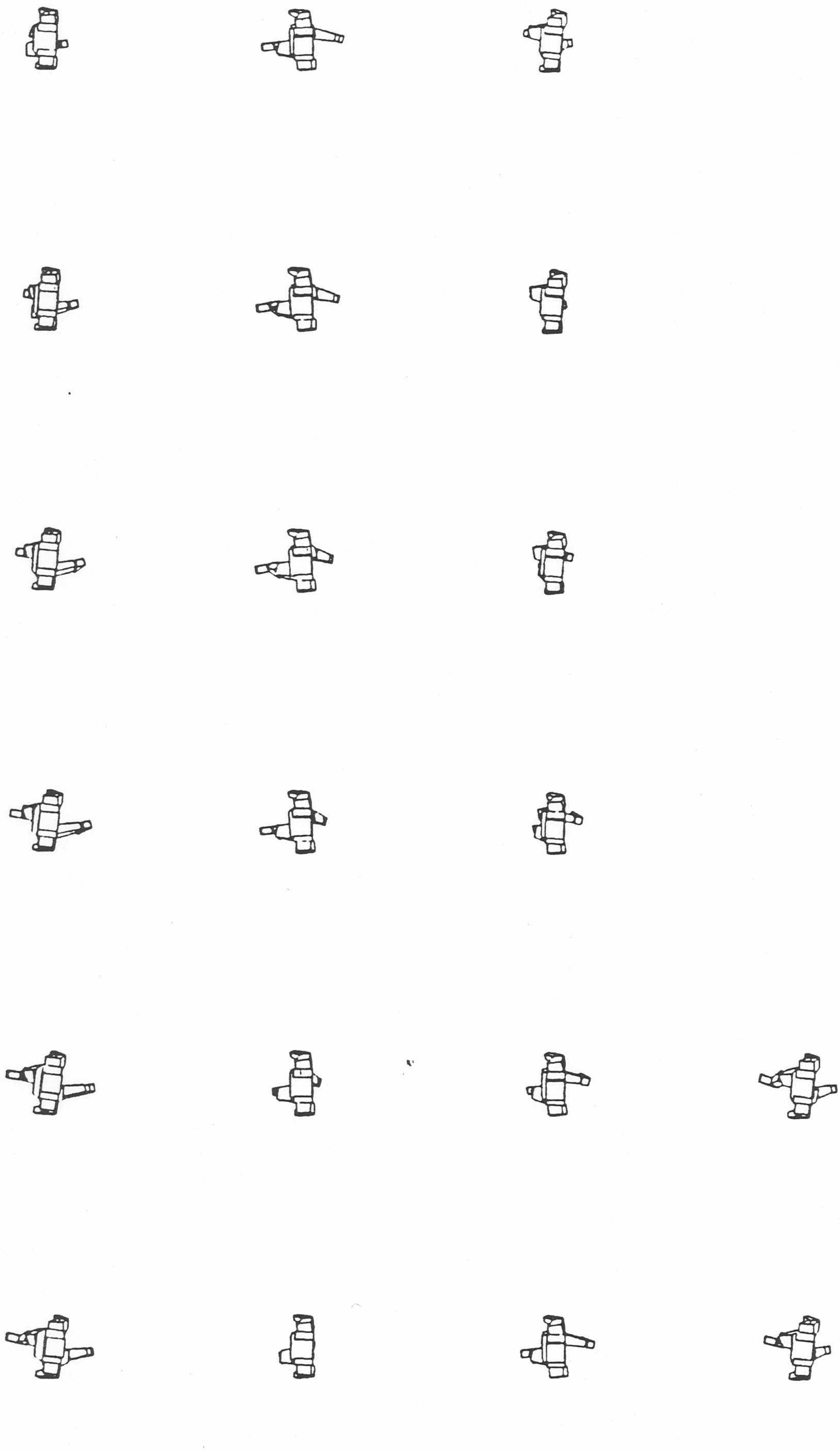
These equations can be found in the routine CalcAJntLoad.

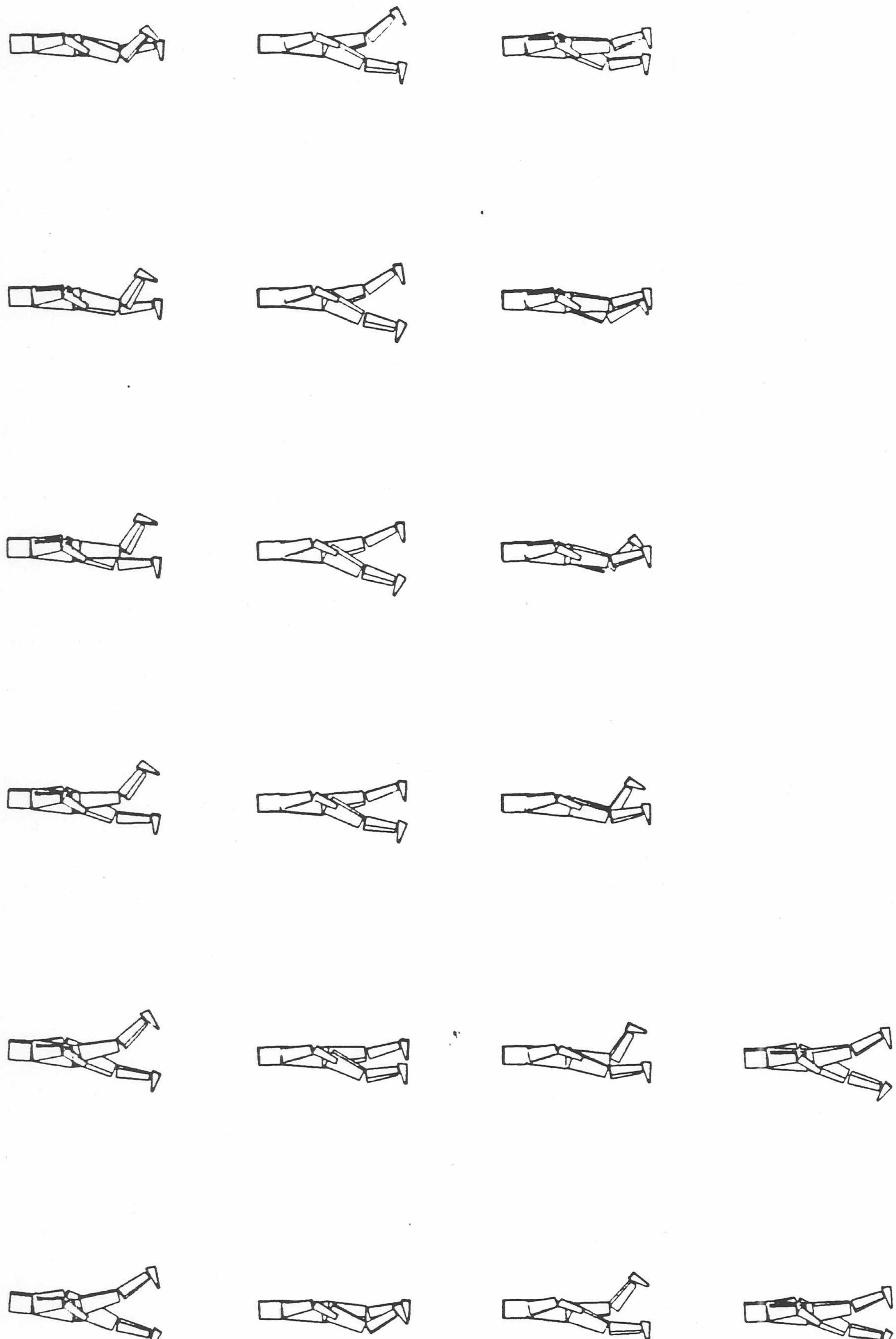
The full sequence of calculations is found in CalcAllJntLoads

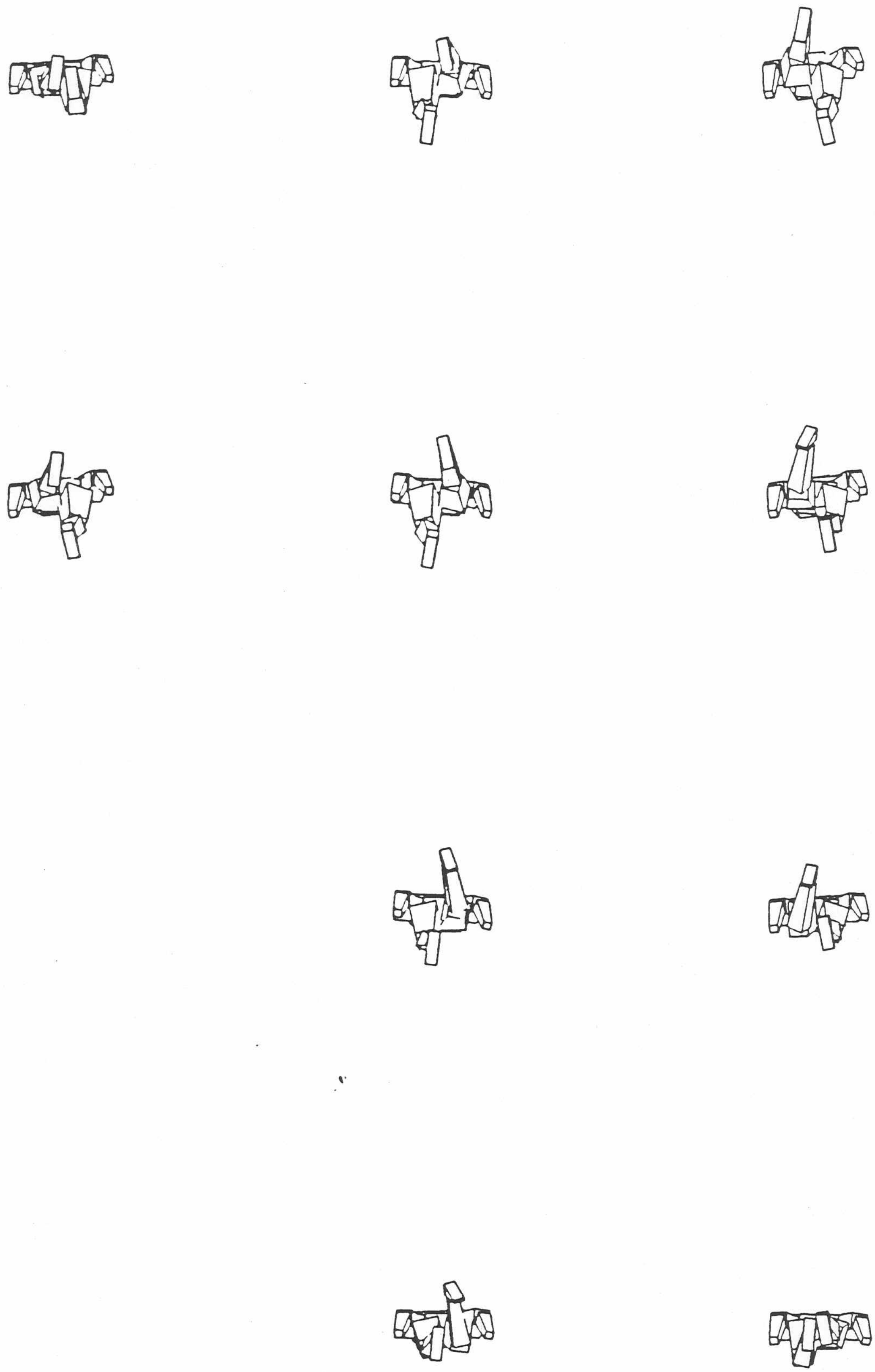
Sample graphics generated in TELIO using data calculated with ANALYZE

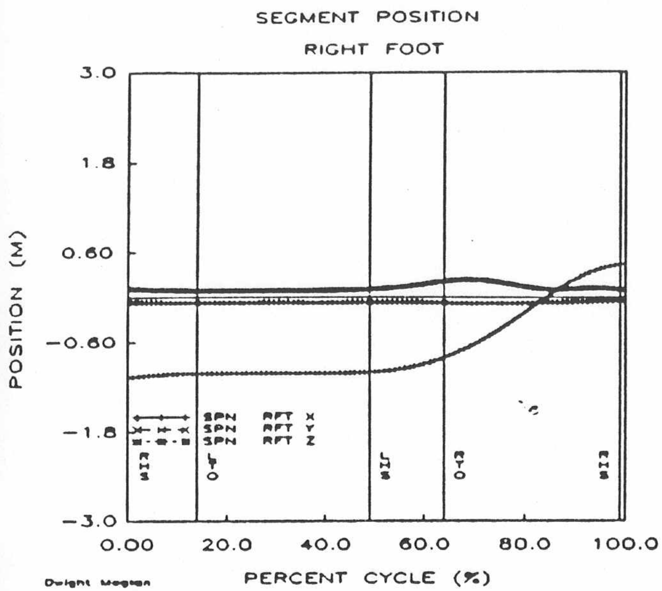


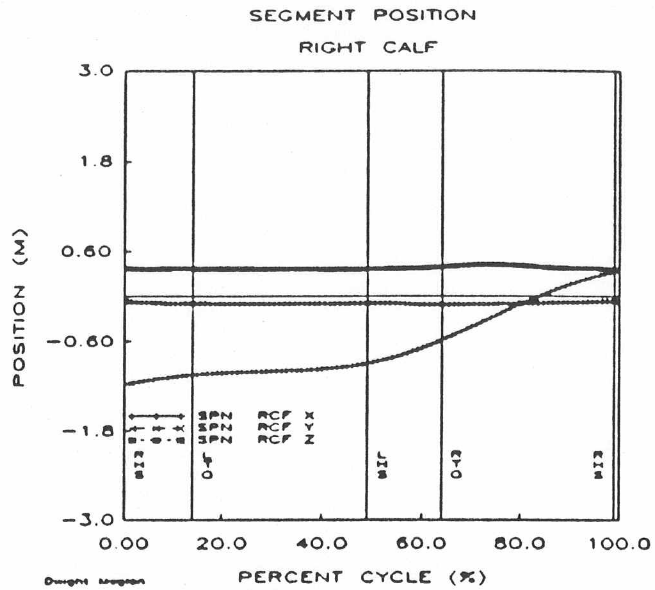


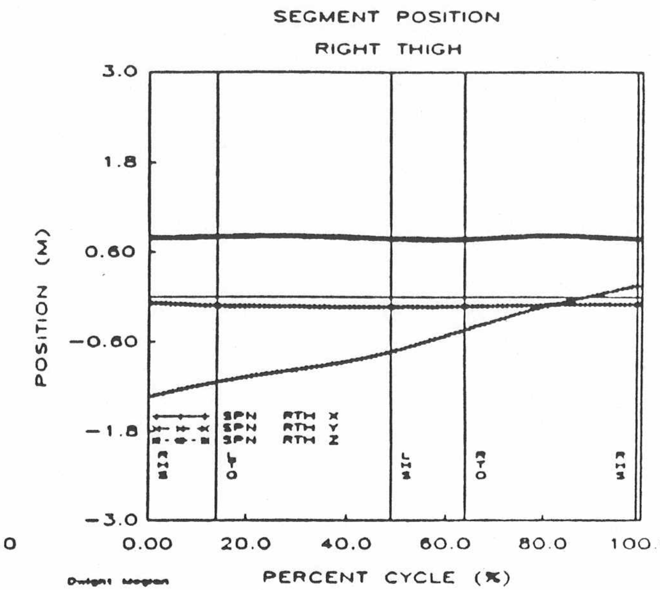


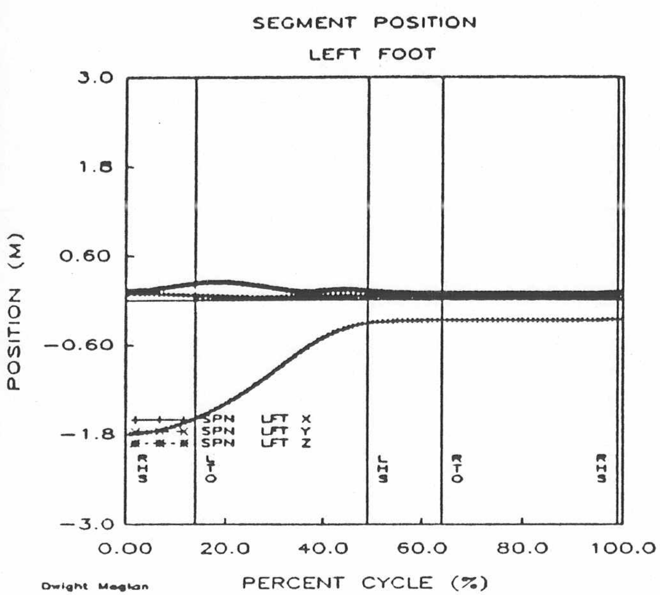


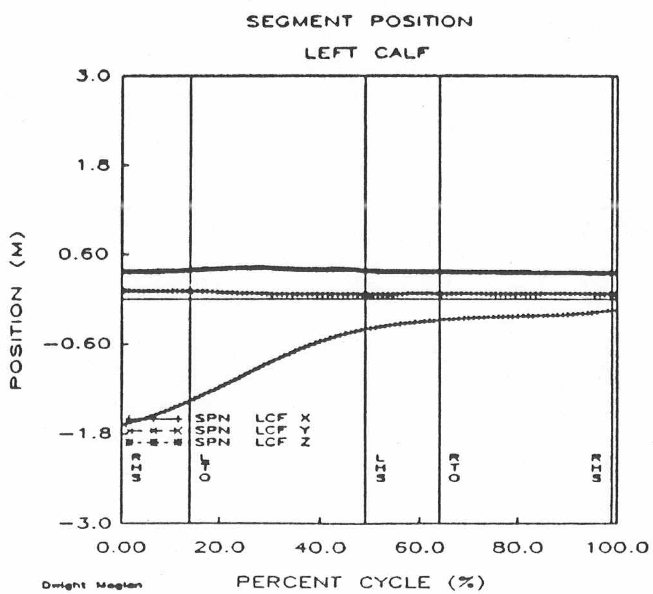


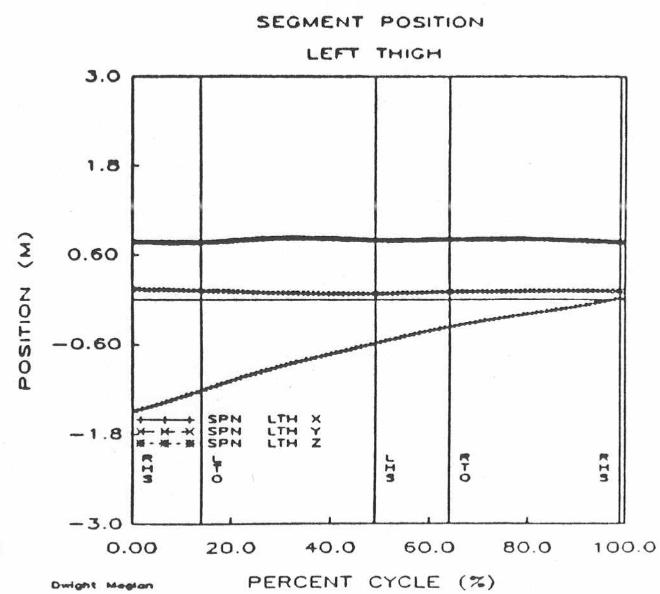

SEGMENT POSITION
RIGHT FOOT
POSITION (M)
PERCENT CYCLE (%)
SPN RFT X
SPN RFT Y
SPN RFT Z
Dwight Meglan


SEGMENT POSITION
RIGHT CALF
POSITION (M)
PERCENT CYCLE (%)
SPN RCF X
SPN RCF Y
SPN RCF Z
Dwight Meglan

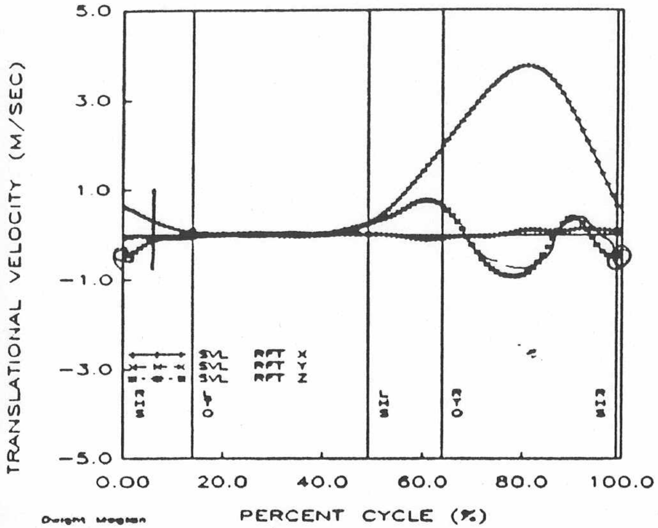

SEGMENT POSITION
RIGHT THIGH
POSITION (M)
PERCENT CYCLE (%)
SPN RTH X
SPN RTH Y
SPN RTH Z
Dwight Meglan


SEGMENT POSITION
LEFT FOOT
POSITION (M)
PERCENT CYCLE (%)
SPN LFT X
SPN LFT Y
SPN LFT Z
Dwight Meglan

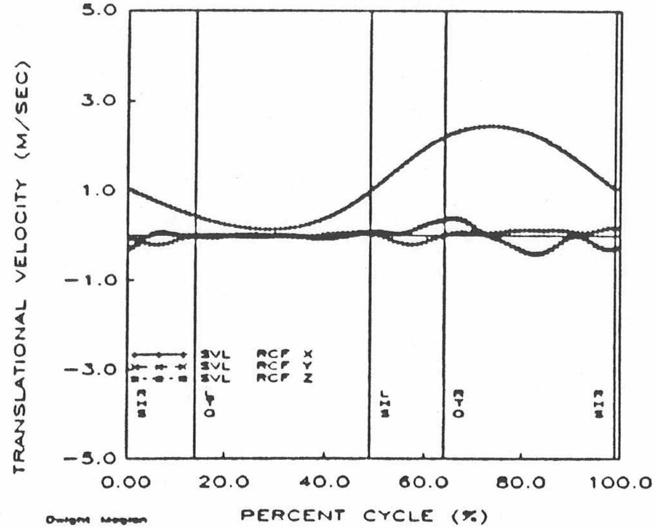

SEGMENT POSITION
LEFT CALF
POSITION (M)
PERCENT CYCLE (%)
SPN LCF X
SPN LCF Y
SPN LCF Z
Dwight Meglan


SEGMENT POSITION
LEFT THIGH
POSITION (M)
PERCENT CYCLE (%)
SPN LTH X
SPN LTH Y
SPN LTH Z
Dwight Meglan

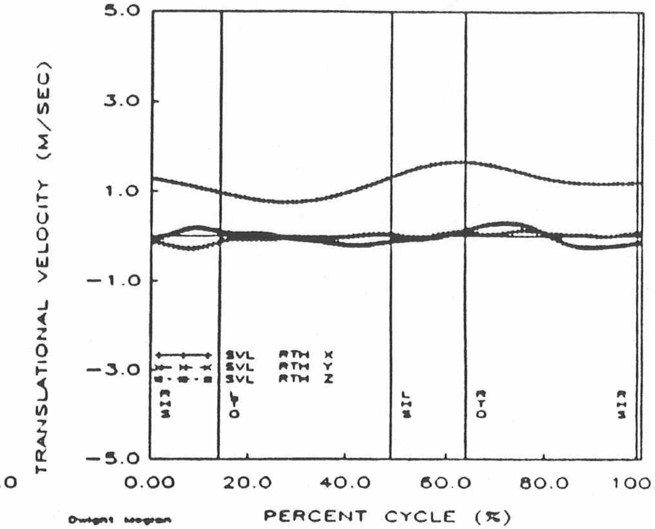
SEGMENT TRANSLATIONAL VELOCITY
RIGHT FOOT



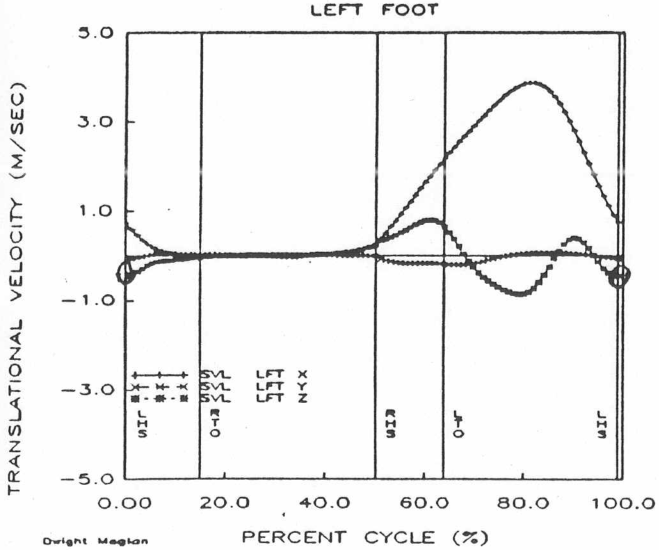
SEGMENT TRANSLATIONAL VELOCITY
RIGHT CALF



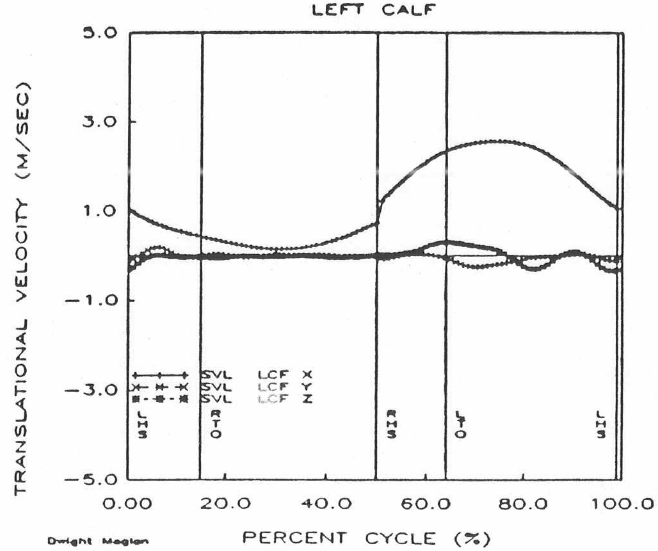
SEGMENT TRANSLATIONAL VELOCITY
RIGHT THIGH



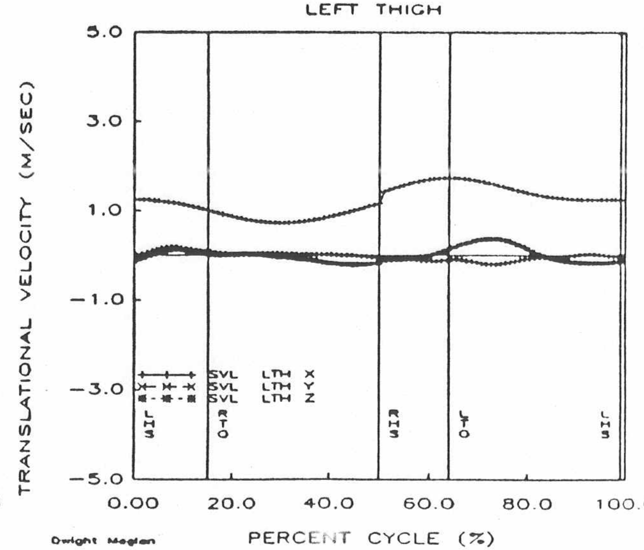
SEGMENT TRANSLATIONAL VELOCITY
LEFT FOOT



SEGMENT TRANSLATIONAL VELOCITY
LEFT CALF

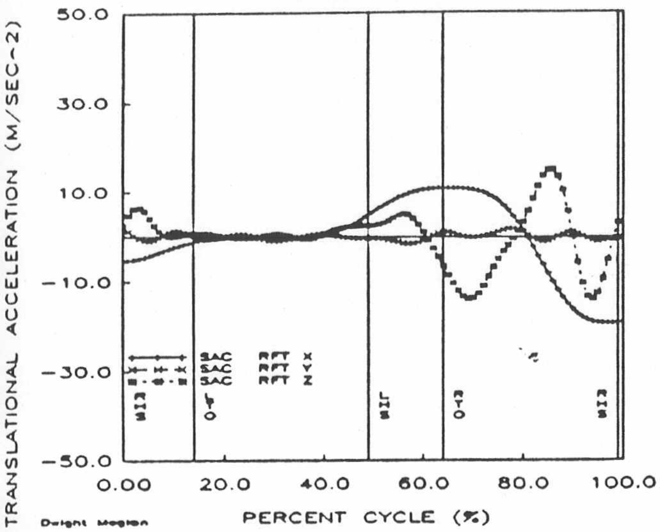


SEGMENT TRANSLATIONAL VELOCITY
LEFT THIGH



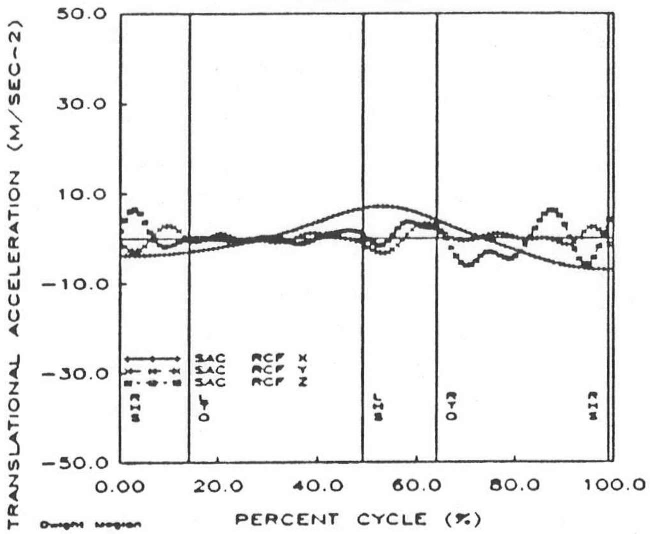
SEGMENT TRANSLATIONAL ACCELERATION

RIGHT FOOT



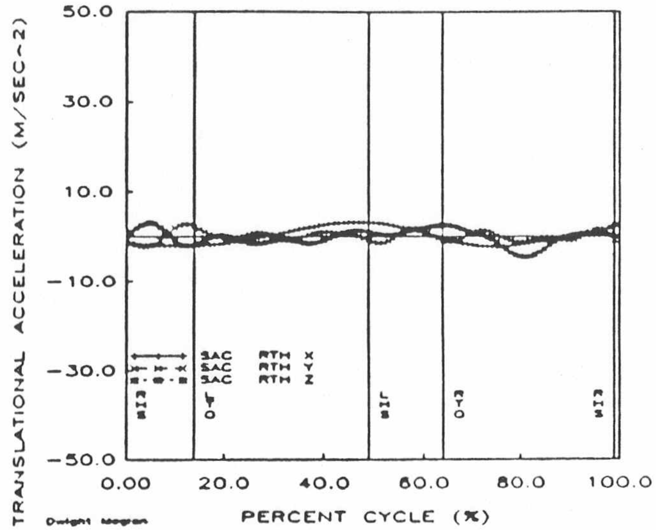
SEGMENT TRANSLATIONAL ACCELERATION

RIGHT CALF



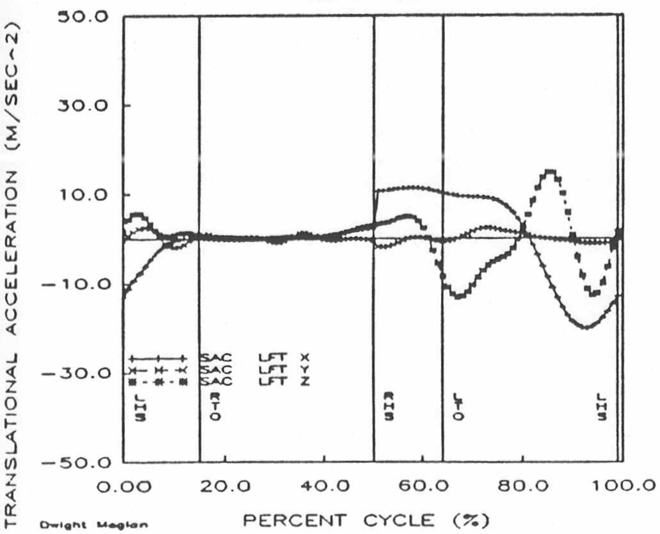
SEGMENT TRANSLATIONAL ACCELERATION

RIGHT THIGH



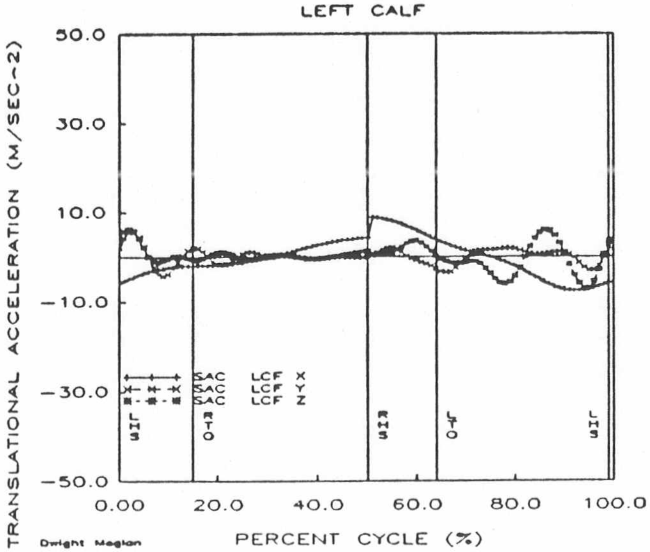
SEGMENT TRANSLATIONAL ACCELERATION

LEFT FOOT



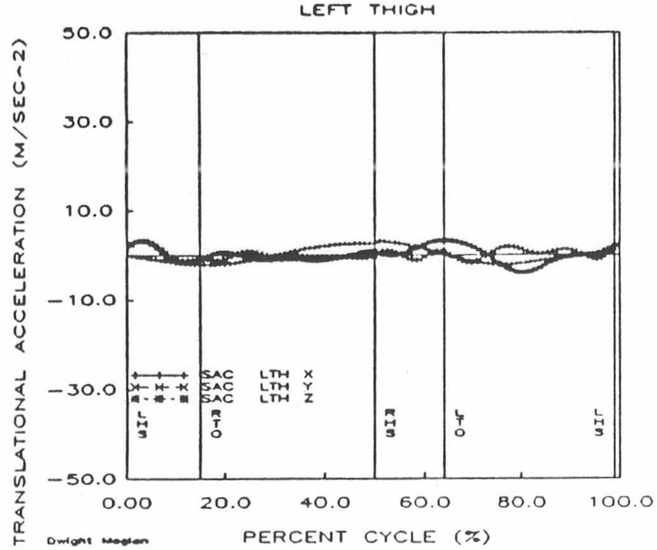
SEGMENT TRANSLATIONAL ACCELERATION

LEFT CALF

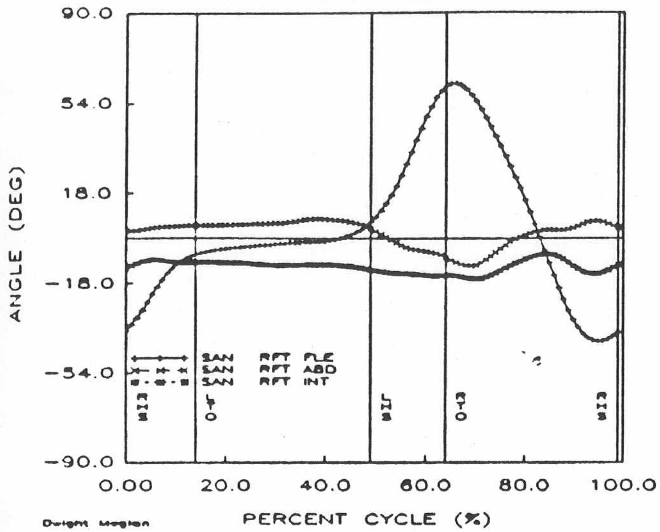


SEGMENT TRANSLATIONAL ACCELERATION

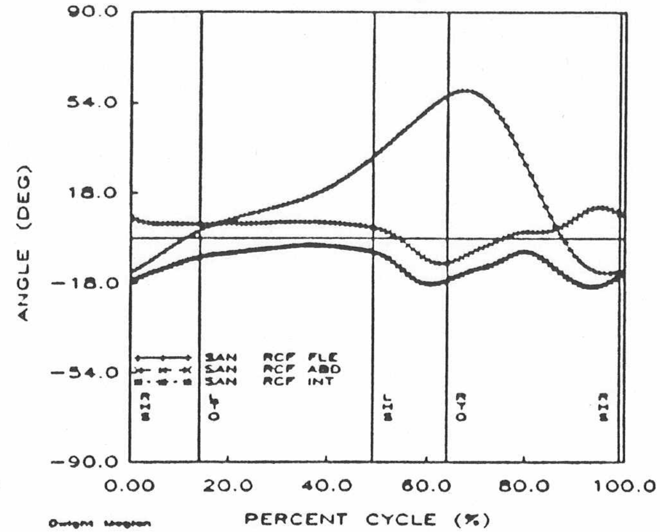
LEFT THIGH



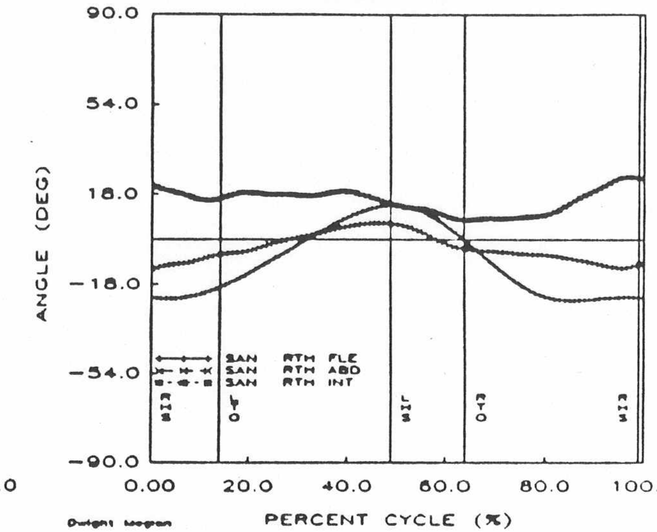
SEGMENT ORIENTATION RELATIVE TO GCS
RIGHT FOOT



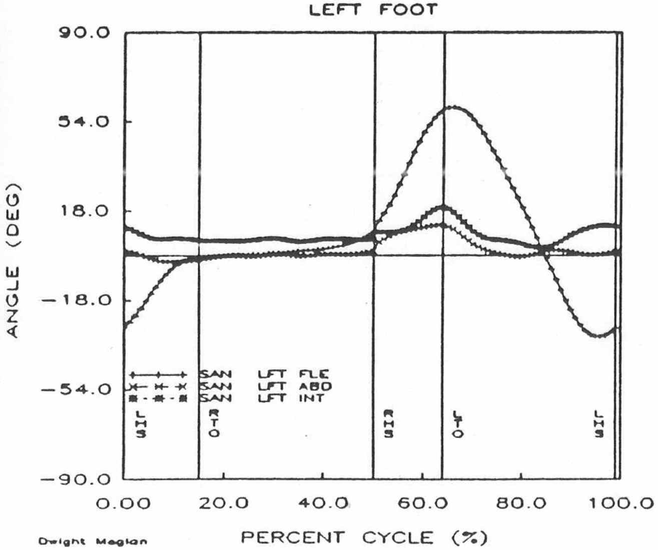
SEGMENT ORIENTATION RELATIVE TO GCS
RIGHT CALF



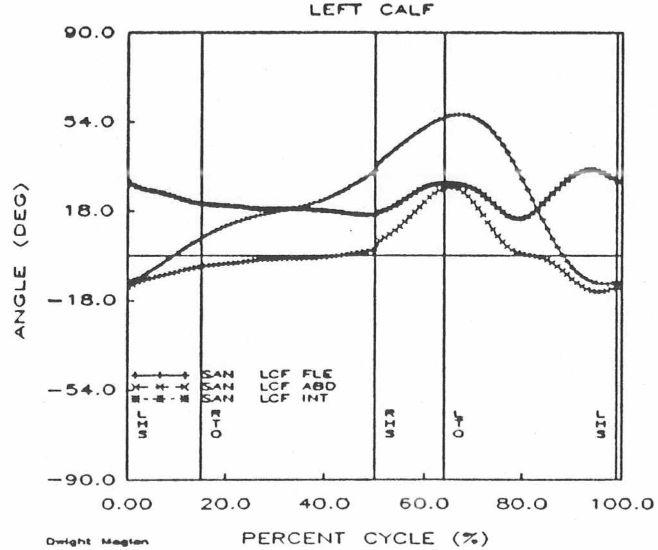
SEGMENT ORIENTATION RELATIVE TO GCS
RIGHT THIGH



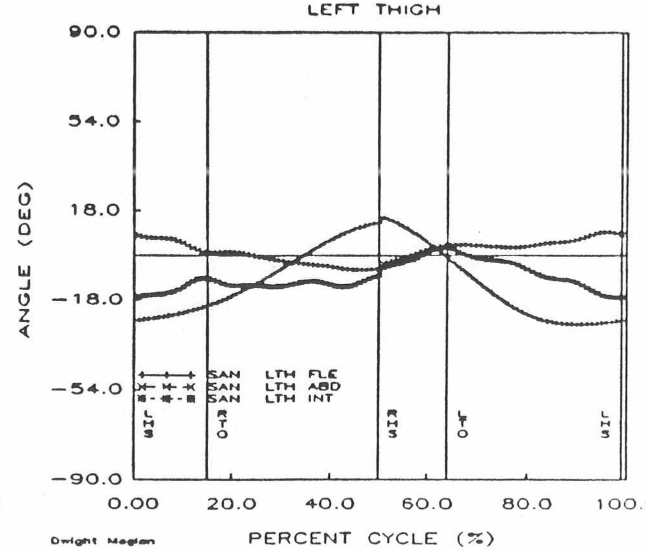
SEGMENT ORIENTATION RELATIVE TO GCS
LEFT FOOT



SEGMENT ORIENTATION RELATIVE TO GCS
LEFT CALF

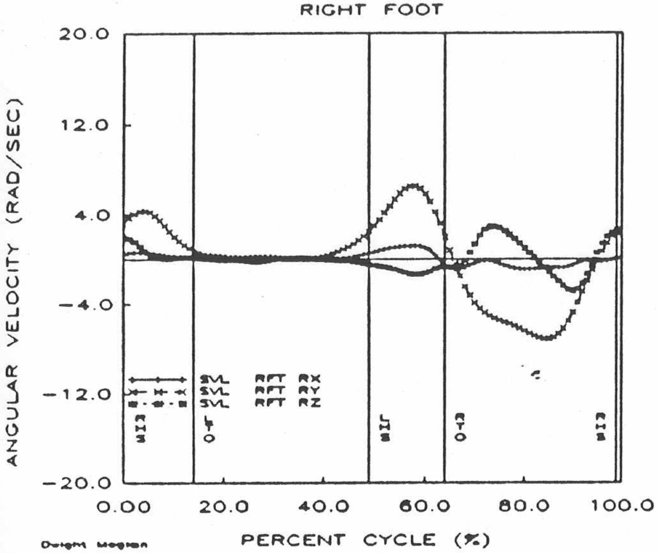


SEGMENT ORIENTATION RELATIVE TO GCS
LEFT THIGH



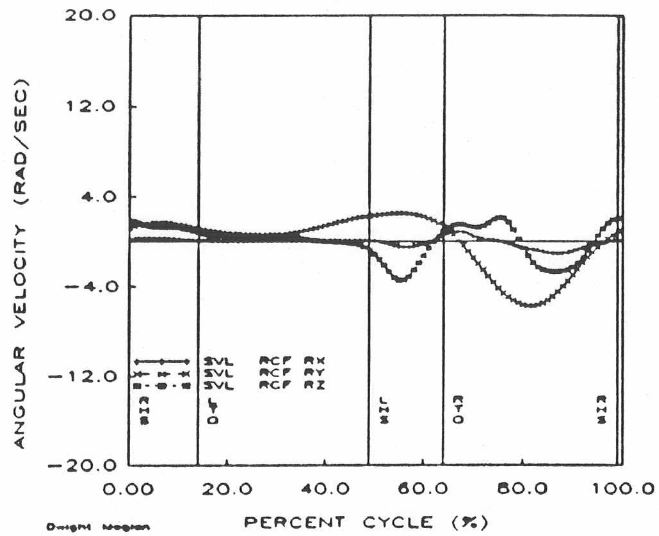
SEGMENT ROTATIONAL VELOCITY

RIGHT FOOT



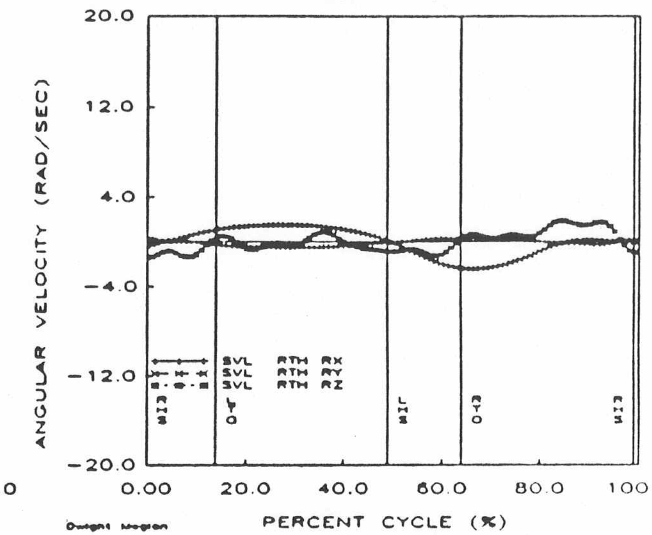
SEGMENT ROTATIONAL VELOCITY

RIGHT CALF



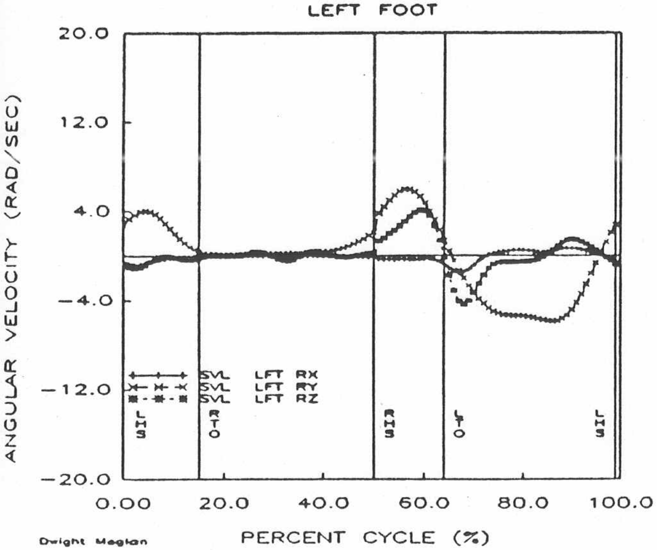
SEGMENT ROTATIONAL VELOCITY

RIGHT THIGH



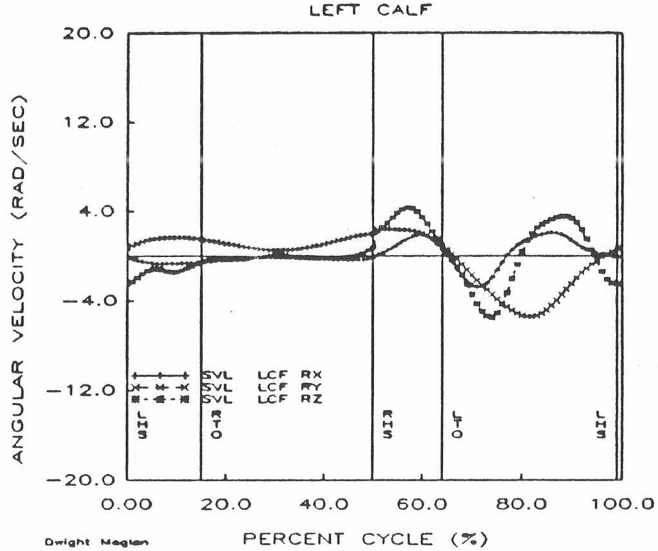
SEGMENT ROTATIONAL VELOCITY

LEFT FOOT



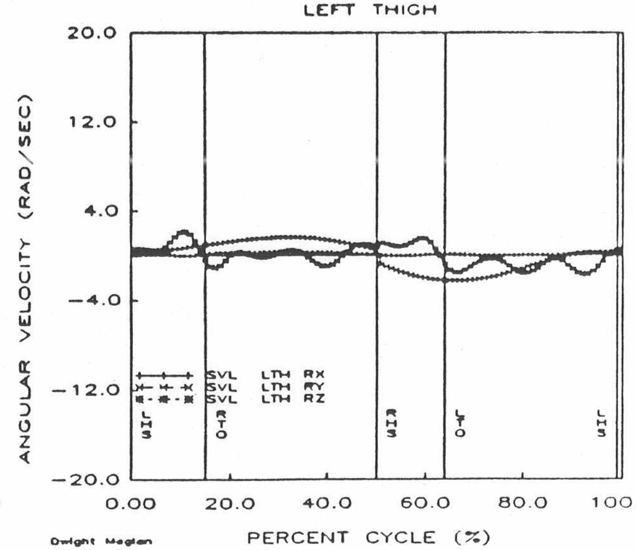
SEGMENT ROTATIONAL VELOCITY

LEFT CALF

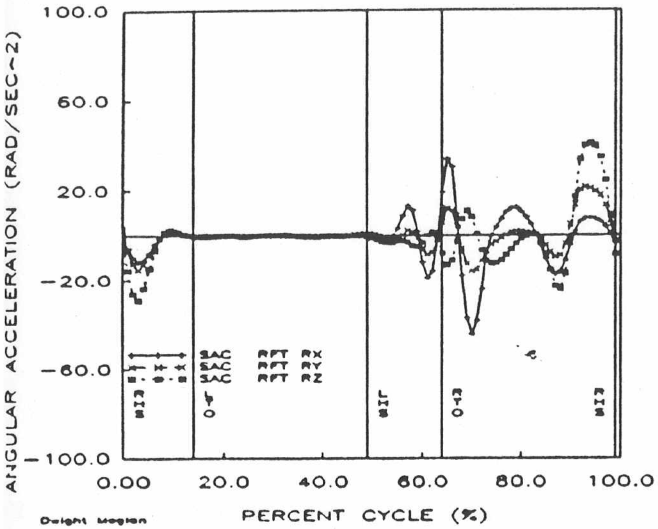


SEGMENT ROTATIONAL VELOCITY

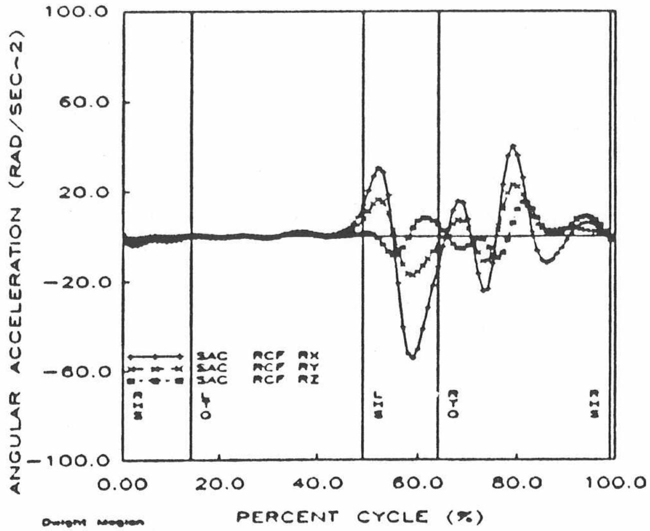
LEFT THIGH



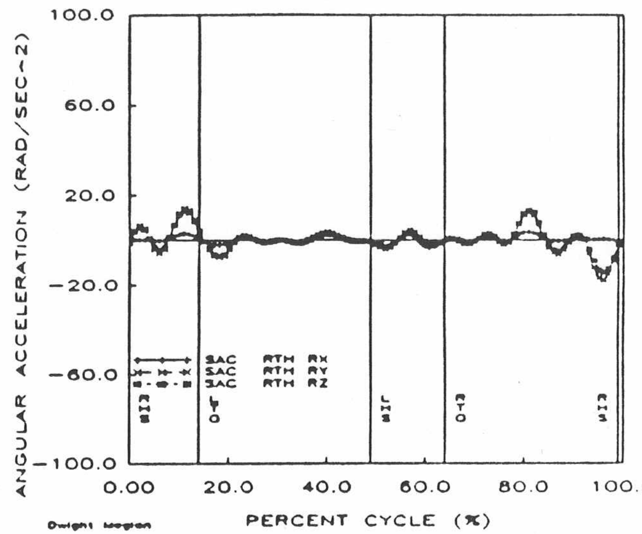
SEGMENT ROTATIONAL ACCELERATION
RIGHT FOOT



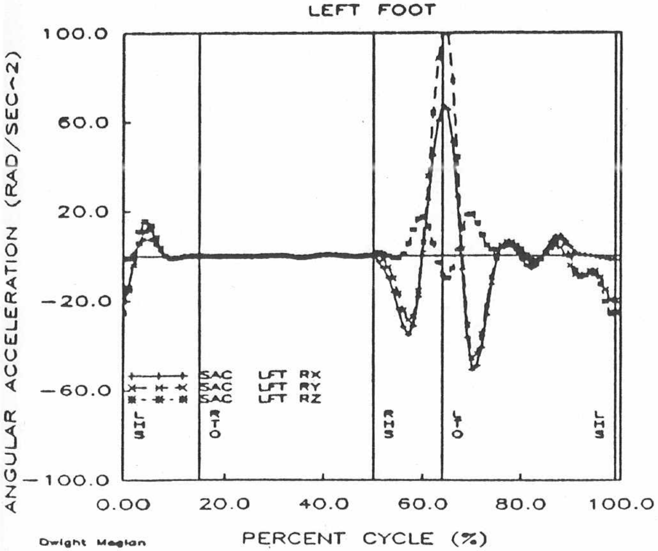
SEGMENT ROTATIONAL ACCELERATION
RIGHT CALF



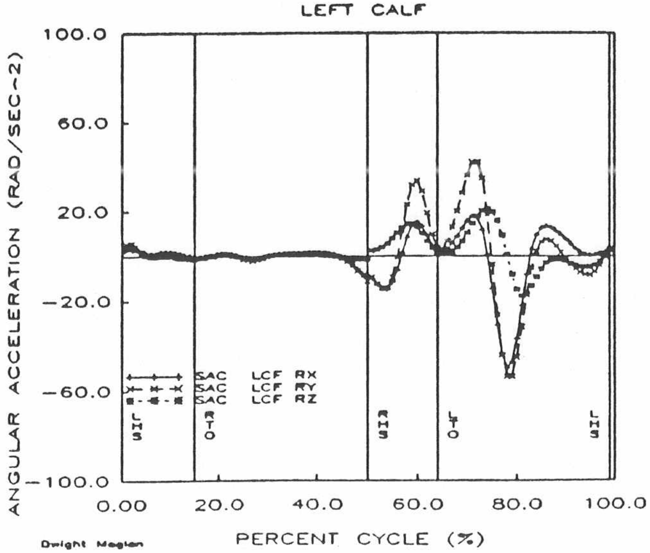
SEGMENT ROTATIONAL ACCELERATION
RIGHT THIGH



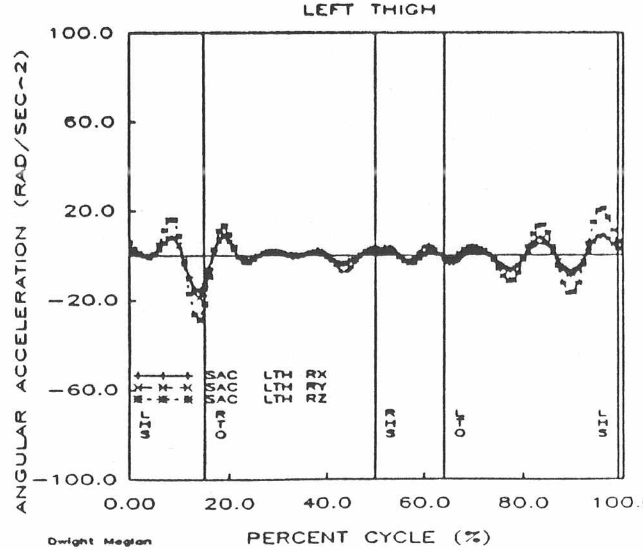
SEGMENT ROTATIONAL ACCELERATION
LEFT FOOT

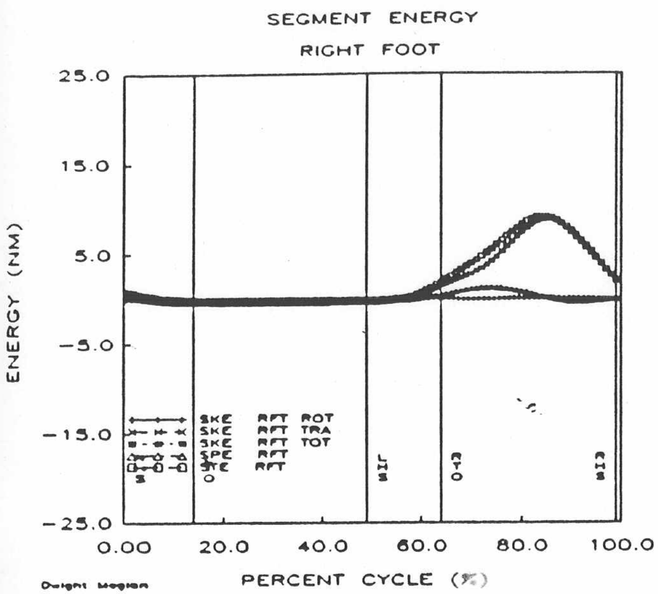


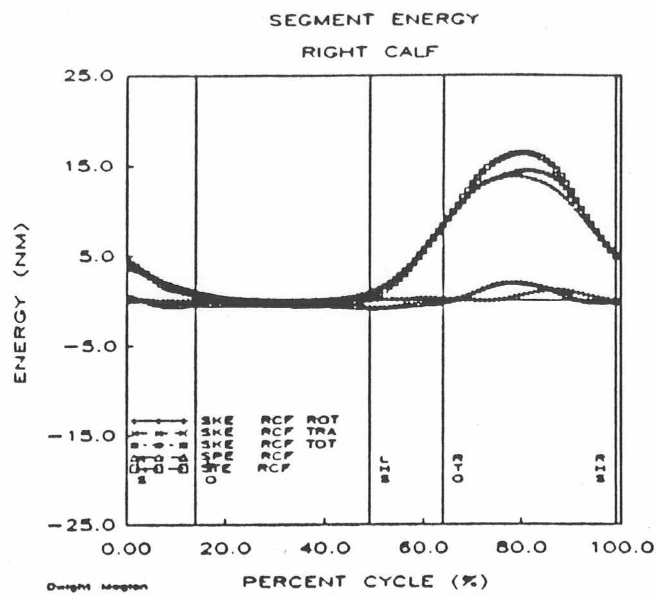
SEGMENT ROTATIONAL ACCELERATION
LEFT CALF

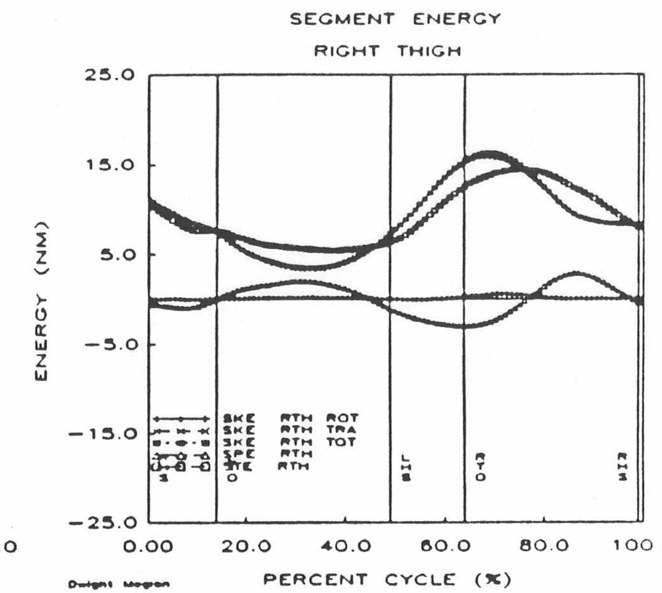


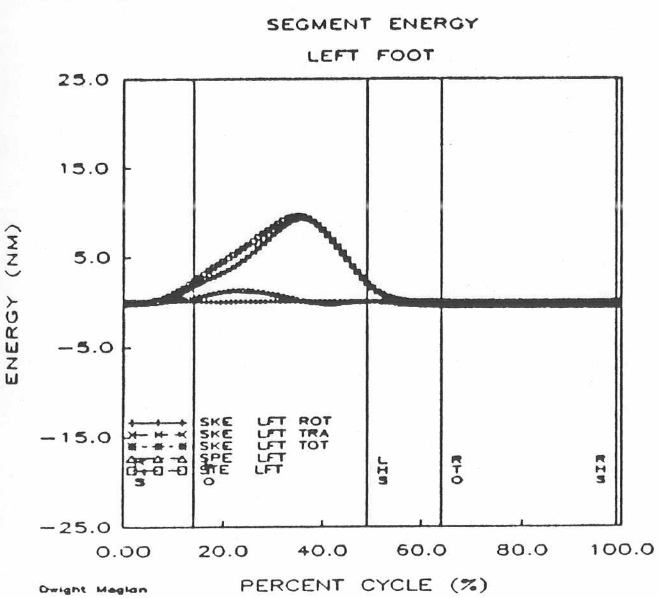
SEGMENT ROTATIONAL ACCELERATION
LEFT THIGH

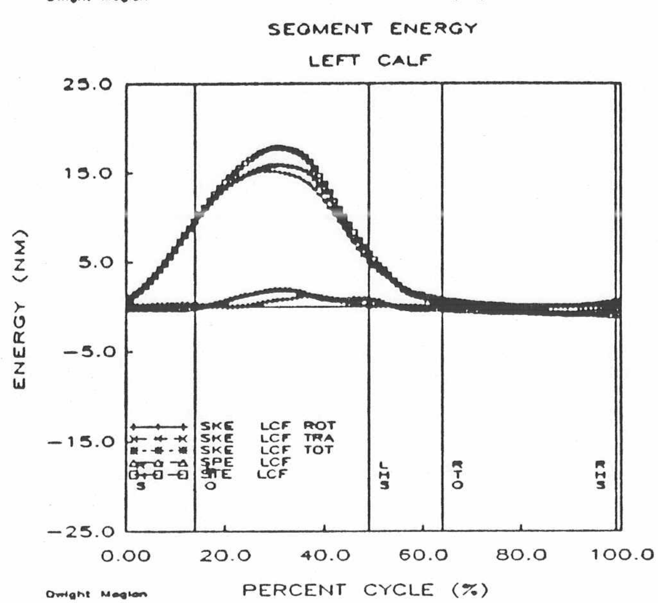


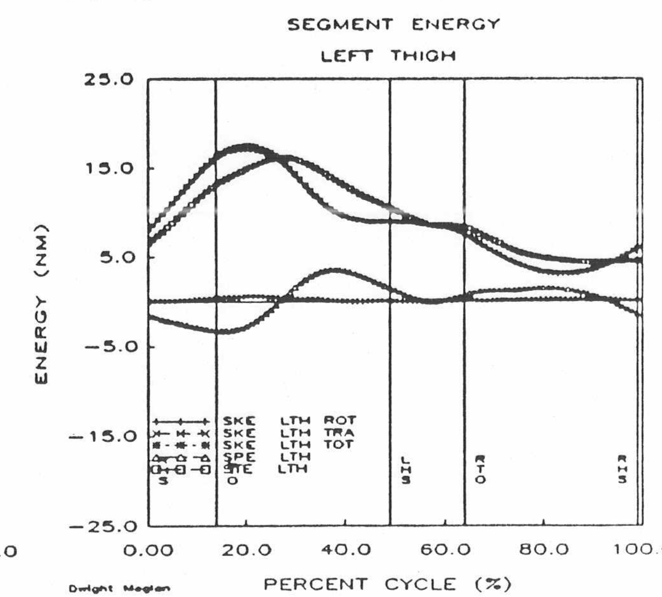

SEGMENT ENERGY
RIGHT FOOT
ENERGY (NM)
PERCENT CYCLE (%)
SKE RFT ROT
SKE RFT TRA
SKE RFT TOT
SPE RFT
STE RFT
Dwight Meglan

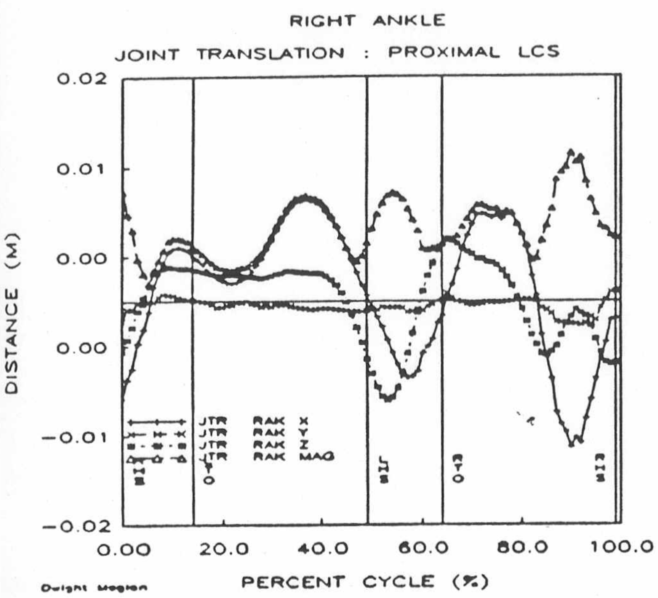

SEGMENT ENERGY
RIGHT CALF
ENERGY (NM)
PERCENT CYCLE (%)
SKE RCF ROT
SKE RCF TRA
SKE RCF TOT
SPE RCF
STE RCF
Dwight Meglan

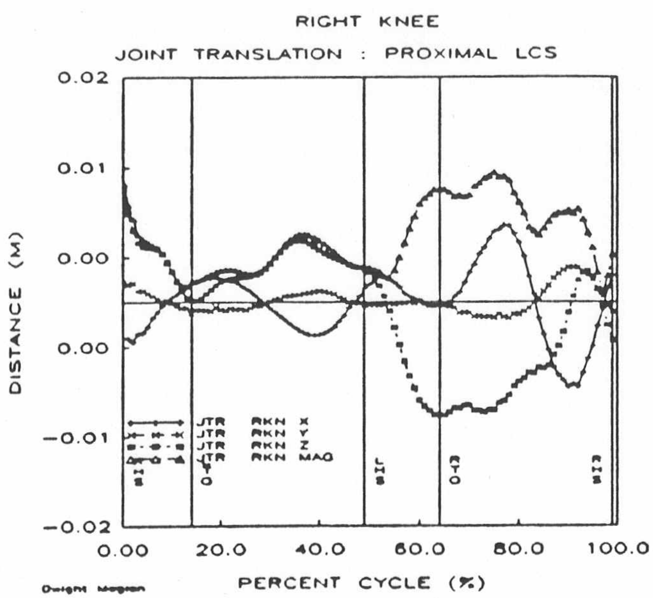

SEGMENT ENERGY
RIGHT THIGH
ENERGY (NM)
PERCENT CYCLE (%)
SKE RTH ROT
SKE RTH TRA
SKE RTH TOT
SPE RTH
STE RTH
Dwight Meglan

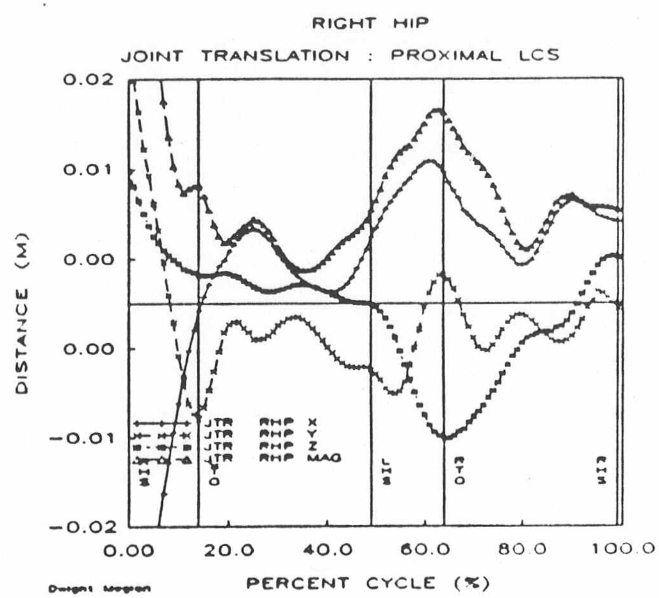

SEGMENT ENERGY
LEFT FOOT
ENERGY (NM)
PERCENT CYCLE (%)
SKE LFT ROT
SKE LFT TRA
SKE LFT TOT
SPE LFT
STE LFT
Dwight Meglan

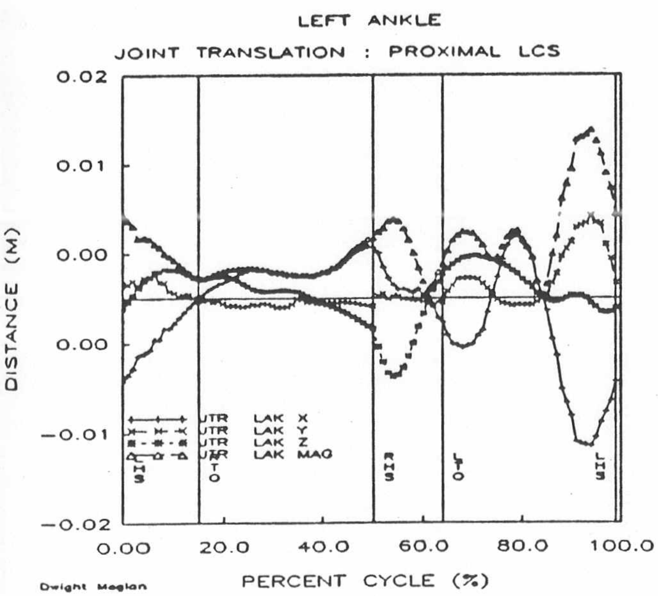

SEGMENT ENERGY
LEFT CALF
ENERGY (NM)
PERCENT CYCLE (%)
SKE LCF ROT
SKE LCF TRA
SKE LCF TOT
SPE LCF
STE LCF
Dwight Meglan

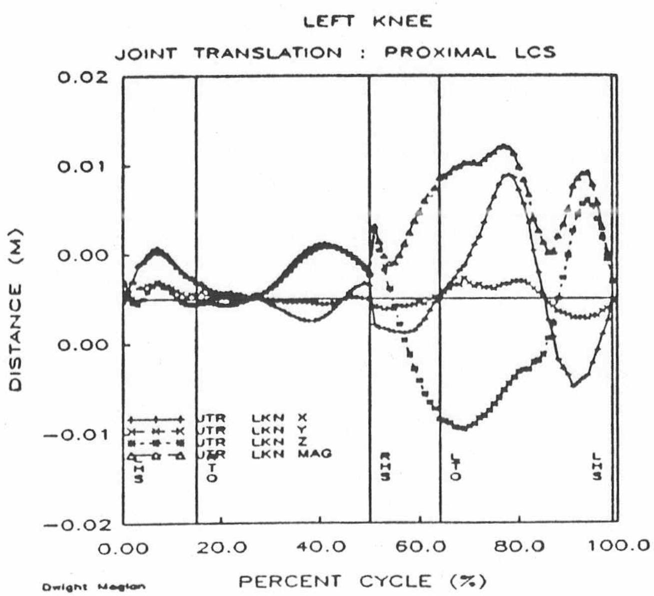

SEGMENT ENERGY
LEFT THIGH
ENERGY (NM)
PERCENT CYCLE (%)
SKE LTH ROT
SKE LTH TRA
SKE LTH TOT
SPE LTH
STE LTH
Dwight Meglan

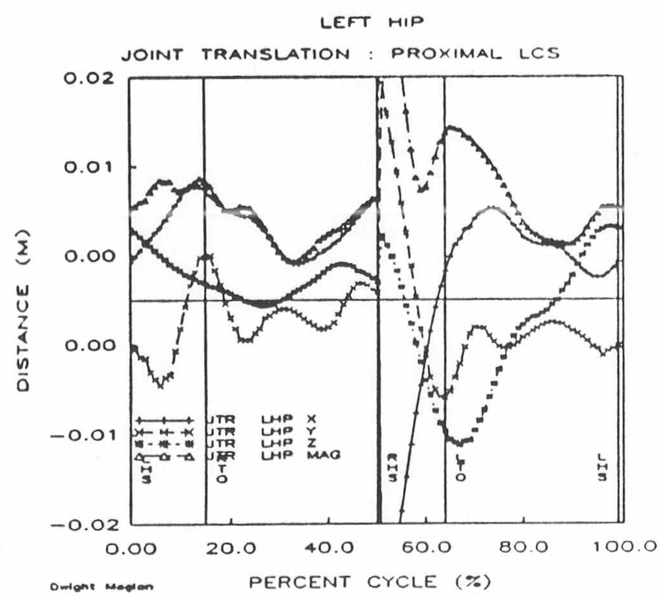

RIGHT ANKLE
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR RAK X
UTR RAK Y
UTR RAK Z
UTR RAK MAG
Dwight Meglan


RIGHT KNEE
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR RKN X
UTR RKN Y
UTR RKN Z
UTR RKN MAG
Dwight Meglan


RIGHT HIP
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR RHP X
UTR RHP Y
UTR RHP Z
UTR RHP MAG
Dwight Meglan

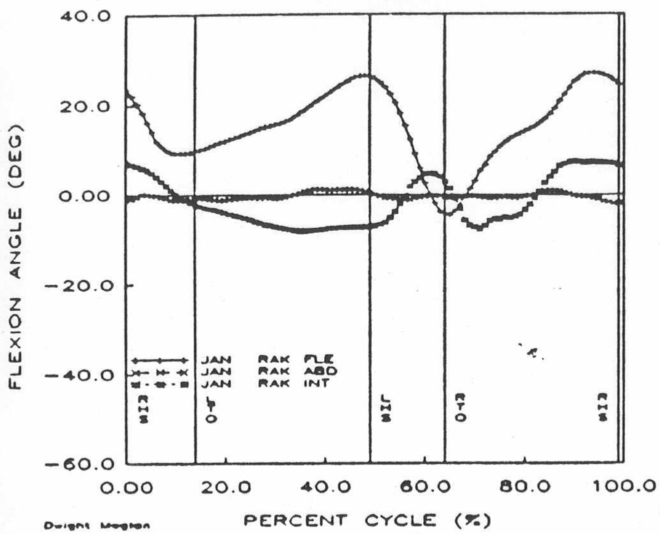

LEFT ANKLE
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR LAK X
UTR LAK Y
UTR LAK Z
UTR LAK MAG
Dwight Meglan


LEFT KNEE
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR LKN X
UTR LKN Y
UTR LKN Z
UTR LKN MAG
Dwight Meglan


LEFT HIP
JOINT TRANSLATION : PROXIMAL LCS
DISTANCE (M)
PERCENT CYCLE (%)
0.02
0.01
0.00
-0.01
-0.02
0.00
20.0
40.0
60.0
80.0
100.0
UTR LHP X
UTR LHP Y
UTR LHP Z
UTR LHP MAG
Dwight Meglan

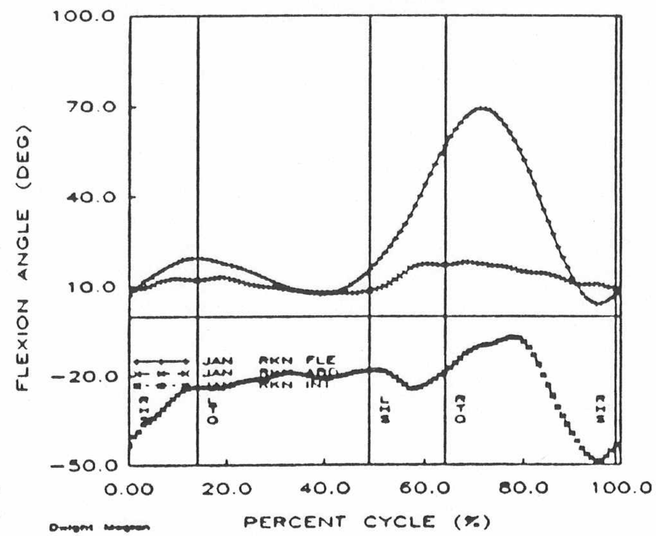
RIGHT ANKLE ANGLE

JCS ANGLES



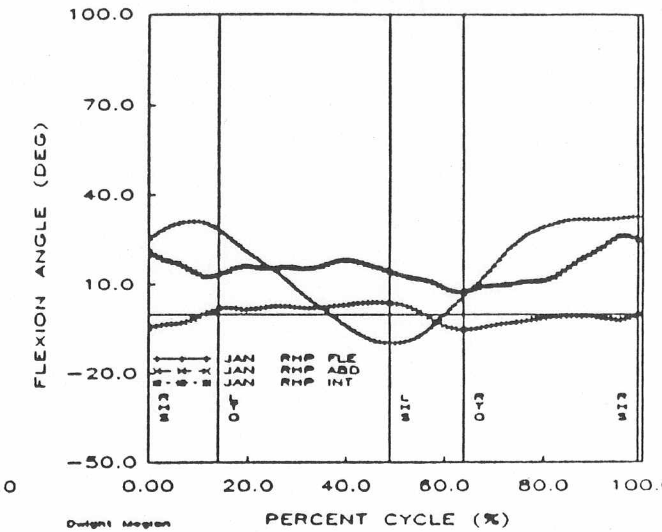
RIGHT KNEE ANGLE

JCS ANGLES



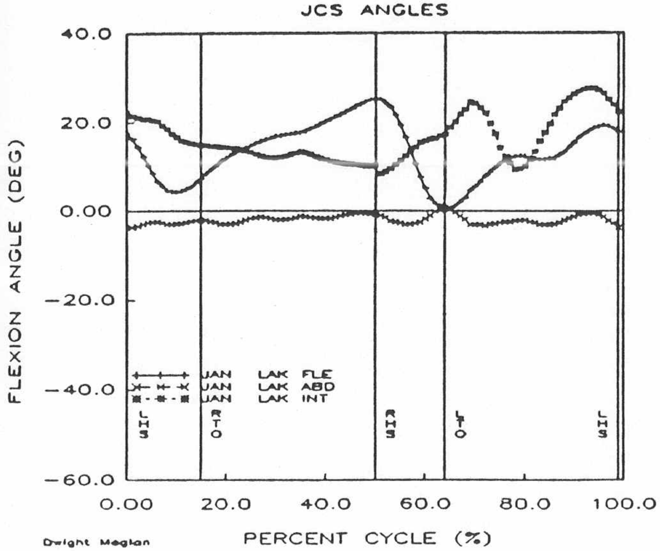
RIGHT HIP ANGLE

JCS ANGLES



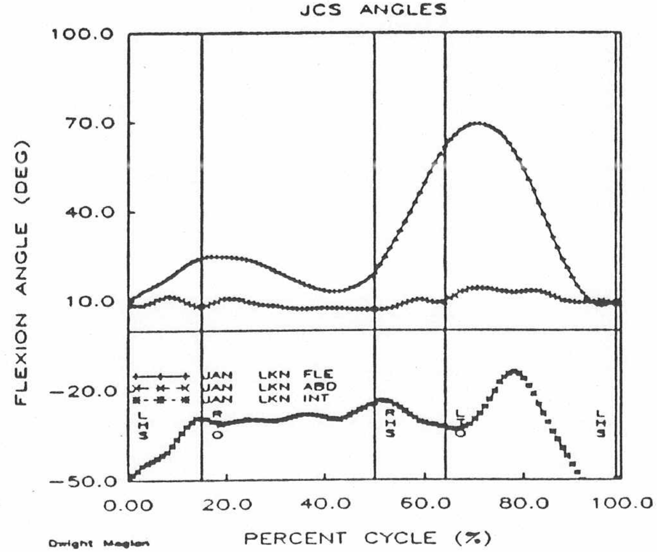
LEFT ANKLE ANGLE

JCS ANGLES



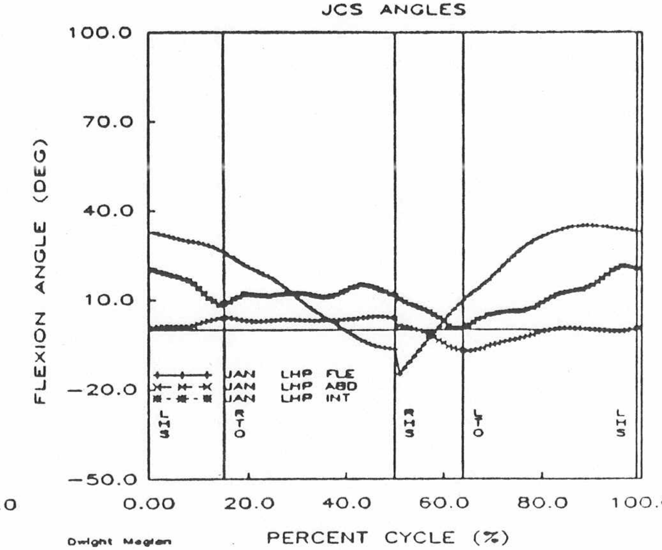
LEFT KNEE ANGLE

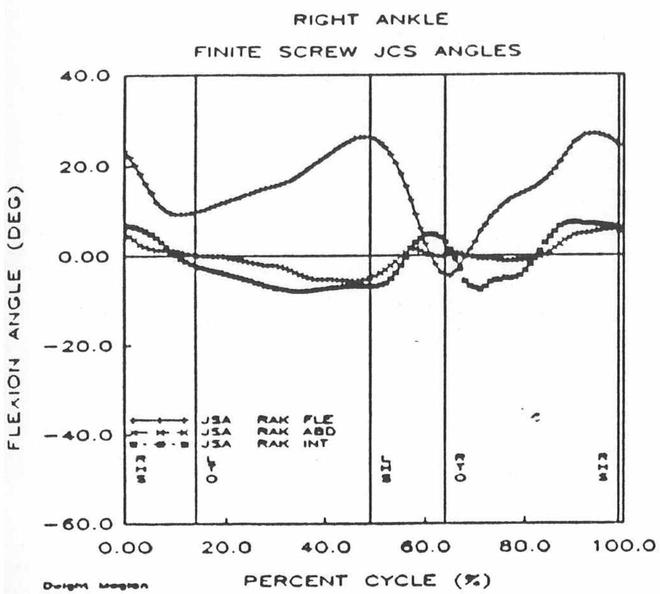
JCS ANGLES

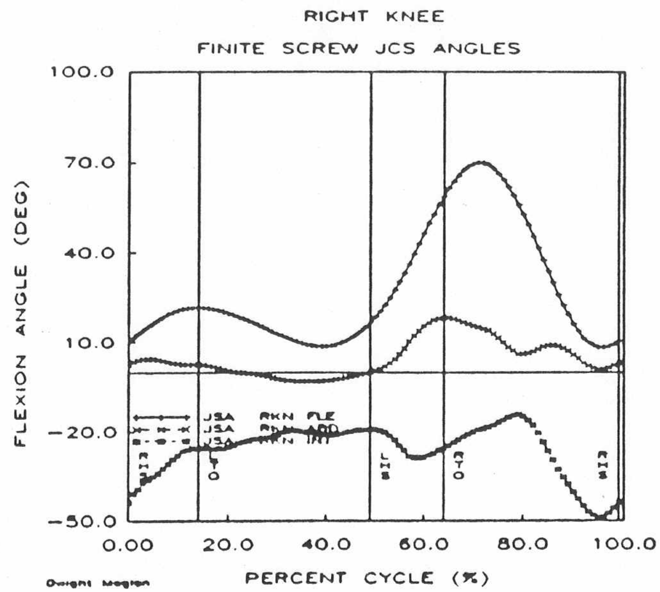


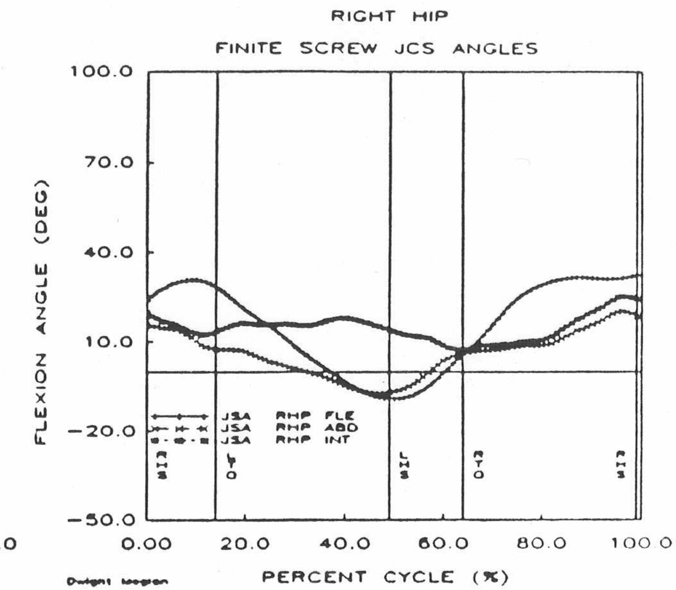
LEFT HIP ANGLE

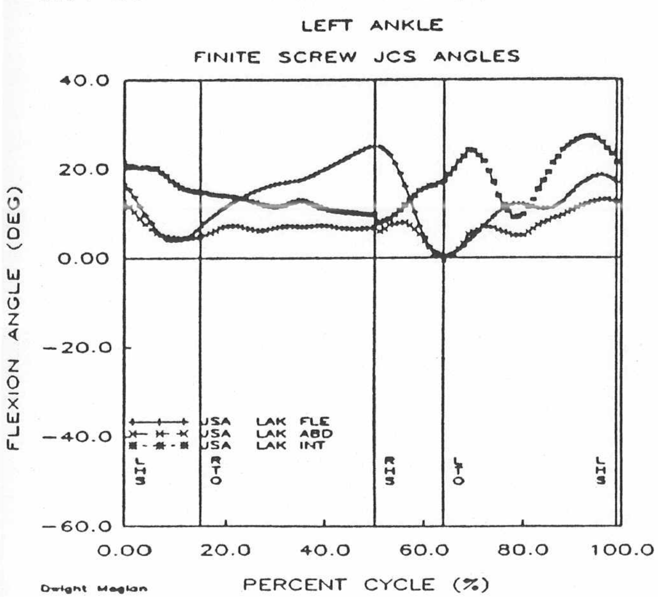
JCS ANGLES

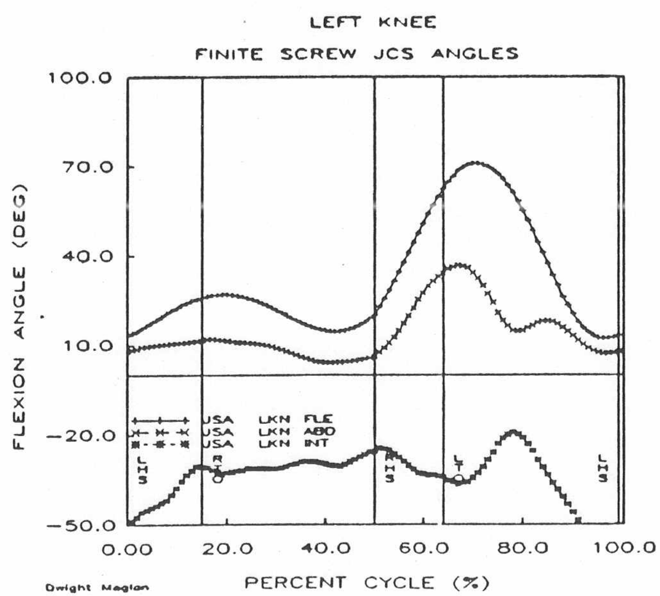


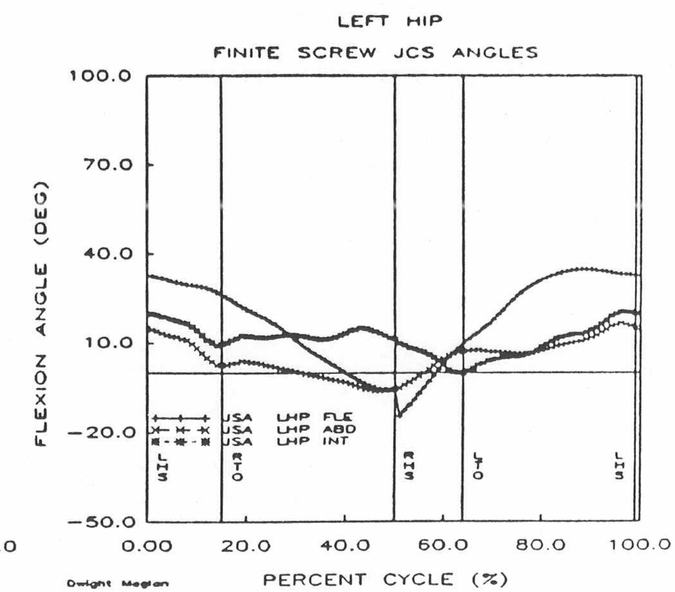

RIGHT ANKLE
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
40.0
20.0
0.00
−20.0
−40.0
−60.0
JSA RAK FLE
JSA RAK ABD
JSA RAK INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

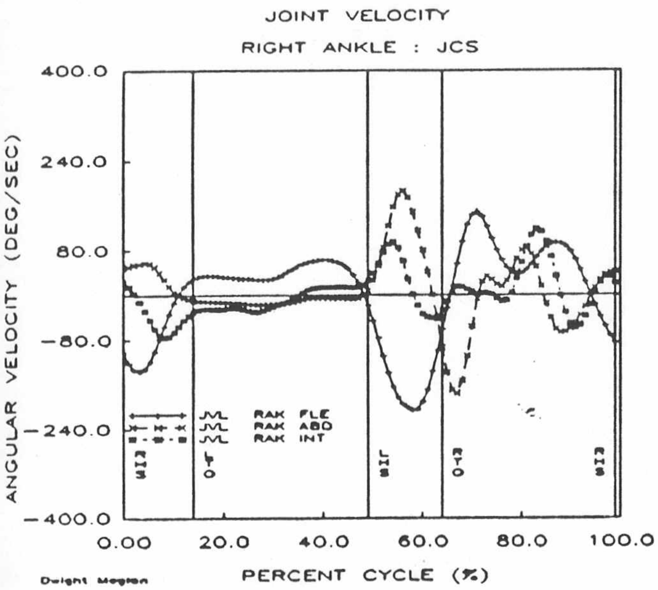

RIGHT KNEE
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
100.0
70.0
40.0
10.0
−20.0
−50.0
JSA RKN FLE
JSA RKN ABD
JSA RKN INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

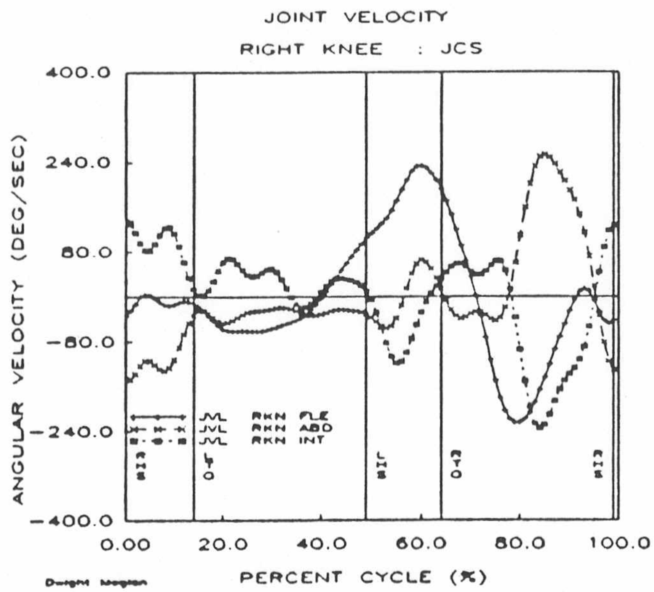

RIGHT HIP
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
100.0
70.0
40.0
10.0
−20.0
−50.0
JSA RHP FLE
JSA RHP ABD
JSA RHP INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

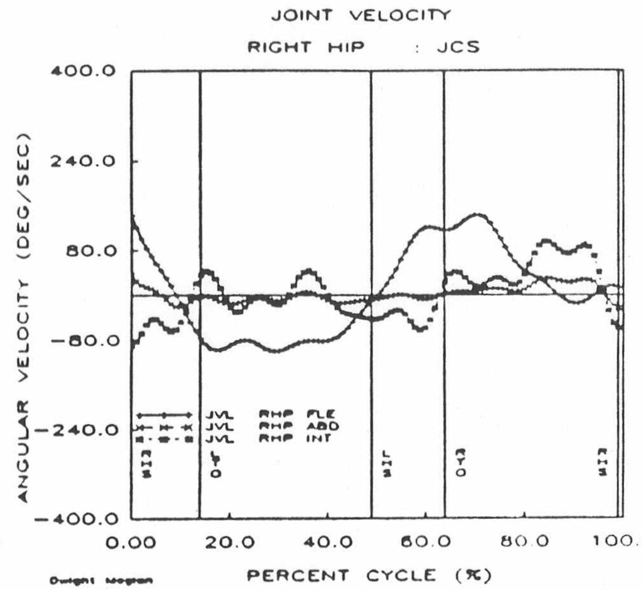

LEFT ANKLE
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
40.0
20.0
0.00
−20.0
−40.0
−60.0
JSA LAK FLE
JSA LAK ABD
JSA LAK INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

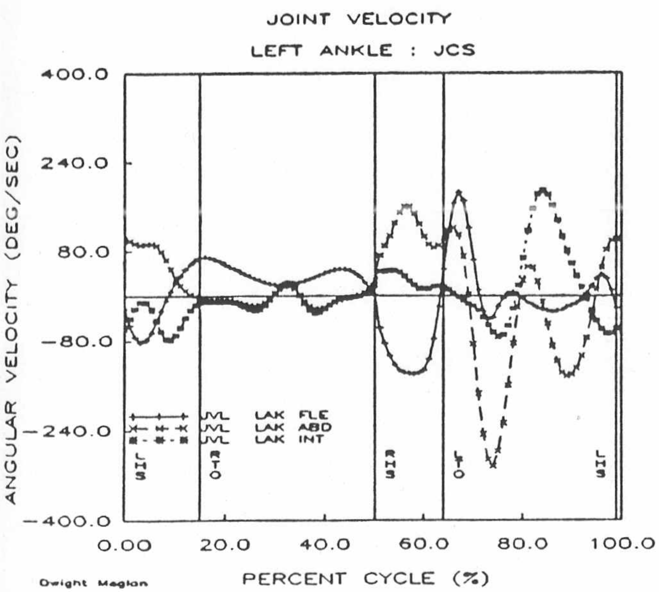

LEFT KNEE
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
100.0
70.0
40.0
10.0
−20.0
−50.0
JSA LKN FLE
JSA LKN ABD
JSA LKN INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

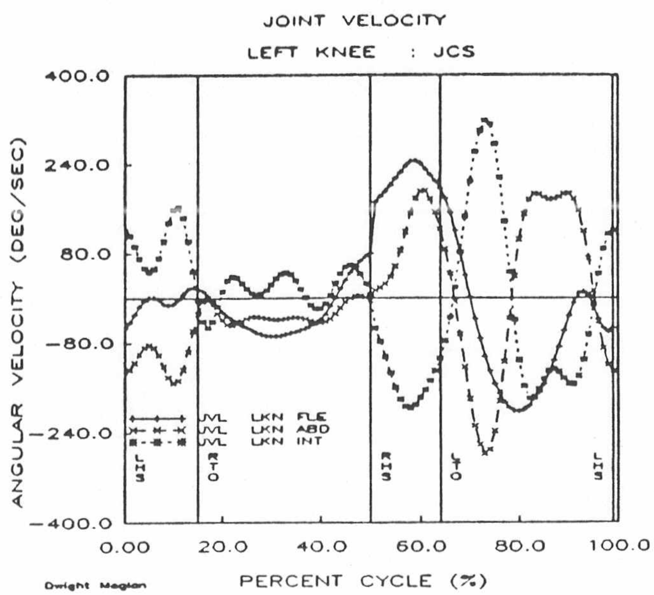

LEFT HIP
FINITE SCREW JCS ANGLES
FLEXION ANGLE (DEG)
100.0
70.0
40.0
10.0
−20.0
−50.0
JSA LHP FLE
JSA LHP ABD
JSA LHP INT
0.00 20.0 40.0 60.0 80.0 100.0
PERCENT CYCLE (%)
Dwight Meglan

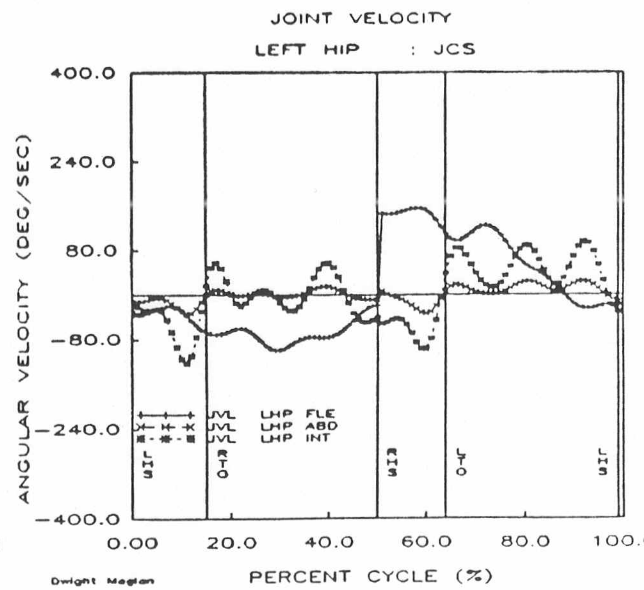

JOINT VELOCITY
RIGHT ANKLE : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL RAK FLE
JVL RAK ABD
JVL RAK INT
PERCENT CYCLE (%)
Dwight Meglan

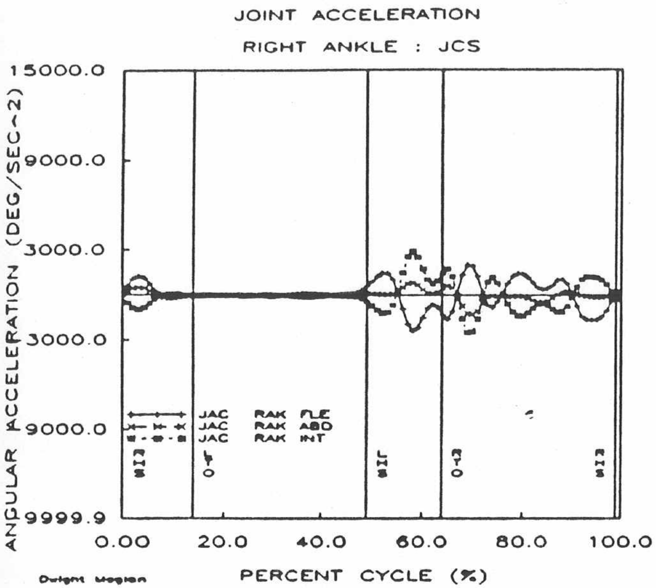

JOINT VELOCITY
RIGHT KNEE : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL RKN FLE
JVL RKN ABD
JVL RKN INT
PERCENT CYCLE (%)
Dwight Meglan

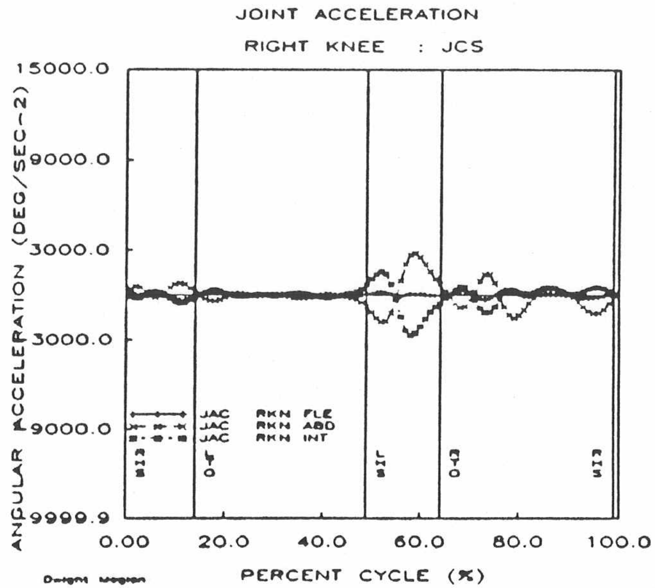

JOINT VELOCITY
RIGHT HIP : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL RHP FLE
JVL RHP ABD
JVL RHP INT
PERCENT CYCLE (%)
Dwight Meglan

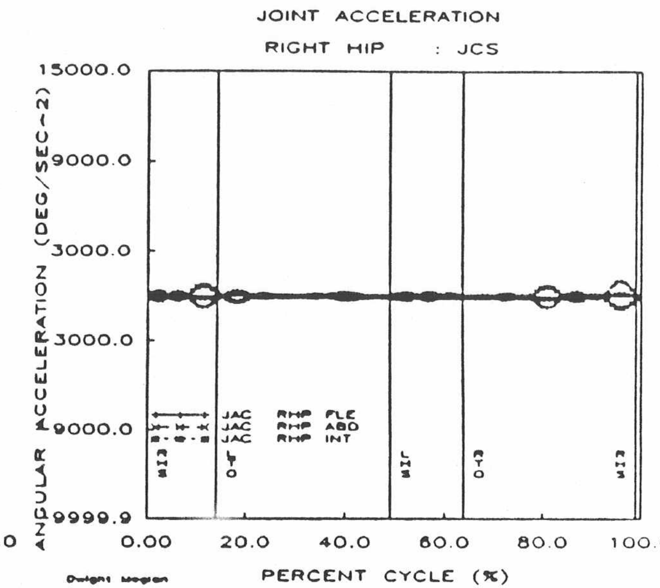

JOINT VELOCITY
LEFT ANKLE : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL LAK FLE
JVL LAK ABD
JVL LAK INT
PERCENT CYCLE (%)
Dwight Meglan

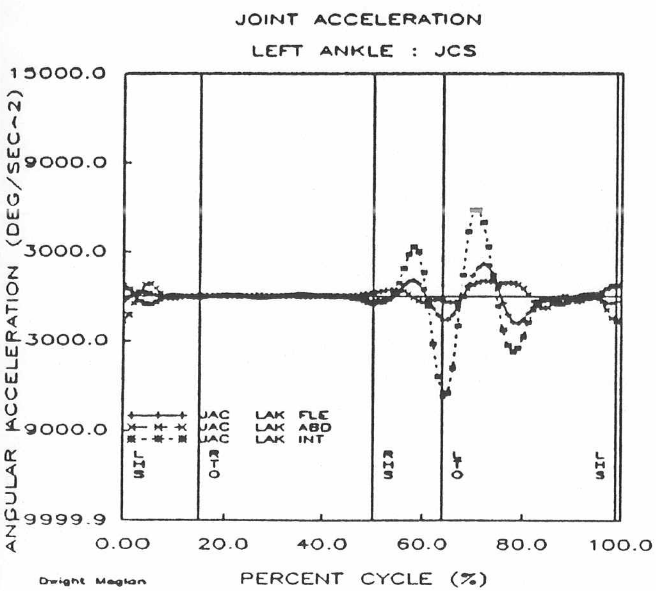

JOINT VELOCITY
LEFT KNEE : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL LKN FLE
JVL LKN ABD
JVL LKN INT
PERCENT CYCLE (%)
Dwight Meglan

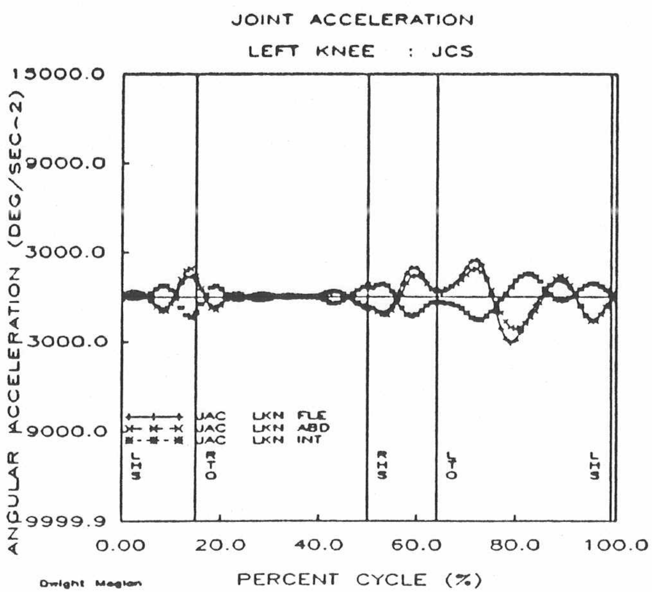

JOINT VELOCITY
LEFT HIP : JCS
ANGULAR VELOCITY (DEG/SEC)
400.0
240.0
80.0
−80.0
−240.0
−400.0
0.00
20.0
40.0
60.0
80.0
100.0
JVL LHP FLE
JVL LHP ABD
JVL LHP INT
PERCENT CYCLE (%)
Dwight Meglan

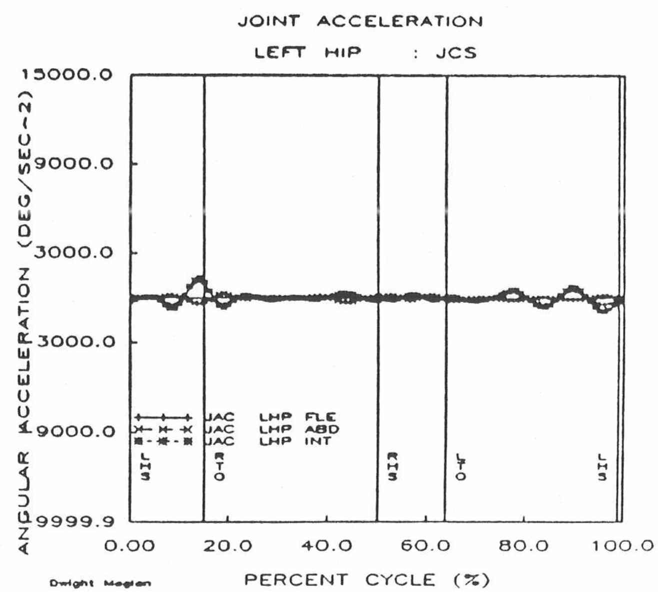

JOINT ACCELERATION
RIGHT ANKLE : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC RAK FLE
JAC RAK ABD
JAC RAK INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan


JOINT ACCELERATION
RIGHT KNEE : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC RKN FLE
JAC RKN ABD
JAC RKN INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan

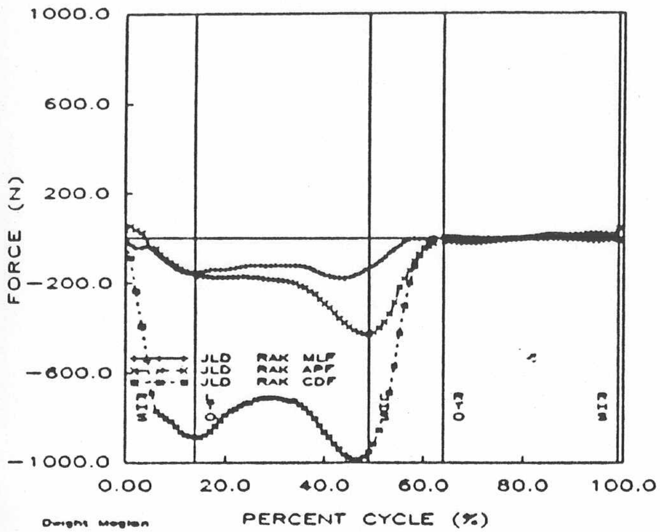

JOINT ACCELERATION
RIGHT HIP : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC RHP FLE
JAC RHP ABD
JAC RHP INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan


JOINT ACCELERATION
LEFT ANKLE : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC LAK FLE
JAC LAK ABD
JAC LAK INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan

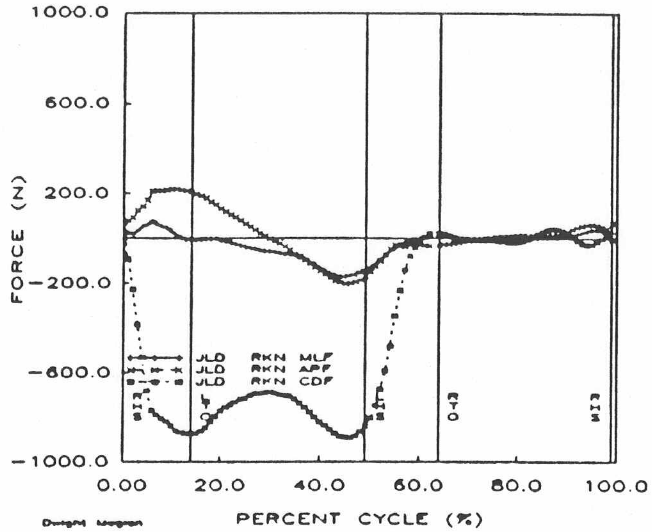

JOINT ACCELERATION
LEFT KNEE : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC LKN FLE
JAC LKN ABD
JAC LKN INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan


JOINT ACCELERATION
LEFT HIP : JCS
ANGULAR ACCELERATION (DEG/SEC-2)
15000.0
9000.0
3000.0
3000.0
9000.0
9999.9
JAC LHP FLE
JAC LHP ABD
JAC LHP INT
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE (%)
Dwight Meglan

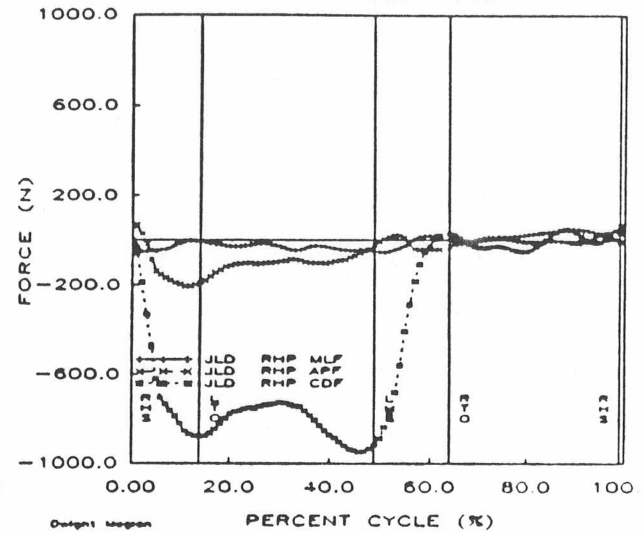
RIGHT ANKLE
JOINT FORCES : JCS



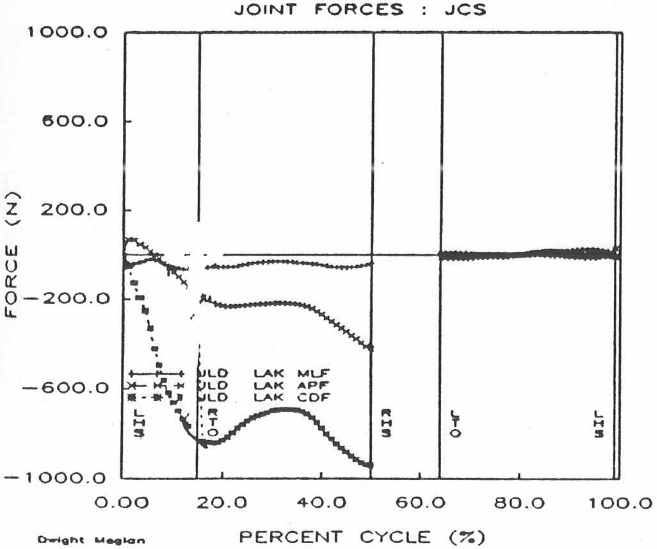
RIGHT KNEE
JOINT FORCES : JCS



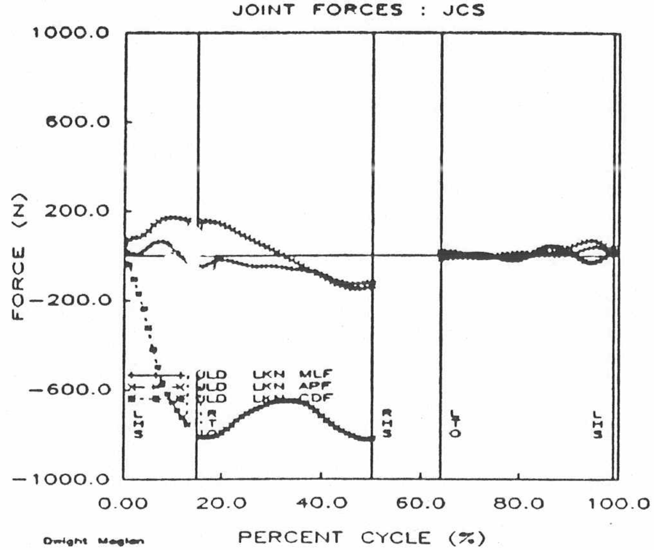
RIGHT HIP
JOINT FORCES : JCS



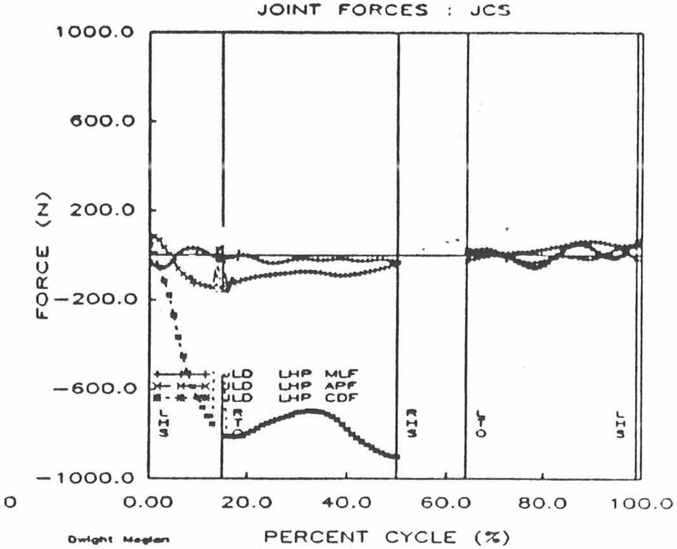
LEFT ANKLE
JOINT FORCES : JCS

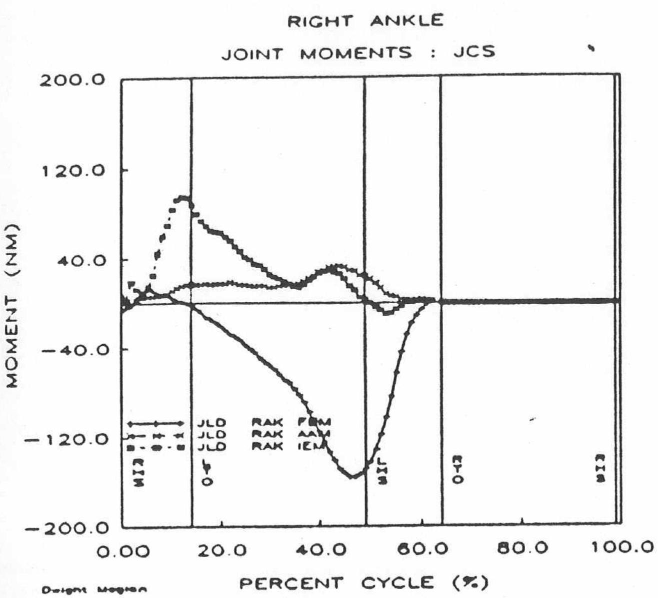


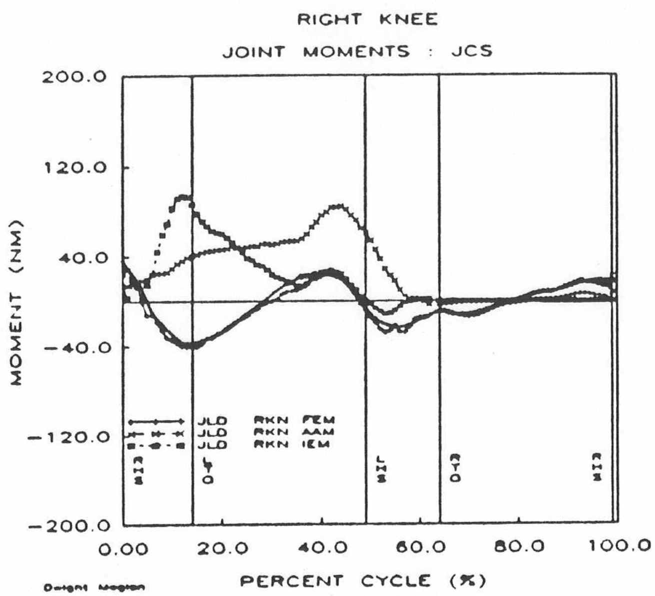
LEFT KNEE
JOINT FORCES : JCS

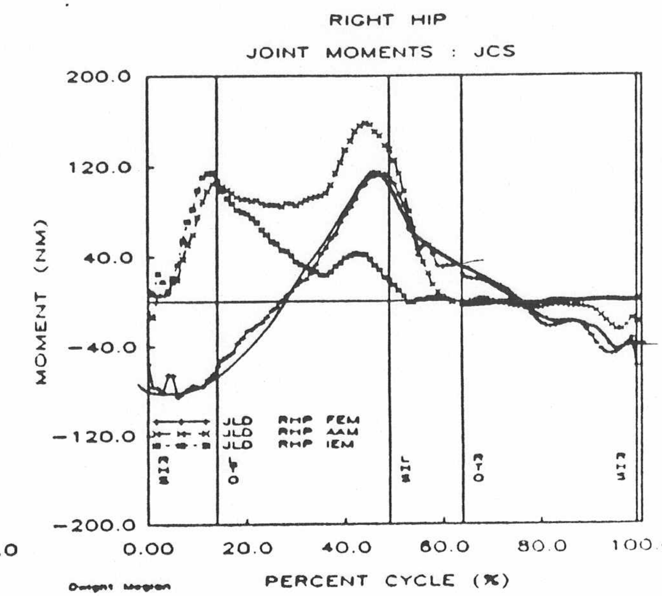


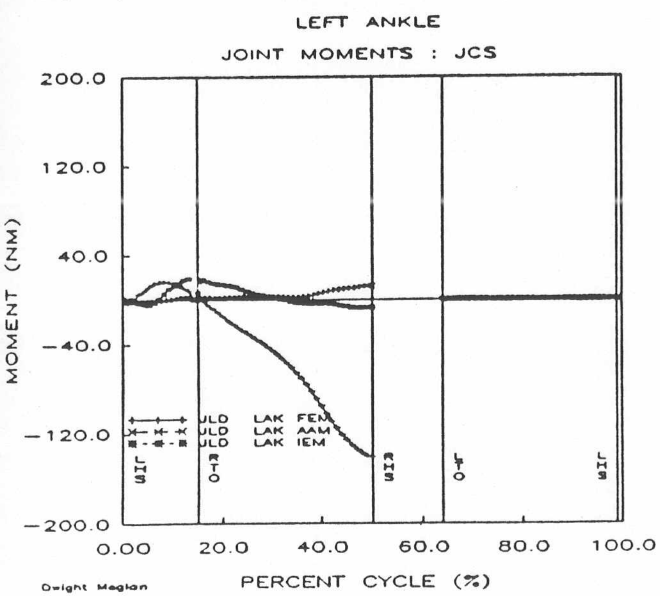
LEFT HIP
JOINT FORCES : JCS

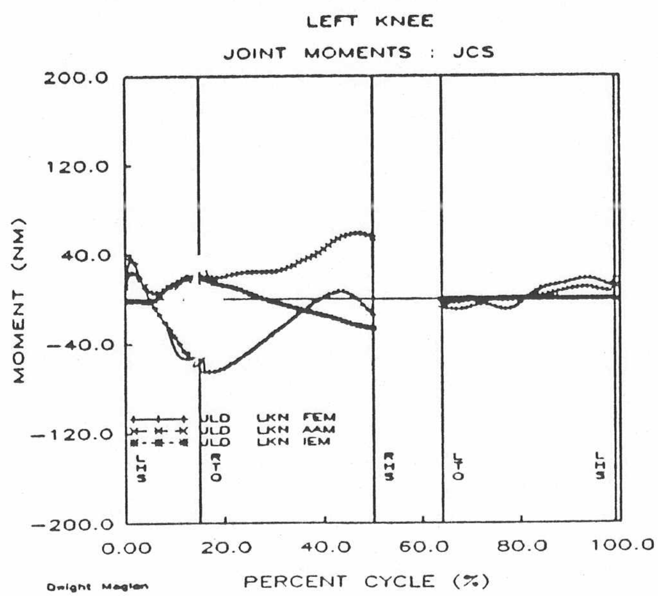


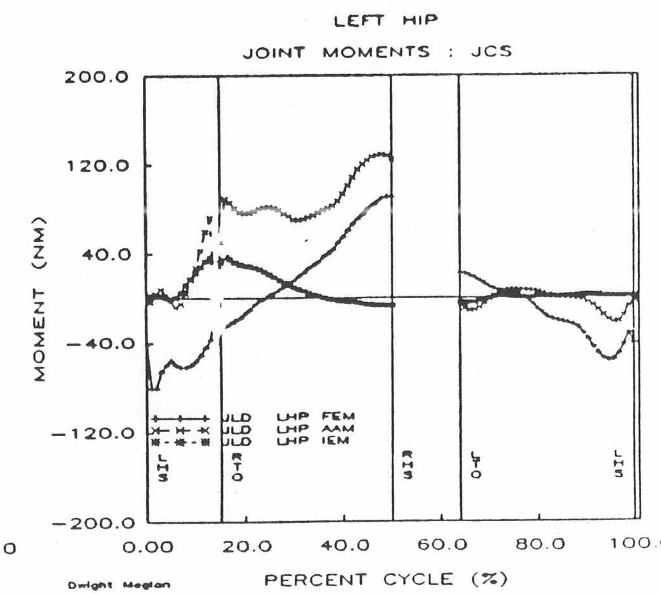

RIGHT ANKLE
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD RAK FEM
JLD RAK AAM
JLD RAK IEM
Dwight Meglan


RIGHT KNEE
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD RKN FEM
JLD RKN AAM
JLD RKN IEM
Dwight Meglan

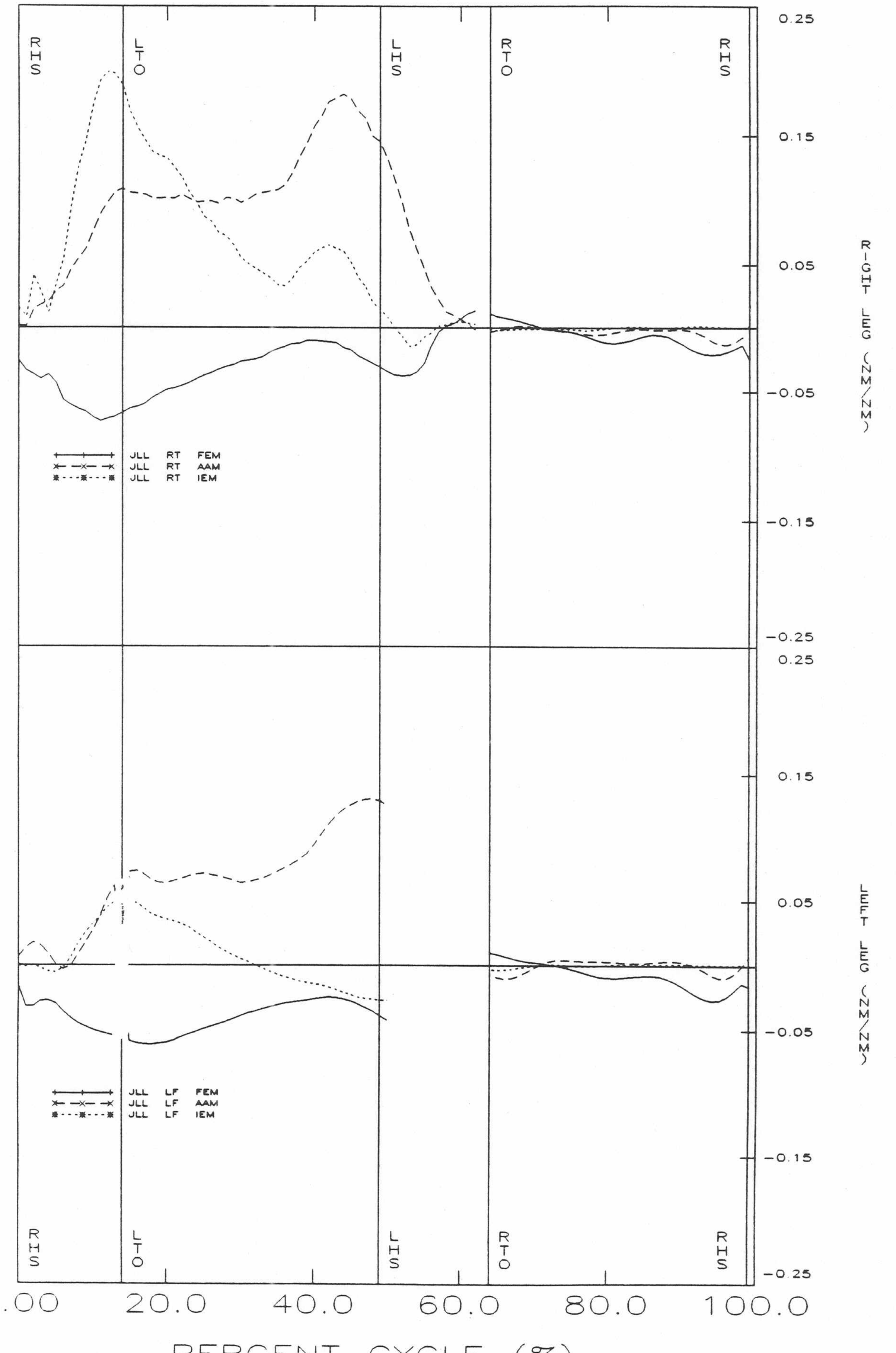

RIGHT HIP
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD RHP FEM
JLD RHP AAM
JLD RHP IEM
Dwight Meglan


LEFT ANKLE
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD LAK FEM
JLD LAK AAM
JLD LAK IEM
Dwight Meglan


LEFT KNEE
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD LKN FEM
JLD LKN AAM
JLD LKN IEM
Dwight Meglan

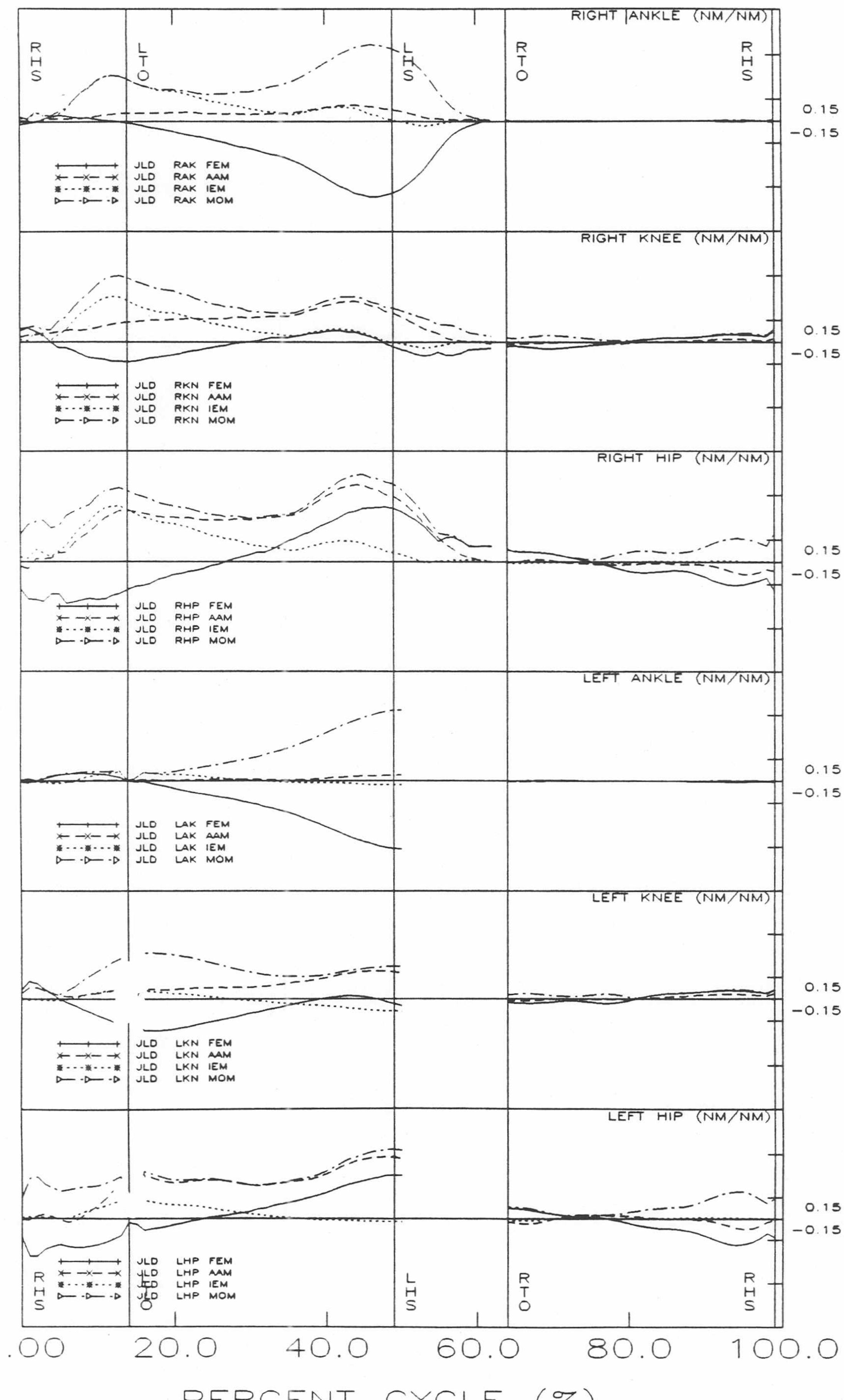

LEFT HIP
JOINT MOMENTS : JCS
MOMENT (NM)
PERCENT CYCLE (%)
JLD LHP FEM
JLD LHP AAM
JLD LHP IEM
Dwight Meglan

MMED LEG MOMENTS NORMWTHT : JCS

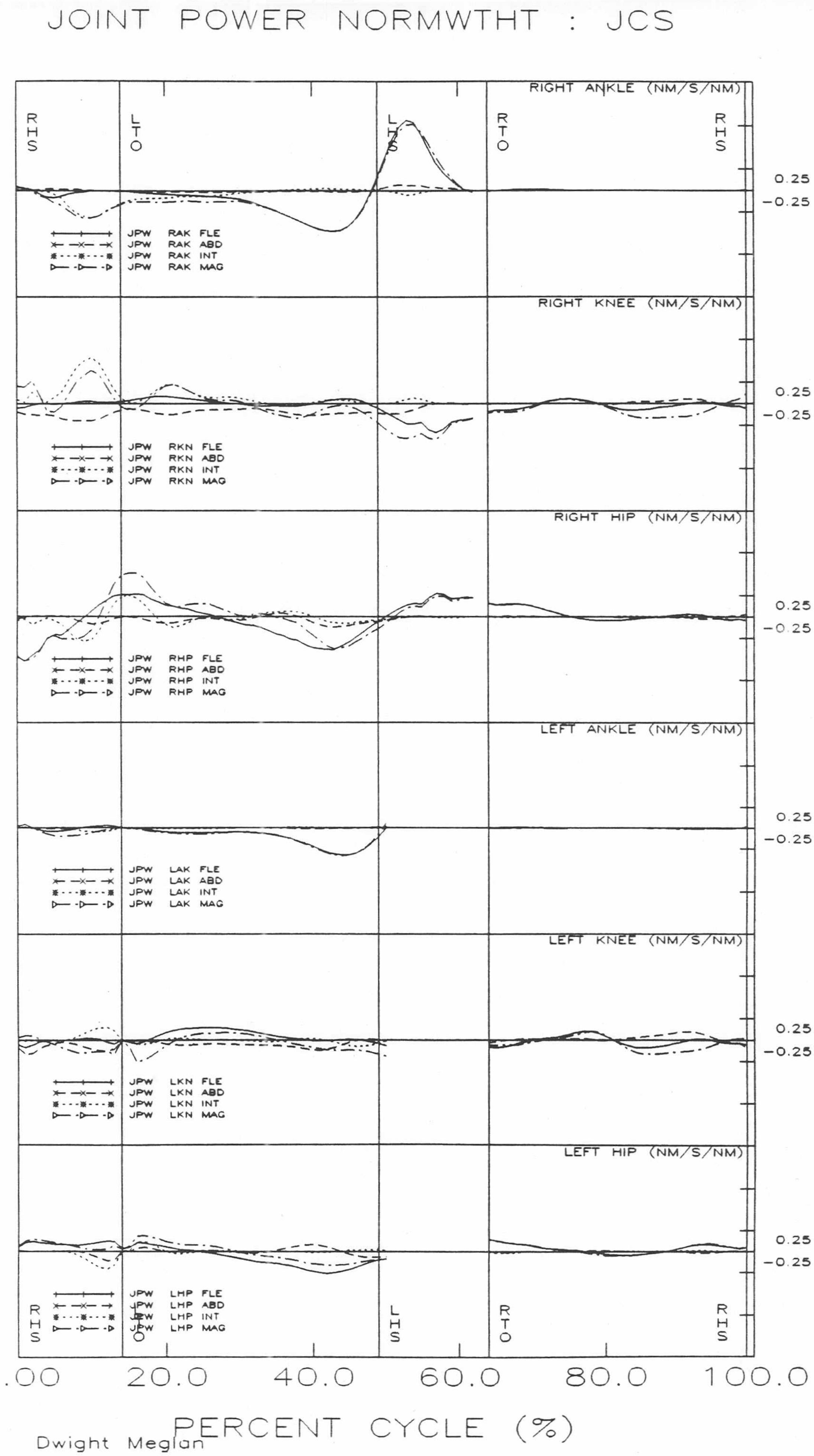


Dwight Meglan

JOINT MOMENTS NORMWTHT : JCS

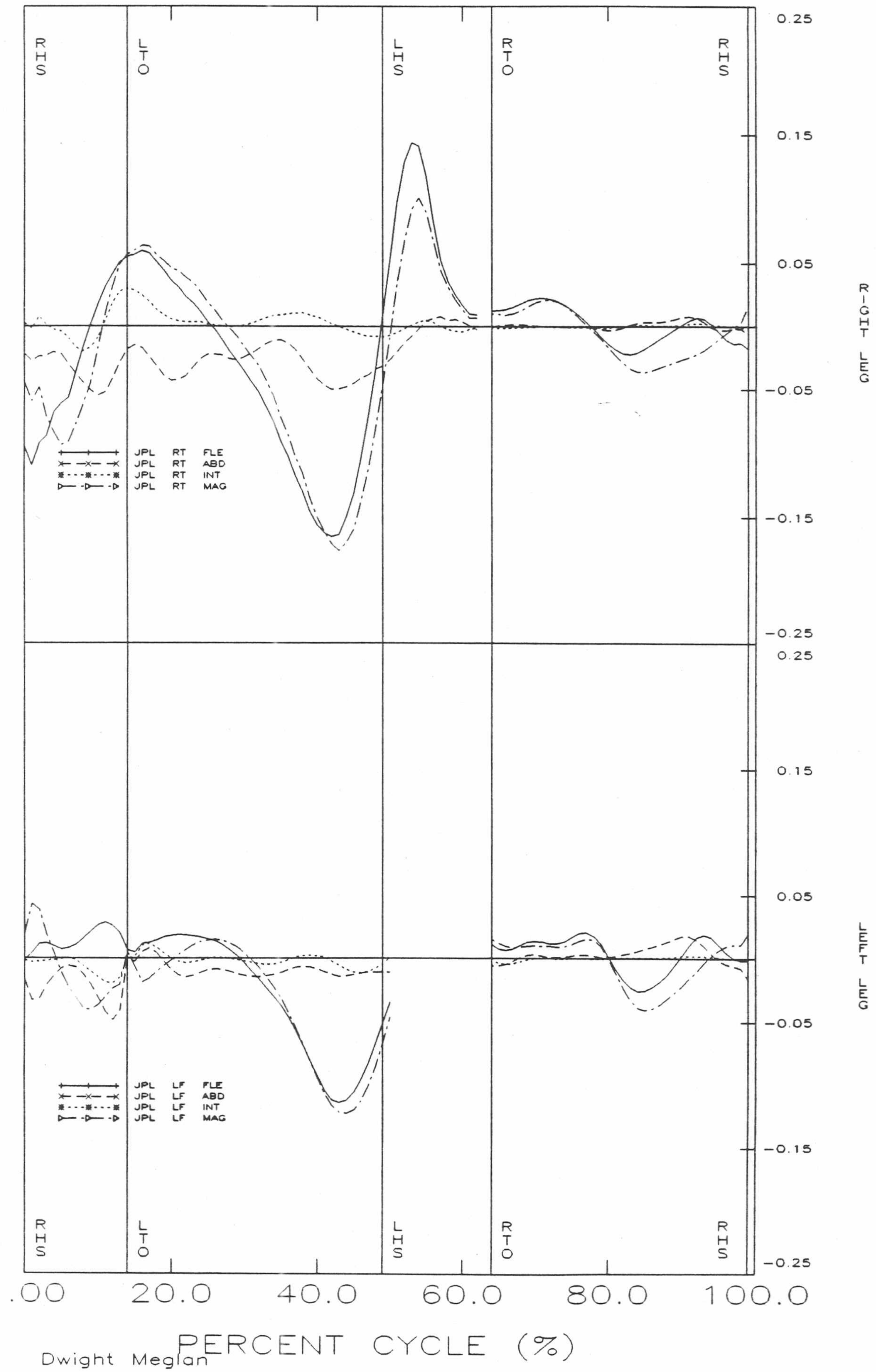


Dwight Meglan

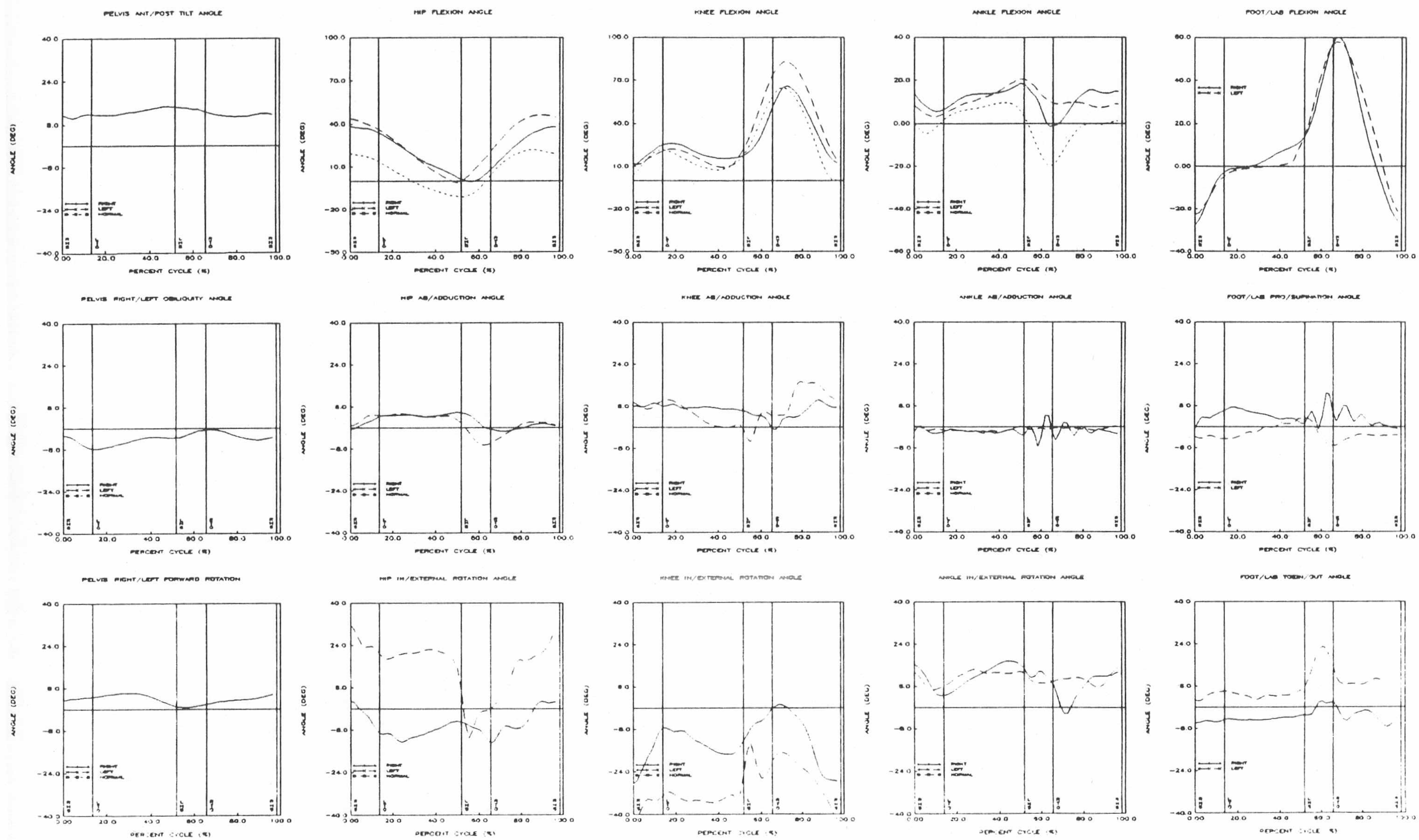


Dwight Meglan

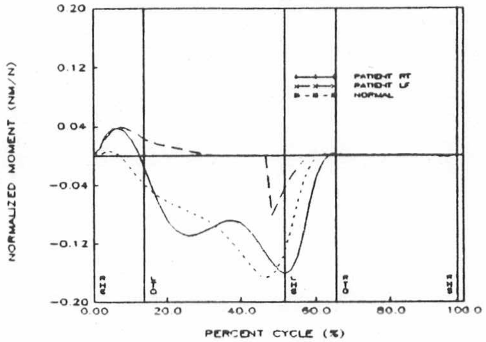
.UMMED LEG POWER NORMWTHT : JCS



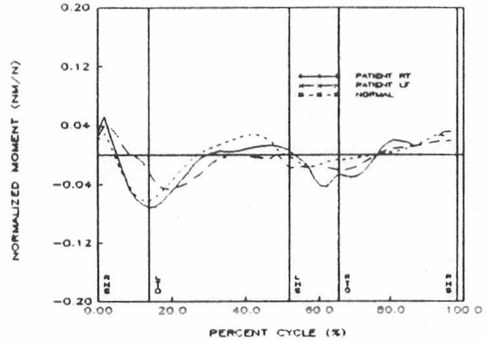
Dwight Meglan


PELVIS ANT/POST TILT ANGLE
HIP FLEXION ANGLE
KNEE FLEXION ANGLE
ANKLE FLEXION ANGLE
FOOT/LAB FLEXION ANGLE
PELVIS RIGHT/LEFT OBLIQUITY ANGLE
HIP AB/ADDUCTION ANGLE
KNEE AB/ADDUCTION ANGLE
ANKLE AB/ADDUCTION ANGLE
FOOT/LAB PRO/SUPINATION ANGLE
PELVIS RIGHT/LEFT FORWARD ROTATION
HIP IN/EXTERNAL ROTATION ANGLE
KNEE IN/EXTERNAL ROTATION ANGLE
ANKLE IN/EXTERNAL ROTATION ANGLE
FOOT/LAB TOEIN/OUT ANGLE
ANGLE (DEG)
PERCENT CYCLE (%)
RIGHT
LEFT
NORMAL

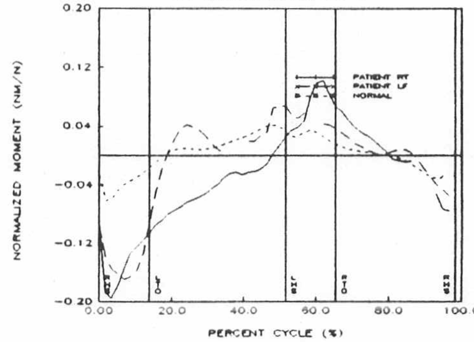
NORMALIZED JOINT MOMENTS
ANKLE FLEX/EXTENSION (+/-)



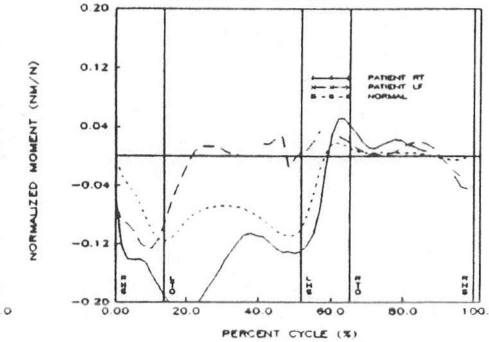
NORMALIZED JOINT MOMENTS
KNEE FLEX/EXTENSION (-/+)



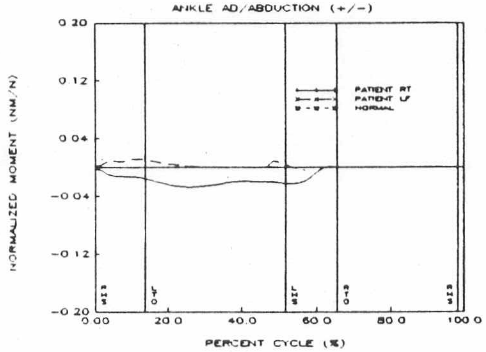
NORMALIZED JOINT MOMENTS
HIP FLEX/EXTENSION (+/-)



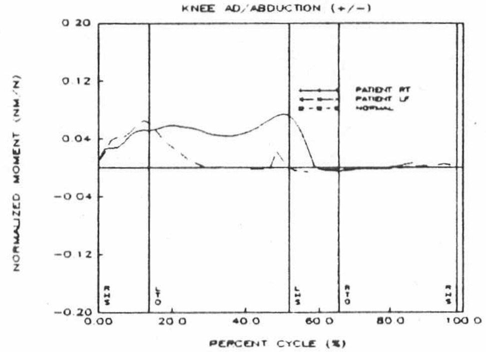
NORMALIZED JOINT MOMENTS
SUPPORT FLEX/EXTENSION (+/-)



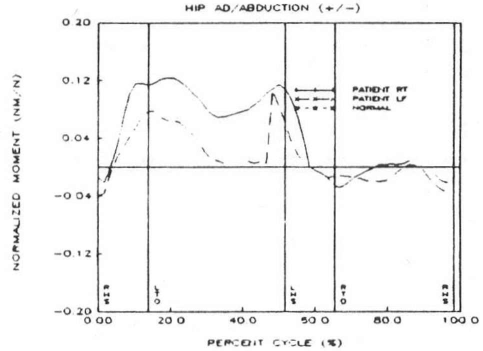
NORMALIZED JOINT MOMENTS
ANKLE AD/ABDUCTION (+/-)



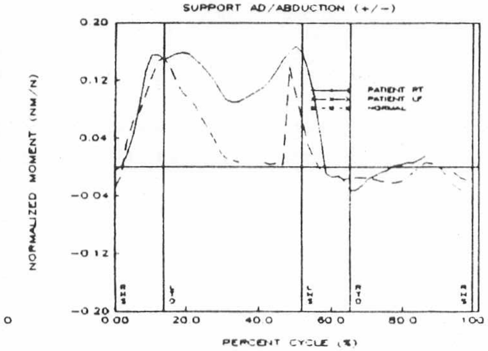
NORMALIZED JOINT MOMENTS
KNEE AD/ABDUCTION (+/-)



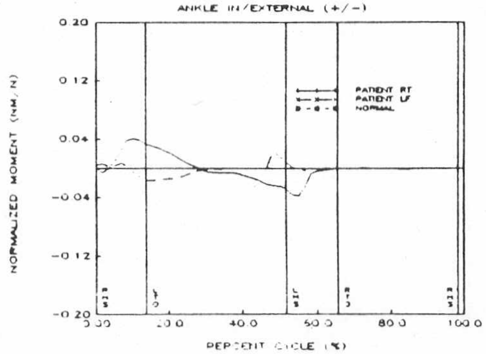
NORMALIZED JOINT MOMENTS
HIP AD/ABDUCTION (+/-)



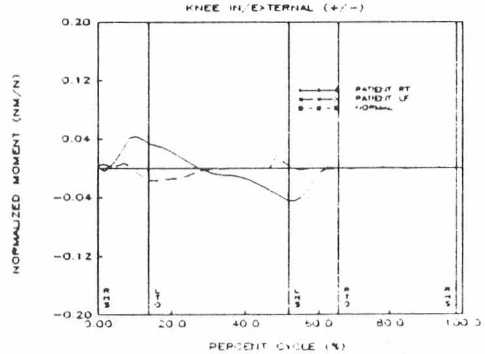
NORMALIZED JOINT MOMENTS
SUPPORT AD/ABDUCTION (+/-)



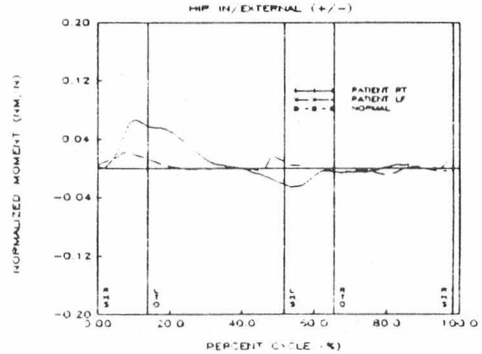
NORMALIZED JOINT MOMENTS
ANKLE IN/EXTERNAL (+/-)



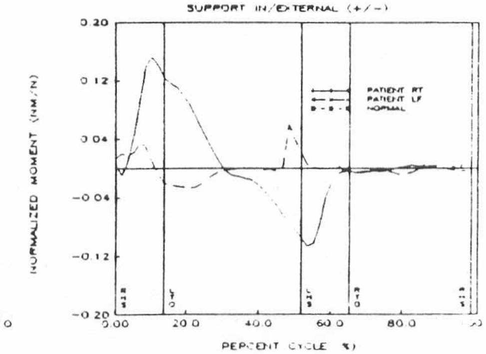
NORMALIZED JOINT MOMENTS
KNEE IN/EXTERNAL (+/-)

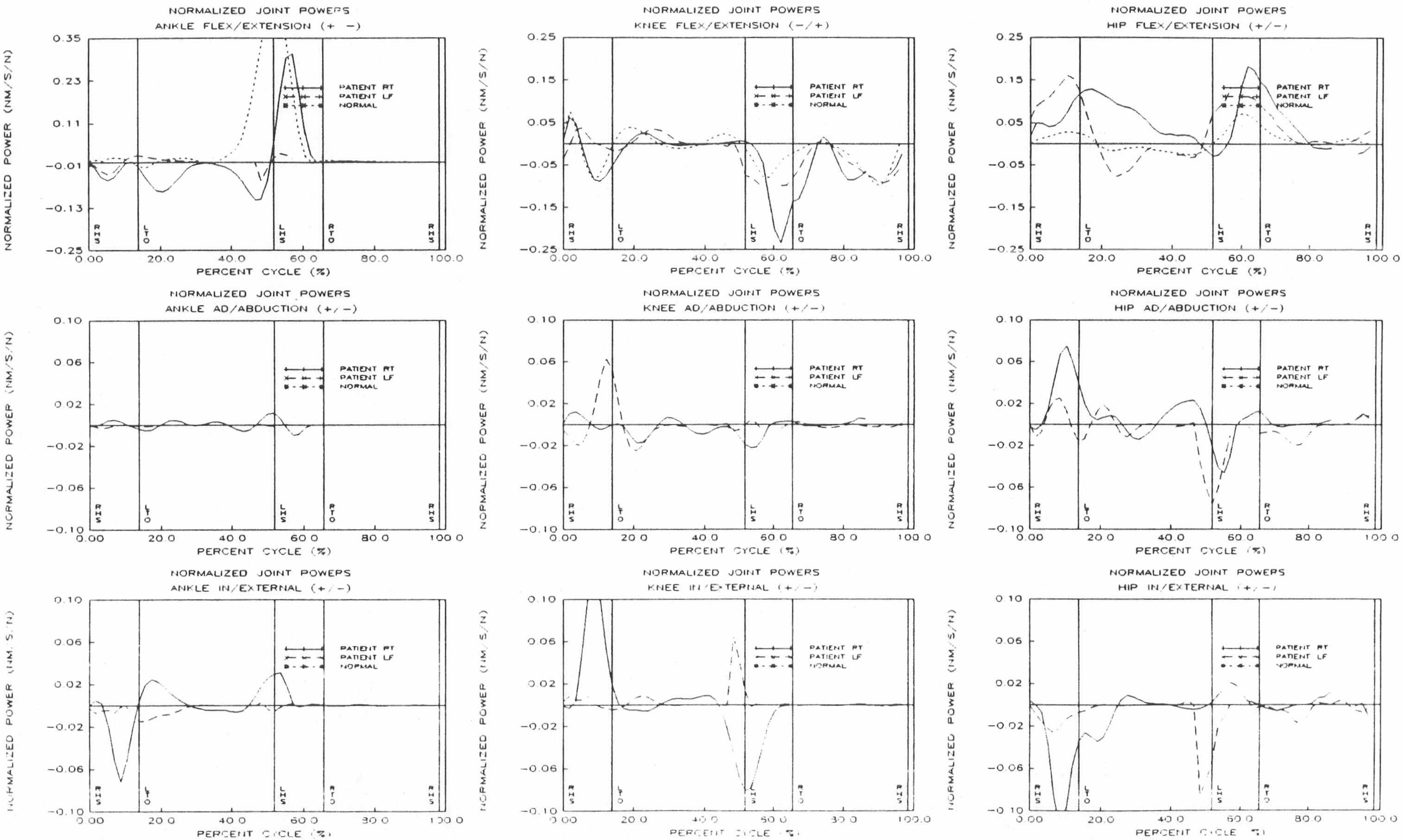


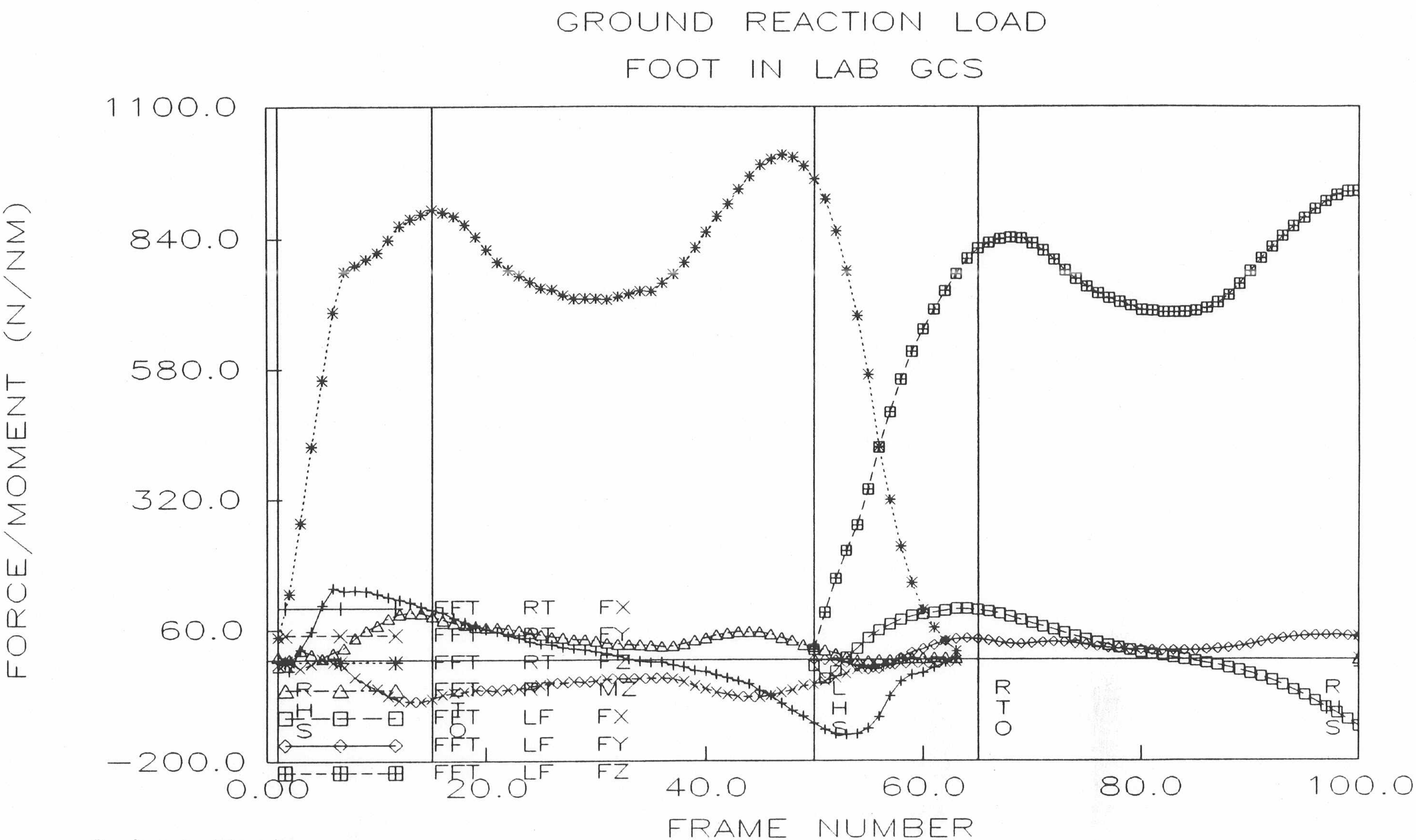
NORMALIZED JOINT MOMENTS
HIP IN/EXTERNAL (+/-)



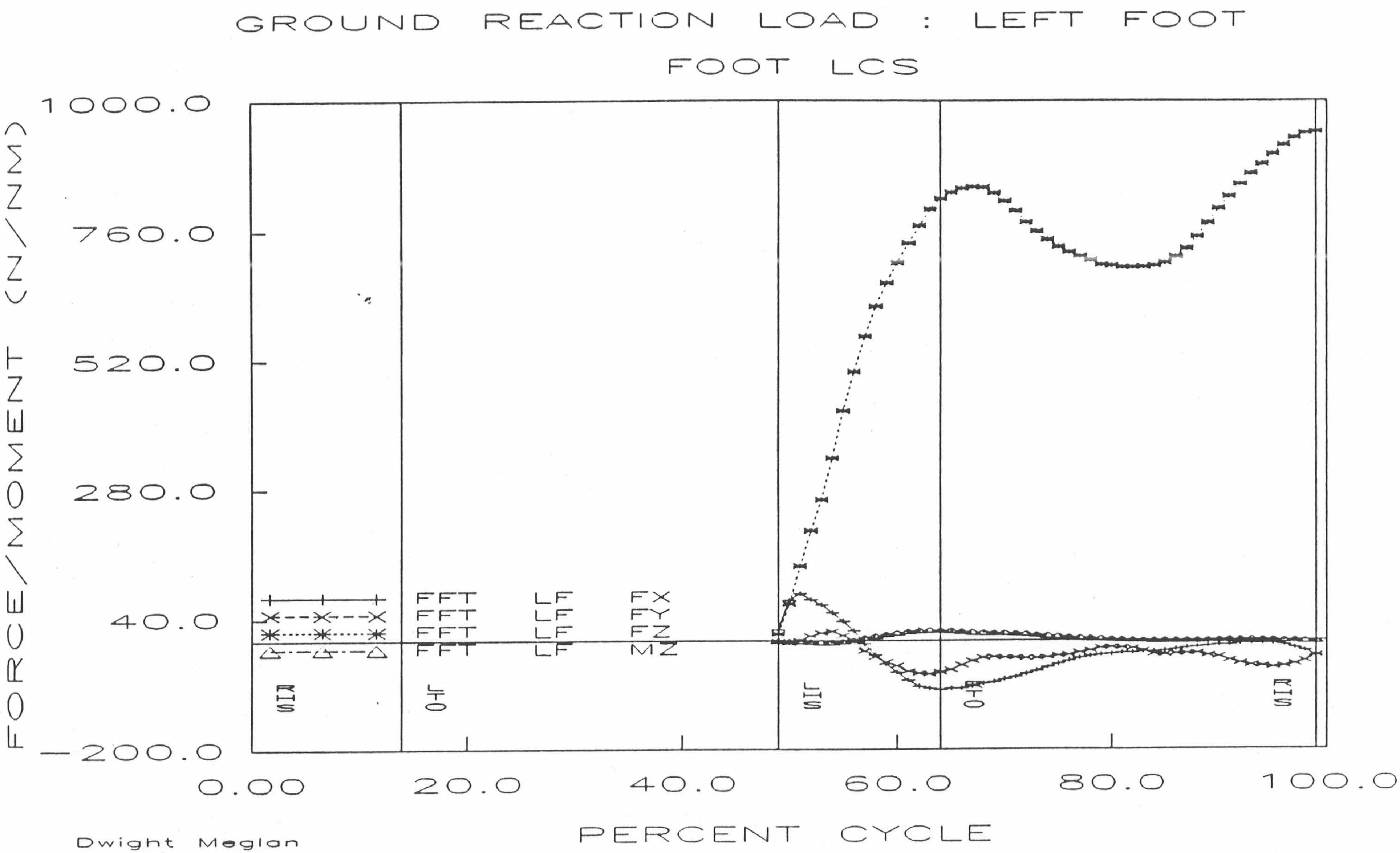
NORMALIZED JOINT MOMENTS
SUPPORT IN/EXTERNAL (+/-)



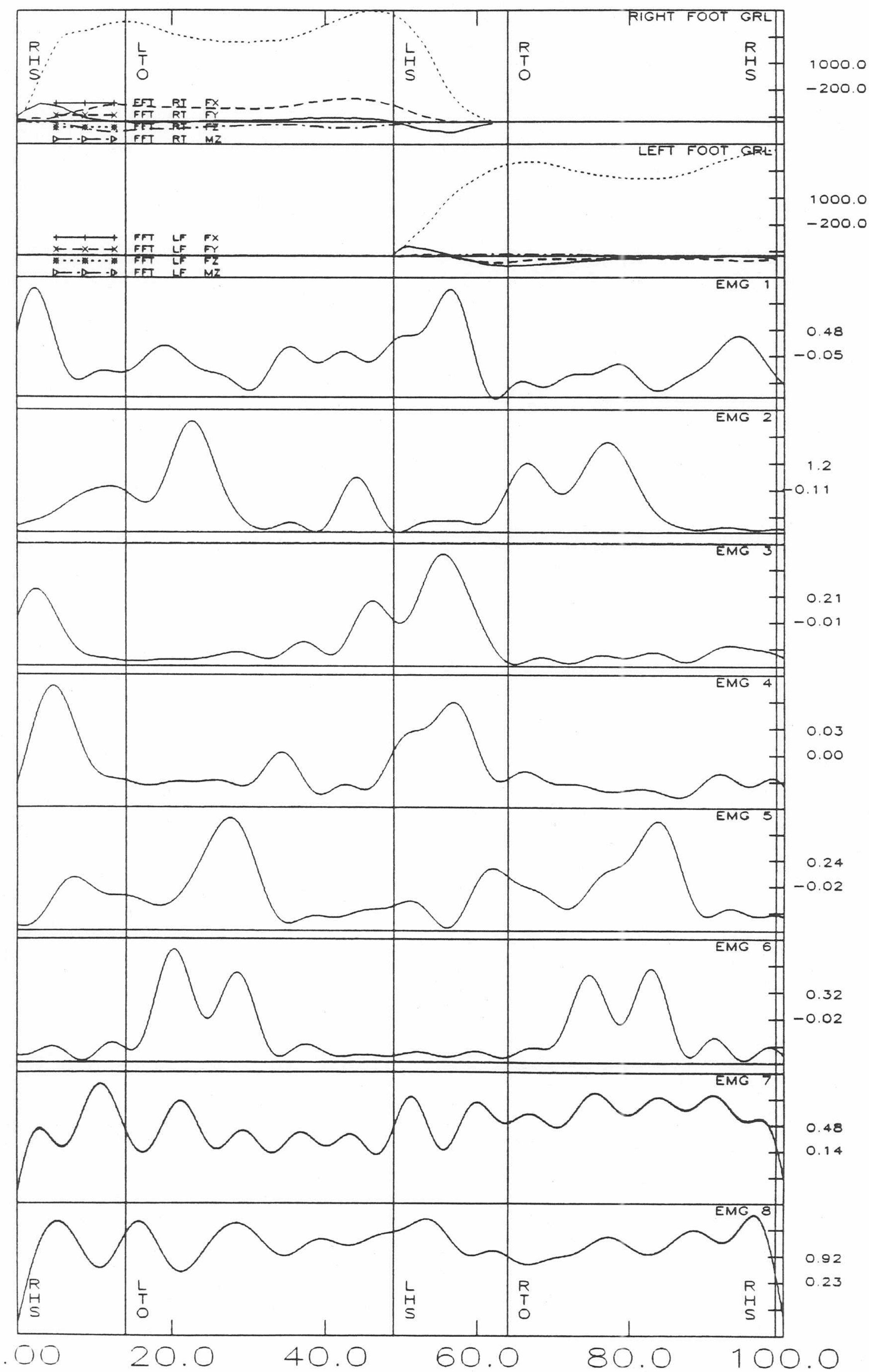

NORMALIZED JOINT POWERS
ANKLE FLEX/EXTENSION (+ −)
NORMALIZED JOINT POWERS
KNEE FLEX/EXTENSION (−/+)
NORMALIZED JOINT POWERS
HIP FLEX/EXTENSION (+/−)
NORMALIZED JOINT POWERS
ANKLE AD/ABDUCTION (+/−)
NORMALIZED JOINT POWERS
KNEE AD/ABDUCTION (+/−)
NORMALIZED JOINT POWERS
HIP AD/ABDUCTION (+/−)
NORMALIZED JOINT POWERS
ANKLE IN/EXTERNAL (+/−)
NORMALIZED JOINT POWERS
KNEE IN/EXTERNAL (+/−)
NORMALIZED JOINT POWERS
HIP IN/EXTERNAL (+/−)
NORMALIZED POWER (NM/S/N)
PERCENT CYCLE (%)
PATIENT RT
PATIENT LF
NORMAL
RHS
LTO
LHS
RTO



Dwight Meglan


GROUND REACTION LOAD : LEFT FOOT
FOOT LCS
FORCE/MOMENT (N/NM)
1000.0
760.0
520.0
280.0
40.0
-200.0
FFT LF FX
FFT LF FY
FFT LF FZ
FFT LF MZ
RIS
LTO
LIS
RTO
RIS
0.00
20.0
40.0
60.0
80.0
100.0
PERCENT CYCLE
Dwight Meglan

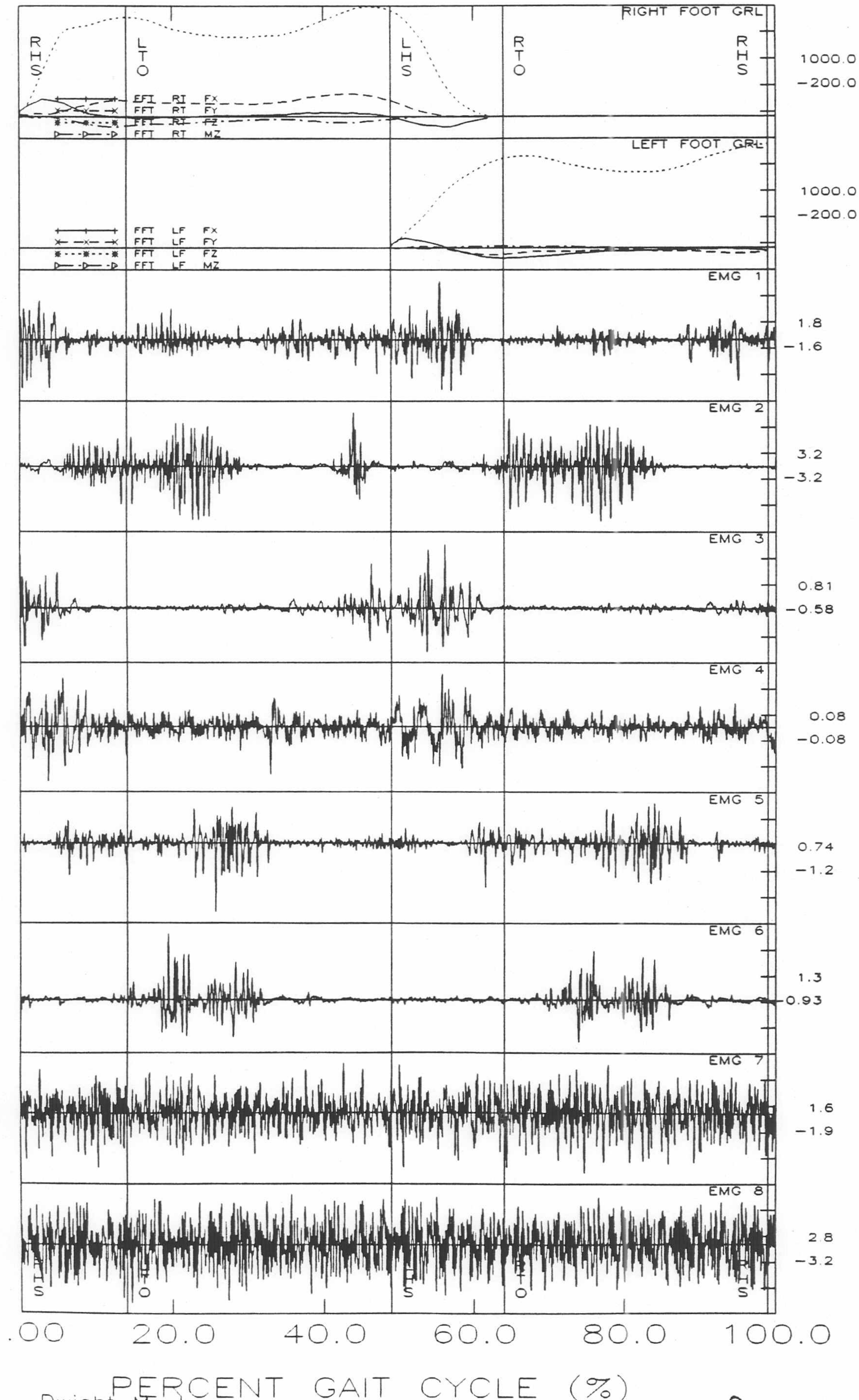
EMG AND FORCE PLATE DATA



$f_{low} = 15\,Hz$ $f_{high} = 250\,H$

Rectified 6Hz low pas

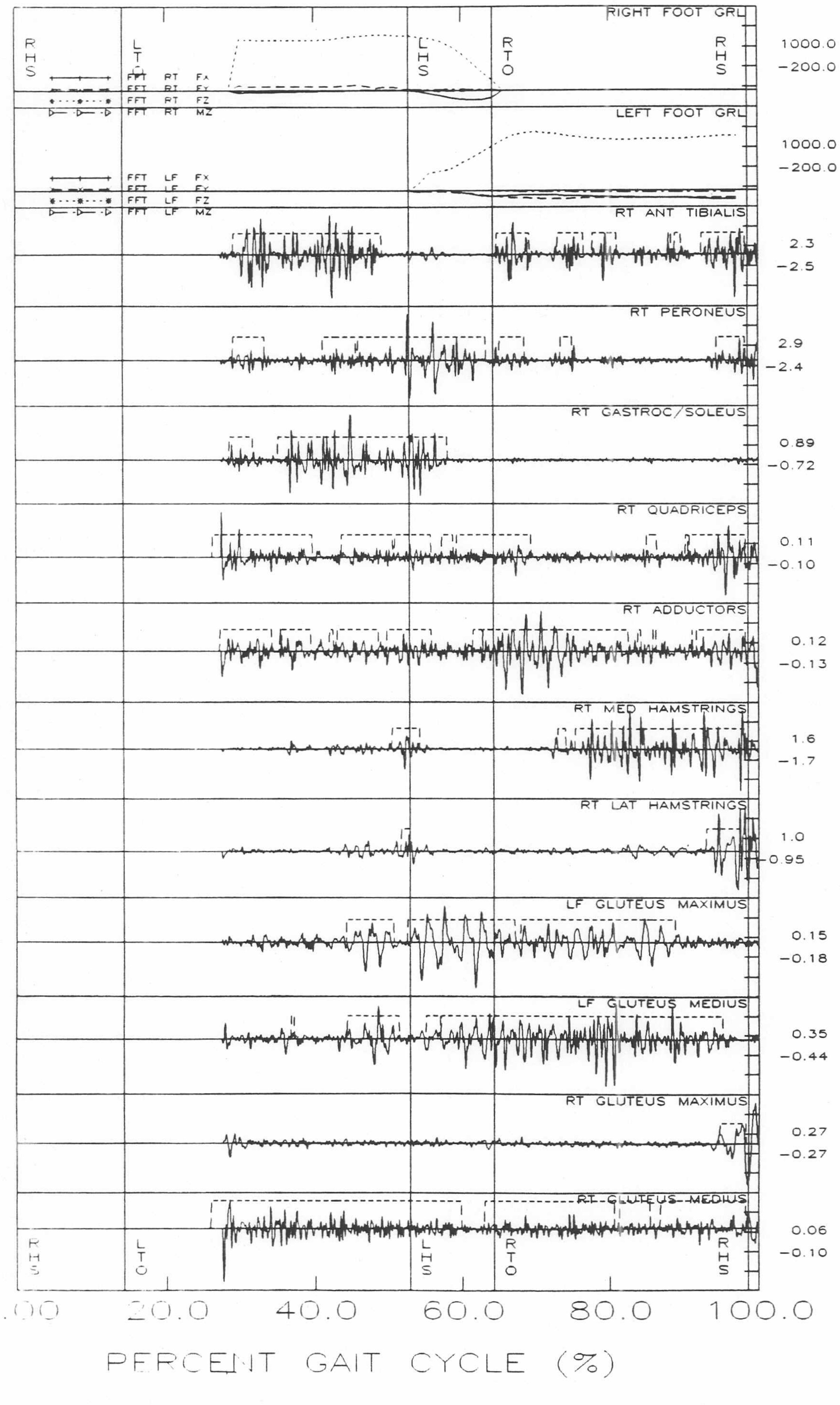
EMG AND FORCE PLATE DATA



Dwight Meglan

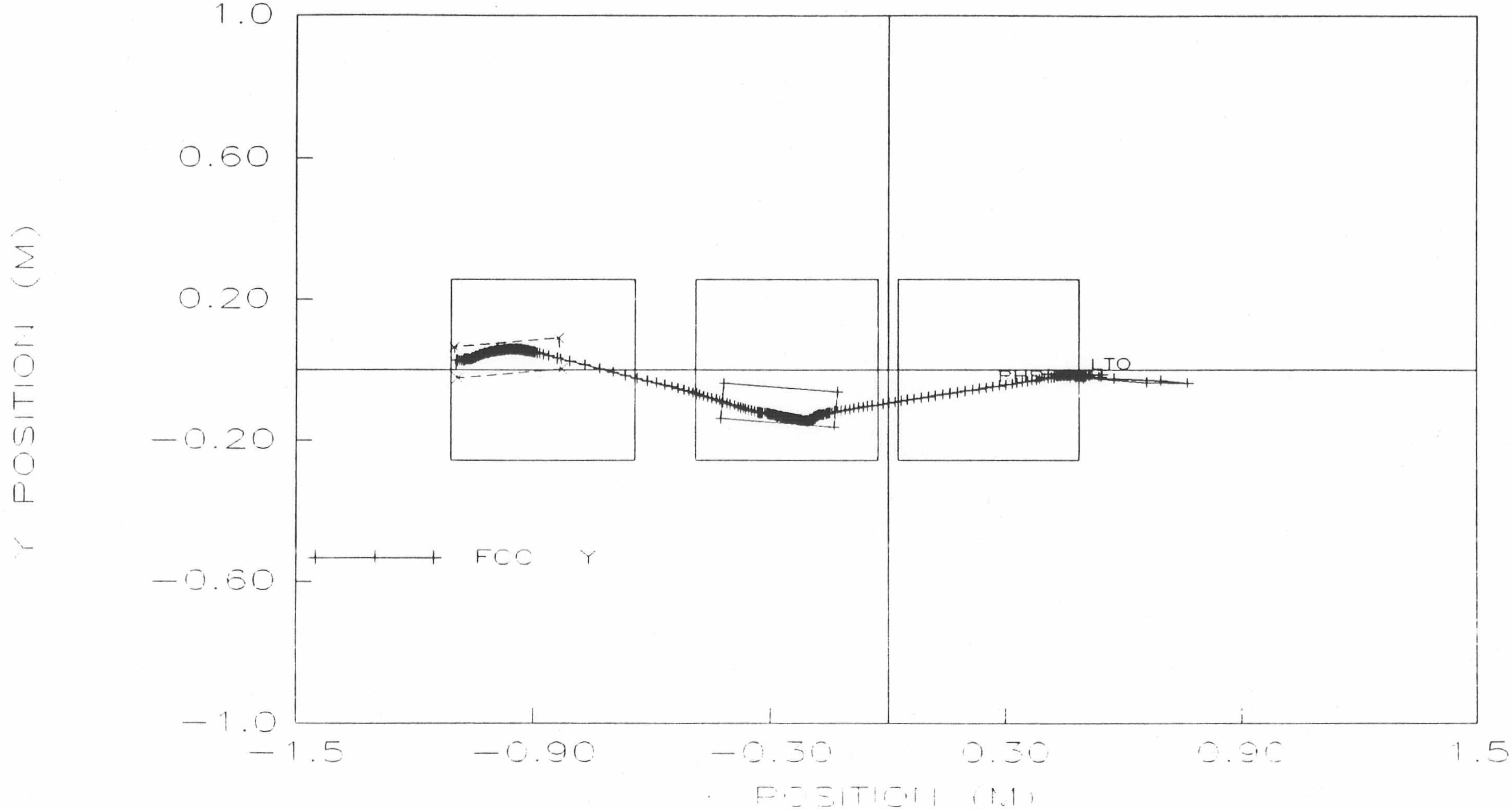
$f_{low} = 15 Hz$ $f_{high} = 250 Hz$

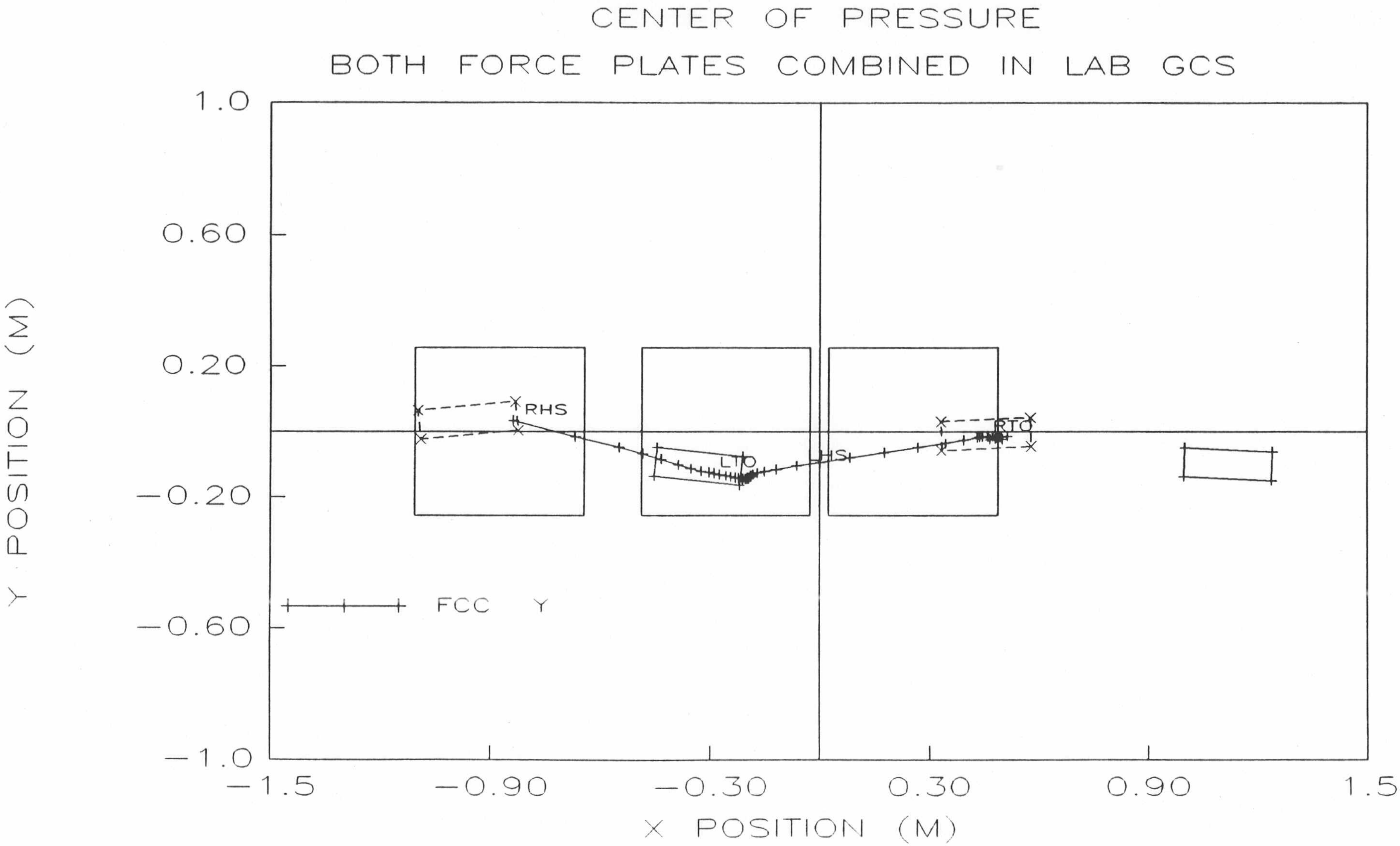
EMG AND FORCE PLATE DATA



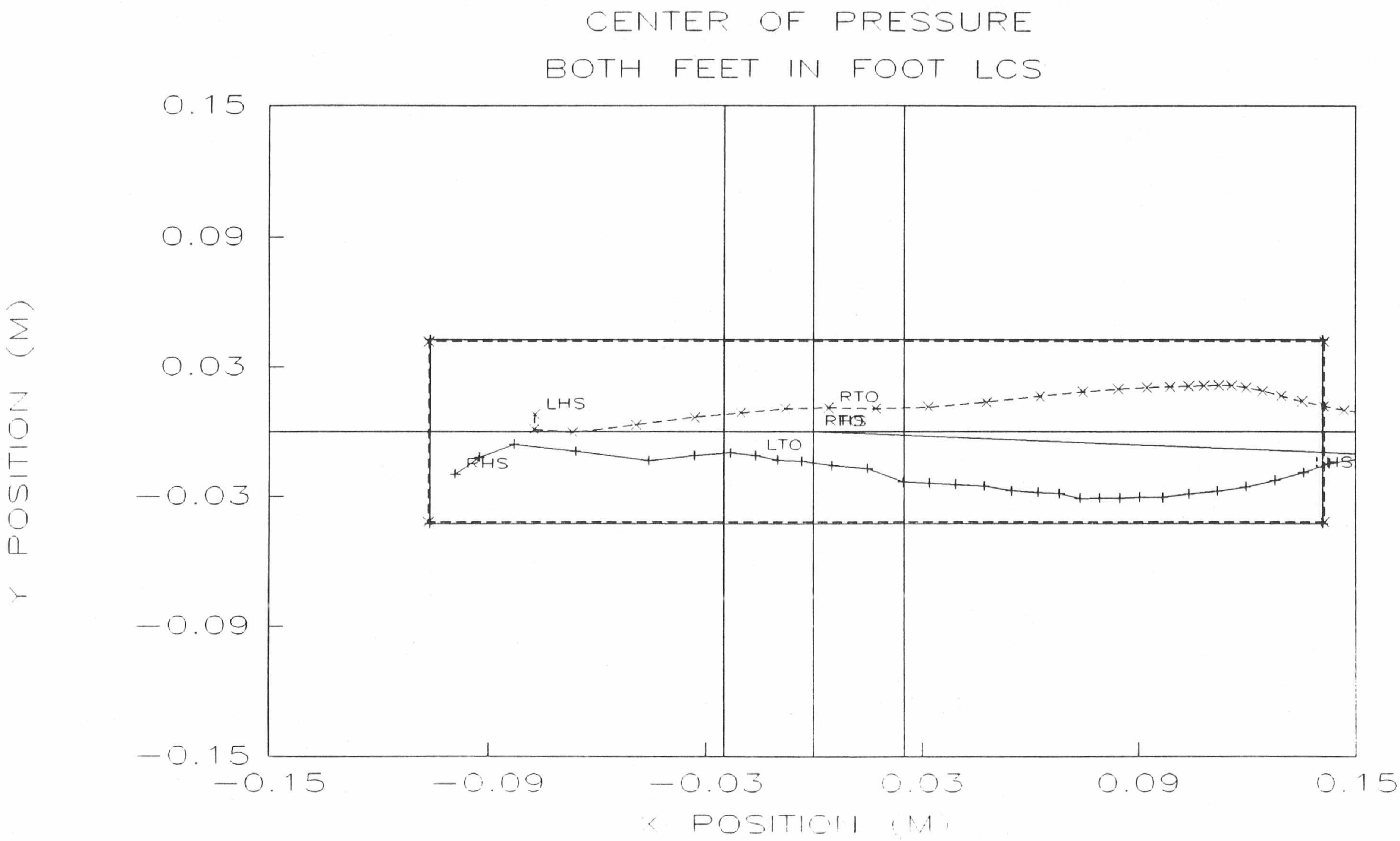
CENTER OF PRESSURE

BOTH FORCE PLATES COMBINED IN LAB GCS



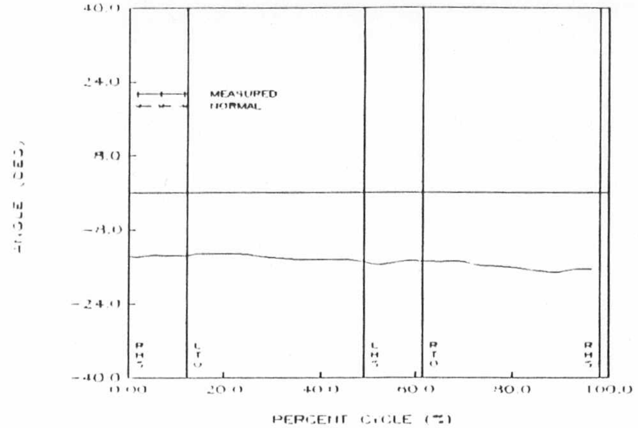


CENTER OF PRESSURE
BOTH FORCE PLATES COMBINED IN LAB GCS
Y POSITION (M)
X POSITION (M)
1.0
0.60
0.20
−0.20
−0.60
−1.0
−1.5
−0.90
−0.30
0.30
0.90
1.5
RHS
LTO
LHS
RTO
FCC Y


CENTER OF PRESSURE
BOTH FEET IN FOOT LCS
0.15
0.09
0.03
−0.03
−0.09
−0.15
−0.15
−0.09
−0.03
0.03
0.09
0.15
Y POSITION (M)
X POSITION (M)
LHS
RTO
RHS
LTO
RHS
LHS

PELVIS

AN/POSTERIOR TILT



PUT A COMMENT OR SOMETHING HERE

PUT ANOTHER COMMENT HERE

Gait Distance/Time Parameters

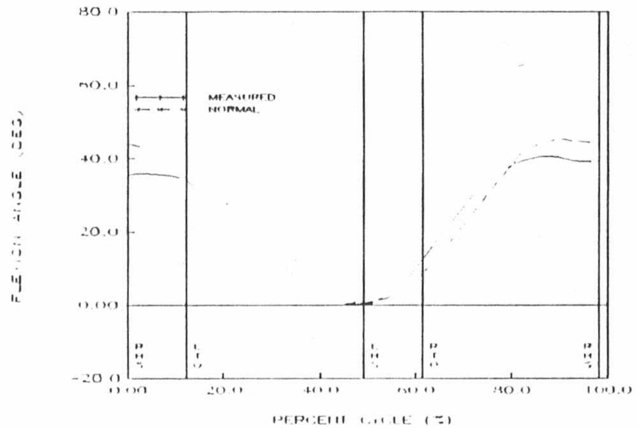
	Meas.(ft)	Normal(ft)	% Normal
Velocity	4.547	4.760	95.521
Stride	5.256	5.144	102.203
Rt Step	2.949	2.572	114.714
Lf Step	2.306	2.572	89.693
Step Width	0.390	0.259	151.091
Cadence	105.263	111.000	94.831

Gait Timing Parameters

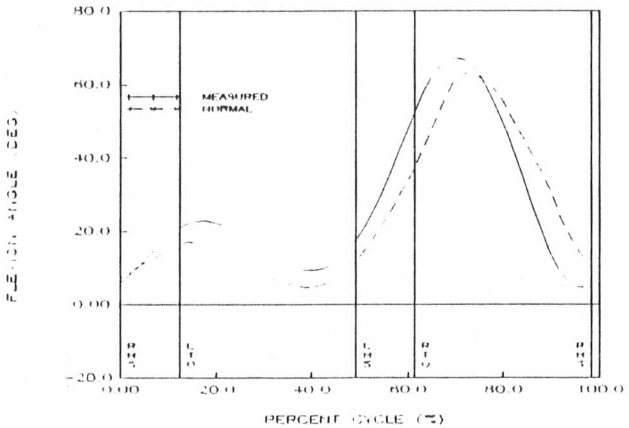
	Time(s)	Cycle(%)	Normal
Rt TLST	0.759	66.666	62.000
Lf TLST	0.759	66.668	62.000
Rt SLST	0.439	38.596	38.000
Lf SLST	0.439	38.596	38.000
Rt DLS	0.159	14.035	12.000
LF DLS	0.159	14.035	12.000
RHS		0.000	0.000
LTO		14.035	12.000
LHS		50.877	50.000
RTO		63.157	62.000
RHS		100.000	100.000

PATH

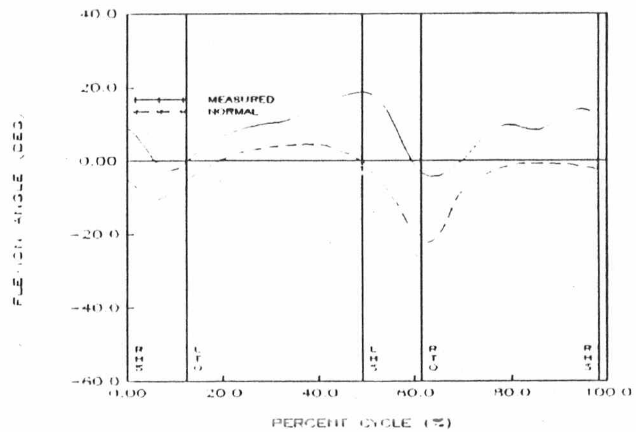
RIGHT HIP FLEXION ANGLE



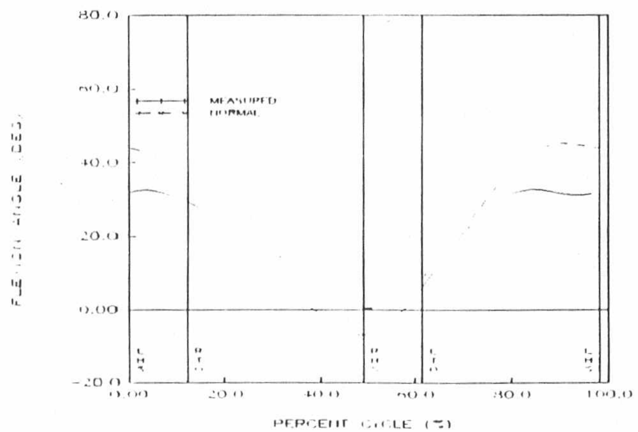
RIGHT KNEE FLEXION ANGLE



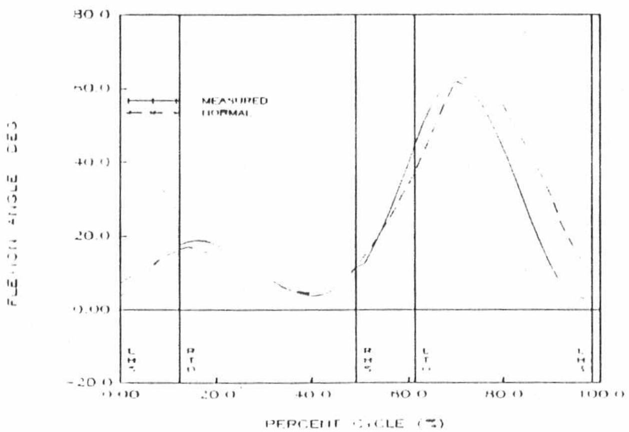
RIGHT ANKLE FLEXION ANGLE



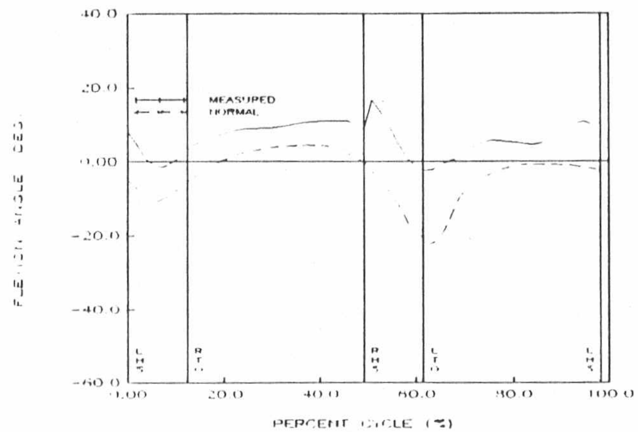
LEFT HIP FLEXION ANGLE



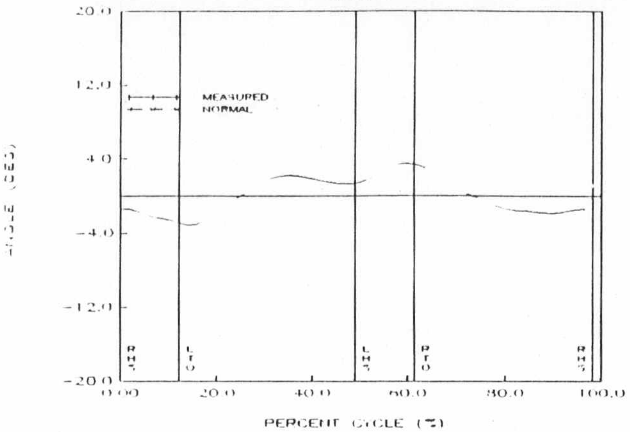
LEFT KNEE FLEXION ANGLE



LEFT ANKLE FLEXION ANGLE



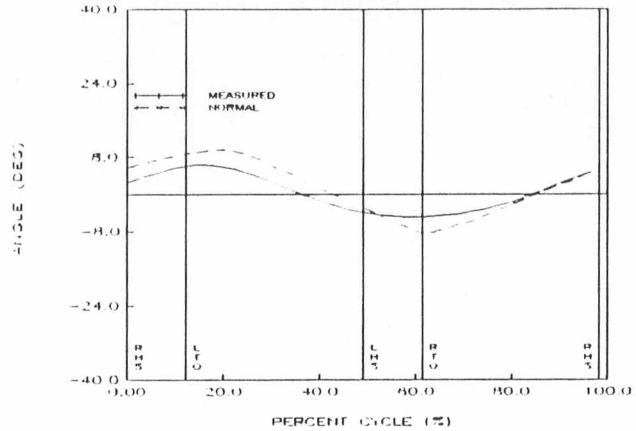
PELVIS
OBIQUITY



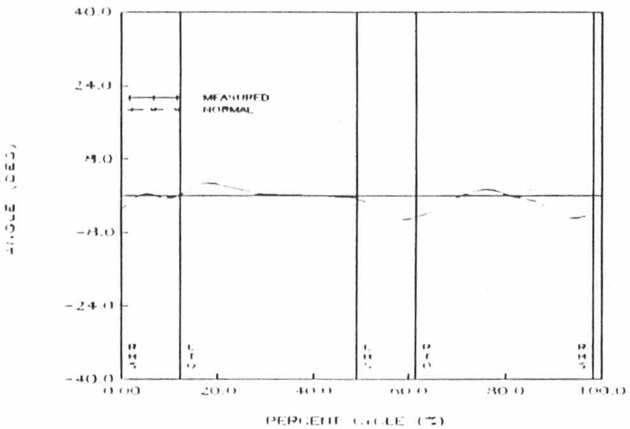
PUT A COMMENT OR SOMETHING OR NOTHING HERE
ANOTHER AVAILABLE LINE

26-AUG-91
CATHY8_OLD ANZ

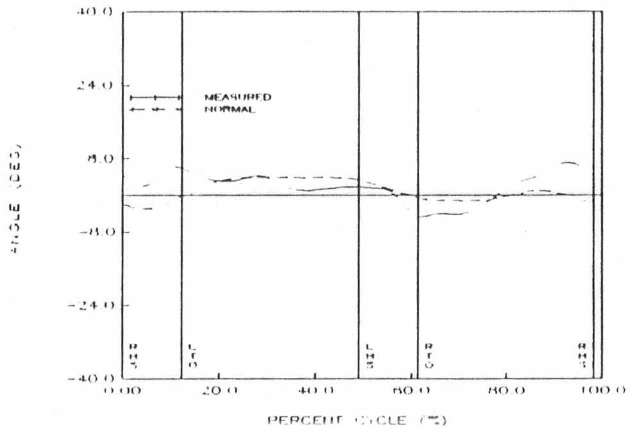
PELVIS
ROTATION



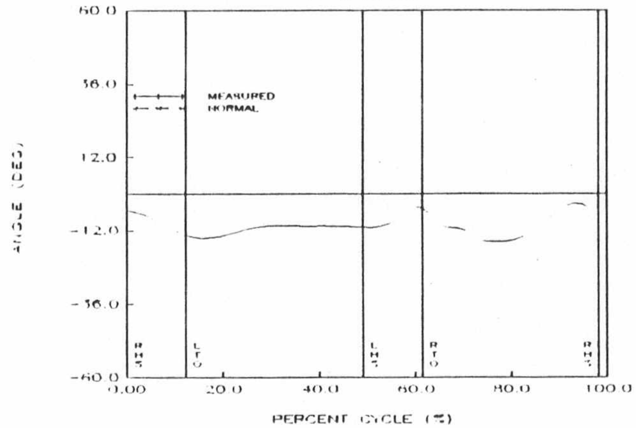
RIGHT HIP
AB/ADDUCTION



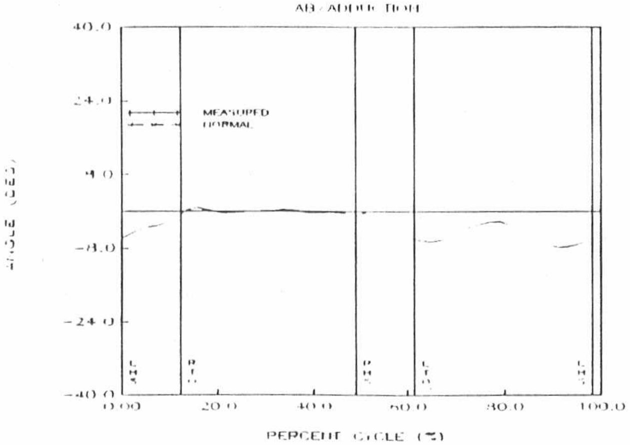
RIGHT HIP
IN/EXTERNAL



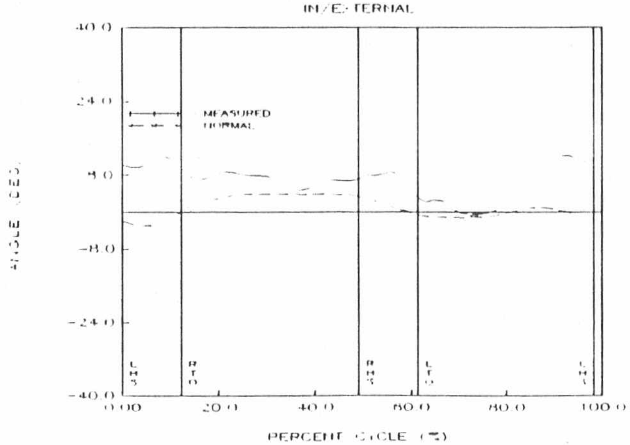
RIGHT ANKLE
IN/EXTERNAL



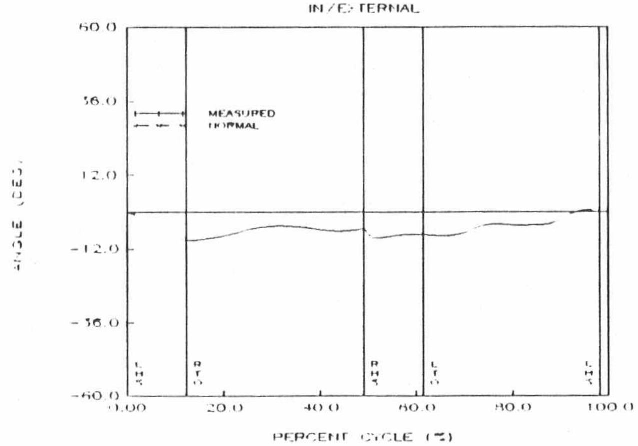
LEFT HIP
AB/ADDUCTION



LEFT HIP
IN/EXTERNAL



LEFT ANKLE
IN/EXTERNAL



Name : Jeff
Age : 37
Weight : 62.136 kg
Height : 1.854 m
Comment:

Cycle event frame #'s

Right heel strike : 1 57
Left heel strike : 29
Right toe off : 36
Left toe off : 8

First motion frame absolute frame # : 1

	meters	feet	inches	Normal(m)	% Normal
Velocity :	1.386	4.547	54.567	1.451	95.521
Stride :	1.603	5.258	63.092	1.568	102.204
R Step :	0.899	2.951	35.407	0.784	114.714
L Step :	0.703	2.307	27.684	0.784	89.693
Step Width :	0.119	0.392	4.699	0.079	151.092
Cadence :	105.263 step/min			111.000	94.832

	Time (s)	Percent Cycle	Normal
R TLST	0.600	66.632	62.000
L TLST	0.600	66.632	62.000
R SLST	0.440	38.596	38.000
L SLST	0.440	38.596	38.000
R DLS	0.160	14.035	12.000
L DLS	0.160	14.035	12.000
RHS		0.000	0.000
LTO		14.035	12.000
LHS		50.877	50.000
RTO		63.158	62.000
RHS		100.000	100.000