Changes in selected biomechanical parameters during long distance running

by

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1 INTRODUCTION

1.1 General Information

Running is one of the most natural forms of human movement, so it is therefore very fascinating and important to analyze and understand the different biomechanical parameters involved. Long distance running has especially become one of the most popular form of exercise over the past years. Many people seem to be running greater weekly mileage, and more and more people have made the dream of running the marathon a reality. Running consists of repeated running cycles or strides containing both a support and non-support phase, in which the non-support phase is defined as that part of the cycle having both feet off the ground at the same instant.

1.2 Running Cycle

The running cycle begins when one foot strikes the ground and continues until the same foot again strikes the ground. Normally the running cycle is defined as beginning with foot strike of the right foot and continuing until the right foot again strikes the ground. Figure 1.1 illustrates the different elements involved in the running cycle. The different parts of the running cycle are as follows:

- Foot strike, when the foot strikes the ground. For most runners the foot strikes at the heel, so the foot strike is usually identical with heel strike.
- Toe-off, when the toe leaves the ground.
- Support phase, when one of the feet is in contact with the ground. The support phase for each foot begins at foot strike and ends at toe-off for that foot.
- Non-support phase, when both feet are off the ground. The non-support phase for each foot begins at toe-off and ends at foot strike for that foot.
- Stride, from one foot strike until the next foot strike for the same foot. It is usually defined as beginning when the right foot strikes the ground and ends when the right foot again strikes the ground. A stride is the same as a running cycle.

During the running cycle, the muscles of the lower leg follow a stretch-shorten cycle (SSC) consisting of a stretch (eccentric contraction) followed immediately by shortening (concentric contraction) (Komi, 1987). The eccentric contraction helps to maintain equilibrium and control motion with gravity, while the concentric contraction controls motion against gravity. Energy is stored in the elastic tissues during the first half of the support phase in which the muscles are stretched and the muscle tissues undergo lengthening under tension. The stored energy is then returned in the last half of the support phase where the shortening takes place and the muscle fibers are shortened. This storage and return of elastic energy is mainly responsible for the power generated in running (Williams, 1985).

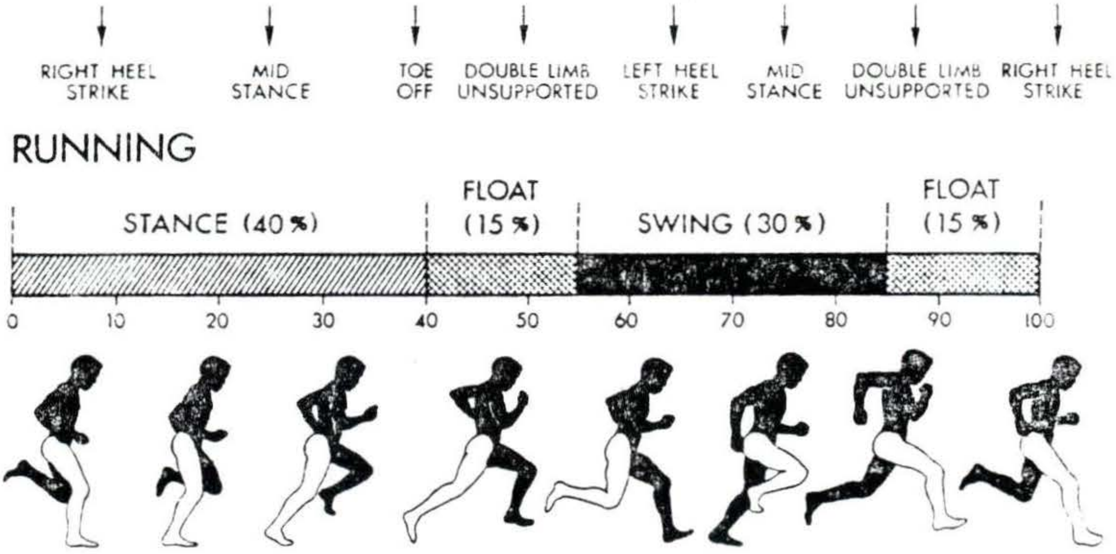

Figure 1.1: Running cycle (Adelaar, 1986)

1.3 Injuries

Injury to joint and bones can occur in long distance running, where peak forces up to 2.5-3 times body weight are generated (Cavanagh and Lafortune. 1980). It is therefore very important to have good shock absorption properties in the running shoes to avoid injury caused by the constant pounding of the leg on the running surface. The gastrocnemius muscle, which is the prime mover for plantarflexion of the lower leg, is most often injured because it crosses both the knee and ankle joints. The forces across the knee and ankle are maximal at push off when the toe leaves the ground, and these high forces cause about 75 % of all running injuries (Winter. 1983). The injuries mostly occur at the Achilles tendon, at the junction of the muscle and tendon, and in the gastrocnemius muscle itself (Perlman. 1982).

1.4 Biomechanics

Biomechanics of human movement is the interdiscipline which describes, analyses, and assesses human movement (Winter, 1979). An understanding of the biomechanical parameters involved in running may help to better understand the mechanisms of the neuromusculoskeletal system, improve an athlete's performance, and prevent injuries (Williams, 1985). High-speed cinematography (CMG) is high-speed photography used to determine changes in the biomechanics (O'Connell and Gardner, 1963). An important parameter in biomechanics is the joint angle, as the joint angles are assumed to be proportional to muscle length (Hof and Van den Berg, 1981a).

1.5 EMG Recording

Electromyograms (EMGs) are a record of electrical changes occuring in the muscle, prior to and during its contraction, used to measure the level of muscular activation (O'Connell and Gardner, 1963). An EMG recording can determine when the muscle is active, and its amplitude can help to determine when fatigue occurs in the muscle.

1.6 Elasticity

Elasticity refers to a muscle fiber's ability to stretch and return to normal resting length. The muscle and tendon elasticity complement and enhance the contractile properties of the muscles. The effectiveness and efficiency of running is affected by the muscle and tendon elasticity through elastic energy storage and force-enhancement (Shorten, 1987).

1.7 FFT-Analysis

Fast Fourier-transform (FFT) is analysis of the frequency spectrum. The resultant power spectra of a fast Fourier-transform performed on EMG recordings can help to determine when muscle fatigue occurs.

1.8 Fatigue

Fatigue is one of the most interesting aspects of running, because it causes a decrease in performance. Fatigue is defined as a decrease in work capacity caused by the work itself, resulting from a decrease in efficiency. In the present study, biomechanical fatigue was defined as observable changes in the movement pattern due to changes in the runner's biomechanics. Muscle fatigue was defined as a decrease in muscle activity.

1.9 Summary

In the present study changes in selected biomechanical parameters during long distance running were evaluated by means of electromyogram (EMG) recordings of the gastrocnemius and soleus muscle synchronized with cinematography (CMG) of the lower leg.

Three male subjects ran on a treadmill for one hour in order to analyze changes in biomechanical parameters due to fatigue. Changes in the biomechanics were analyzed, and moment and energy calculations for the lower leg were performed.

Amplitudes of the raw EMG signals were also studied. The different parameters of the elasticity of the calf muscle was calculated, where the inputs were the EMG from the gastrocnemius and soleus muscle together with the angle of the ankle joint obtained from the CMG. A fast Fourier-transform was performed on the EMG from the gastrocnemius and soleus muscle and the resultant power spectra was displayed.

The parameters were analyzed for changes over time to determine which of the changes (in biomechanics, EMG recording, elasticity, and FFT-analysis) might best indicate the onset of fatigue.

2 OBJECTIVE

The objective of the present study was to analyze changes in selected biomechanical parameters during long distance running. These parameters were:

- running cycle time
- support and non-support time
- stride rate and stride length
- angle of ankle and knee
- energy and moments calculations of lower leg
- amplitude of raw EMG of gastrocnemius and soleus muscle
- elasticity of the calf muscle
- FFT-analysis of EMG signals of gastrocnemius and soleus muscle

The primary objective of the present study was to analyze the above mentioned parameters over time to determine which of the changes (in biomechanics, EMG recording, elasticity, and FFT-analysis) might best indicate the onset of fatigue.

3 LITERATURE REVIEW

3.1 Biomechanics

Slocum and James (1968) and Adelaar (1986) described the different parts of the running cycle. Williams and Cavangh (1987) investigated the relationships between distance running mechanics, running economy (the rate of submaximal O_2 consumption), and performance, showed that the more economical runners (low rate of submaximal O_2 consumption is defined as high economy) seem to have the same pattern in their running mechanics. A study done on sprinters investigated the relationship between ground reaction forces, EMG, elasticity and running velocity. The findings demonstrated that most of the parameters increased with increased running velocity (Mero and Komi, 1986). It has also been shown that with an increase in running velocity there is a increase in hip flexion, knee extension decreases in the swing and support phases, while there is no change in the ankle flexion and extension patterns (Sinning and Forsyth, 1970).

The biomechanics of overground versus treadmill running have been studied by use of high speed cinematography. Studies showed that there were significant differences in the biomechanics between treadmill and overground running. In treadmill running there was a longer support phase, lower vertical velocity, and less variable vertical and horizontal velocities than for overground running. The conclusion was that treadmill running produces significant changes in the biomechanics of running (Nelson et al., 1972; Dal Monte et al., 1973). Another study showed that in treadmill running the stride length decreased, stride rate increased and the non-support phase was less as compared to overground running. However, there were no significant differences when running velocities were between 3.33 and 4.78 m/s, or between 7.45 to 10.69 mph (Elliott and Blanksby, 1976b). In the present study a treadmill was used since it would be very difficult to obtain EMG recordings in road or track running.

3.2 EMG Recording

Synchronized electromyography (EMG) and cinematography have been used to describe the electromyographic activity of the lower extremities during the running cycle. Normally the calf muscles are active only in the stance phase, as the maximum EMG occurs at push-off (Elliott and Blanksby, 1979a; Elliott and Blanksby, 1979b; Hof, Geelen, and Van den Berg, 1983; Mann et al., 1986; Schwab et al., 1983). The correlation between muscle length and EMGs have also been studied, indicating that maximum activity occurs when the muscle is closest to its anatomical length (Frigo et al., 1978). This means that the muscle is closest to its anatomical length at push-off in the stance phase.

3.3 Elasticity

In the literature, the role of tendons during locomotion has been given little attention. However, it has been shown that the tendon stiffness plays a very important role during lengthening contractions (Proske and Morgan, 1987).

To date no work has been done to determine the changes in the elasticity components of the lower limbs resulting from fatigue in distance running. Some studies have been done in which a muscle model for the different components of the elasticity of the lower limbs has been proposed (Hof, Geelen, and Van den Berg, 1983; Hof, Pronk, and Van Best, 1987; Hof and Van den Berg, 1978; Hof and Van den Berg, 1981a; Hof and Van den Berg, 1981b; Hof and Van den Berg, 1981c; Hof and Van den Berg, 1981d). The studies by Hof and Van den Berg (1981a, b, c, d) was therefore applied to the present studies in order to determine changes in the elasticity parameters during long distance running.

3.4 FFT-Analysis

Studies have shown that with increase in fatigue the Fourier power spectral plot of EMG waveforms shift toward lower frequencies (Winter, 1979; De Luca, 1984). The resultant power spectra of a fast Fourier-transform performed on muscles EMG can therefore help in determining when muscle fatigue occurs during running.

3.5 Fatigue

Bates and Osternig (1977) investigated fatigue effects in running and concluded that fatigue completely changes the relationship of the components in a movement pattern. In another study, where fatigue in a 10,000 meter race was investigated, it was found that as the running speed decreased linearly, the stride length decreased, and the stride rate remained constant during the race (Elliott and Ackland, 1981). Another study investigated the role of fatigue in middle-distance running in a 3,000 meter race, and found no significant changes in the biomechanics until about 2,900 meters into the race, where the support time increased, the non-support time decreased, stride rate increased, and stride length decreased (Elliott and Roberts, 1980). One study tested runners running a 4-minute mile on a treadmill, and showed that fatigue causes obvious changes in the mechanical movements of the joints. The stride length decreased and an increase in stride frequency was shown. It was also shown that the stride length increases rather than the stride frequency with an increase in running speed (Sparks, 1975). Komi and Gollhofer (1987) showed that fatigue affects the EMG-force relationship primarily during the eccentric part of the contraction. Another study by the same authors showed that fatigue induced an increase in EMG/force ratio in the push-off phase. The reason for this might be because the muscles loose their recoil characteristics from the constant pounding of the feet on the ground (Gollhofer and Komi, 1987). Fatigue in general affects fast twitch fibers more than slow twitch fibers (Secher, 1987). However, elite distance runners have between 60-98% slow twitch fibers in their leg muscles. In distance running there is more stress on the slow twitch fibers than on the fast twitch fibers as the nervous system first recruits the slow twitch and some fast twitch *a* fibers. More fast twitch *a* fibers become active when the slow twitch fibers begin to fatigue. As the fast twitch *a* fibers become exhausted, the nervous system recruits the fast twitch *b* fibers. However, fast twitch *b* fibers are not easily recruited, so great mental effort is required of the runner to maintain the pace and to activate the fast twitch *b* fibers. Fatigue usually comes in stages as a result of this process of recruiting muscle fibers (Costill, 1986).

3.6 Experimental Procedures Used to Study Fatigue

The experimental procedure used to analyze biomechanics, EMG, elasticity, and FFT have also been covered in the literature. The most common used procedure is EMG recording synchronized with CMG.

Synchronizating motion pictures with EMG may be the most accurate method of correlating multi-joint movement with EMG recordings. High speed cinematography has made it easier to get a better understanding of human skills (O'Connell and Gardner, 1963).

Skin resistance usually ranges from 200 Ω to about 2 MΩ. Input impedance to the amplifier should be at least ten times the maximum skin impedance. Amplifier gain normally ranges from 100 to 10,000. The maximum peak to peak voltage of raw EMG signals is 5 mV. Most of the information of EMG signals is in the frequency spectrum 10-1000 Hz (Winter, 1979). The EMG power density spectrum normally only extends from 10- 300 HZ, being maximal from 50-150 Hz (Hof and Van den Berg, 1981a). However, to make sure that no information is lost, a recommended range for surface EMG is 10 to 1000 Hz (Winter, 1979). The low frequency cut-off is designed to eliminate motion artifact and DC drift, while the high frequency cut-off is to limit signal bandwidth prior to A/D conversion thereby avoiding aliasing errors. To obtain quantitative EMG information, bipolar surface electrodes should be used for the EMG recording (Hof, 1984). In the present study the amplifier gain was 5000× with bandpass filter 10-1000 Hz.

Frequencies above half the sampling frequency should not be contained when the signal is digitized for further processing (Halbertsma and Boer, 1981). In the present study the sampling occured every millisecond, giving a sampling frequency of 1000 Hz, as all the EMG information were obtained.

In one study obtaining EMG from the gastrocnemius and soleus muscle, it was suggested that the gastrocnemius electrodes be positioned one on the medial and one on the lateral head of the muscle. The soleus electrode pair (surface area 0.5 cm^2) was placed 2.5 cm apart on the edge at the medial side, where the muscle protrudes from under the gastrocnemius (Hof and Van den Berg, 1977). In the present study the electrodes were placed vertically in order to perform FFT-analysis on the EMGs. The soleus electrode pair was placed as suggested by Hof and Van den Berg (1977), while the gastrocnemius electrode pair was placed between the medial and lateral head of the muscle.

4 THEORETICAL CONSIDERATIONS

4.1 Hill's Muscle Model

In 1938 a muscle model was introduced by A.V. Hill. It consists of three components: a parallel elastic component (PEC), a contractile component (CC), and a series elastic component (SEC).

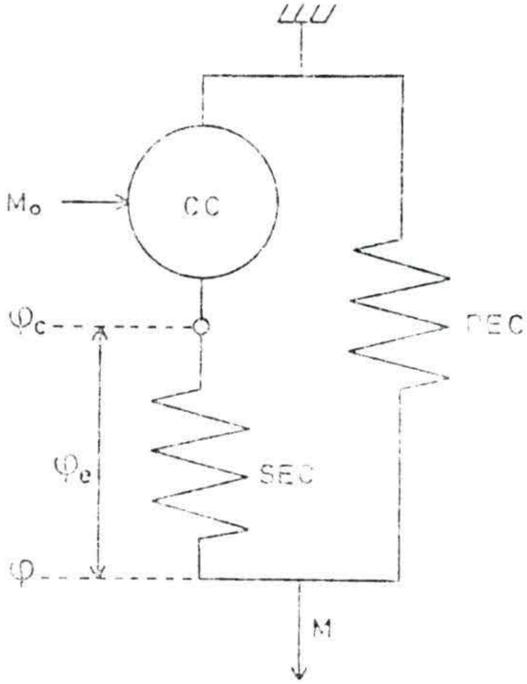

Figure 4.1: Diagram of the Hill muscle model (Hof and Van den Berg, 1981a)

The PEC is the elasticity of the passive muscle and the joint ligaments. It carries the passive tension across a joint when the muscle is passive, but is not present under tension. The CC is the force generating process in the muscle, and is connected in series with the SEC. The SEC transmit the force of a muscular contraction as it is transmitted to an external load. The CC develops a torque M_C, which is a function of the active state M_O, the length of the CC represented by ϕ_C, and its derivative $\dot{\phi}_C$. M_p is the torque from the PEC, which is a function of the length of the PEC represented by ϕ. The length of the SEC is represented by ϕ_ϵ, and the sum of ϕ and ϕ_ϵ is equal to ϕ_C. M is the total torque developed around a joint, which is the sum of M_c and M_p (Hof and Van den Berg, 1981a).

4.2 EMG to Muscle Force Processing Method

The Hill muscle model was used by Hof and Van den Berg (1981a, b, c, d) to represent a EMG to muscle force processing method where surface electromyogram is processed to indicate muscle force. There are two inputs to the process, the EMG and the joint angle. The EMG is a measure of muscle activity, and the joint angle is assumed to be proportional to muscle length. The muscle's activity and length can then be used to determine the torque M developed around a joint. The processing method can be applied to any skeletal muscle, but in the present study is applied only to the human calf muscle (gastrocnemius and soleus). The input to the processing method is then the EMG from the calf muscle represented by $U(t)$ in Newton-meters, and the angle of the ankle joint ϕ in degrees. $U(t)$ is a function of the EMG from the gastrocnemius u_g and soleus u_s muscle in millivolts, which are preamplified, full-wave rectified, added, converted to Nm, and smoothened by a filter to produce the function $U(t)$. The different components of the elasticity of the calf muscle are then determined in the calculations described in the steps below. The output from the processing method is the muscle torque M around the ankle joint.

The calculations are:

- A: Definition of the variable parameters:

  CC = contractile component

  PEC = parallel elastic component

  SEC = series elastic component

  M = total torque [Nm]

  M_o = active state [Nm]

  M_c = torque due to the CC [Nm]

  M_p = torque from the PEC [Nm]

  ϕ = angle of the ankle joint [deg]

  ϕ_c = angle corresponding to CC-length [deg]

  ϕ_e = SEC stretch [deg]

- B: Definition of constant parameters present in formulas:

  M_s = parameter of SEC = 1 Nm

  ϕ_p = exponential constant PEC = 8°

  b = velocity parameter torque-velocity relation = 1.2 rad/s

  c = parameter torque-velocity relation at negative velocities = 0.05

f = frequency of oscillation of the foot = 3.62

g_g = torque-EMG ratio of the gastrocnemius = 1.4

g_s = torque-EMG ratio of the soleus = 3.5

n = parameter torque-velocity relation = 0.12

K = linear elasticity parameter SEC [Nm/rad]

M_{po} = proportionality constant of PEC = 3.33 Nm

β = logarithmic elasticity parameter SEC = 20 rad^{-1}

τ_1 = time constant EMG smoothing filter = 20 ms

τ_2 = plateau duration active state = 30 ms

τ_3 = time constant exponential decay of active state = 60 ms

ϕ_1 = parameter torque-angle relation = 130°

ϕ_2 = parameter torque-angle relation = 90°

u_g = EMG of gastrocnemius as recorded at the electrodes [mV]

u_s = EMG of soleus as recorded at the electrodes [mV]

U_g = mean rectified EMG of gastrocnemius [mV]

U_s = mean rectified EMG of soleus [mV]

$U(t)$ = mean rectified added and converted EMG [Nm]

- C: The following parameters were determined for each subject:

  d = horizontal distance between toe and ankle [m]

  m = weight of subject [kg]

- D: First M_{ref} is determined:

$$M_{ref} = m \cdot g \cdot d$$

- E: Then K is determined:

$$K = \left(\frac{1}{(2 \cdot \pi \cdot f)^2 \cdot m \cdot d^2} - \frac{1}{3 \cdot M_{ref}} \right)^{-1}$$

- F: The EMG from the gastrocnemius u_g and soleus u_s muscle in millivolts, were preamplified, bandpass filtered and full-wave rectified. The gain of the amplifier was set to 5000 ×. The two full-wave rectified signals were added and converted to Newton-meters. 1 V of mean rectified EMG corresponded to a torque of 100 Nm (Hof and Van den Berg, 1977). The added converted signal was then smoothened by a filter. Step F can be described mathematically as:

  Preamplification:

  $U_g = u_g \cdot 5000 \cdot g_g$ and $U_s = u_s \cdot 5000 \cdot g_s$

  Full-wave rectifying:

  $|U_g| = \sqrt{U_g^2}$ and $|U_s| = \sqrt{U_s^2}$

  Adding and conversion to Nm:

  $U(t) = (|U_g| + |U_s|) \cdot 0.1$

  Filtering:

  The filter had these parameters:

$t = \tau_1 = 0.02$

$dt = 0.01$

$\alpha = \exp(-dt/t)$

The filter works in the following way:

$U(1) = (1 - \alpha) \cdot U(1)$

$U(2) = (1 - \alpha) \cdot U(2) \cdot \alpha$

$U(n) = (1 - \alpha) \cdot (U(1) + U(2) \cdot \alpha + U(3) \cdot \alpha^2 - ... - U(n) \cdot \alpha^{n-1})$

The output from the filter then served as input to the processing method together with the angle of the ankle joint in degrees obtained from the CMG.

- G: The conversion of EMG to active state M_o, is described by:

$$M_o(t) = \max \begin{cases} U(t) & 0 \leq \Delta t < \tau_2 \\ U(t) \cdot e^{-(\frac{\Delta t - \tau_2}{\tau_3})} & \tau_2 \leq \Delta t \end{cases}$$

  It can be seen that $Mo(t)$ follows $U(t)$ until it rises to a relative maximum. The maximum is then held for τ_2 milliseconds whereafter $U(t)$ decreases with an exponential decay with a time constant τ_3, until $U(t)$ gets larger than $M_o(t)$.

- H: The torque angle relation $f(\phi_c)$ used in the formulas for M_c was determined as follows:

$$f(\phi_c) = \begin{cases} 1 & \phi_c < \phi_2 \\ \frac{\phi_1 - \phi_c}{\phi_1 - \phi_2} & \phi_2 < \phi_c < \phi_1 \\ 0 & \phi_c > \phi_1 \end{cases}$$

- I: The length of the CC represented by ϕ_c is determined by:

$$\phi_c = \phi + \phi_e$$

The derivatives are:

$$\dot{\phi} = \frac{d\phi}{dt}$$

$$\dot{\phi_c} = \frac{d\phi_c}{dt}$$

- J: The total torque around the ankle joint was determined by:

$$M = M_c + M_p$$

- K: The torque M_p from the PEC was determined by:

$$M_p = M_{po} \cdot \exp^{-\frac{\phi - 90^\circ}{\phi_p}}$$

- L: The torque M_c due to the CC can be found as:

$$M_c = M_o \cdot \frac{f(\phi_c) - n \cdot \dot{\phi_c}/b}{1 + \dot{\phi_c}/b}$$

With $M_C \leq (1-c) \cdot M_O \cdot f(\phi_C)$ and $\dot{\phi}_C \leq \frac{b}{n} \cdot f(\phi_C)$, and M_C constrained to be ≥ 0.

- M: The SEC stretch represented by ϕ_ϵ can by found as:

$$\phi_\epsilon = \frac{1}{3} \cdot \ln(\frac{M_C + M_S}{M_S}) + \frac{M_C}{K}$$

Since many of the parameters are dependent on each other, it is necessary to use interpolation in the calculations. The program for the calculation of the elasticity of the calf muscle is shown in Appendix E: Elasticity of Calf Muscle.

4.3 Biomechanics

The general formulas to calculate biomechanics are the following:

m = mass

r = radius

ρ = radius of gyration

I = moment of inertia

$\triangle x$ = horizontal displacement

$\triangle y$ = vertical displacement

$\triangle t$ = time interval

Velocities and accelerations:

Linear:

$$v_x = \frac{\triangle x}{\triangle t} = \text{horizontal velocity}$$
$$v_y = \frac{\triangle y}{\triangle t} = \text{vertical velocity}$$
$$a_x = \frac{\triangle v_x}{\triangle t} = \text{horizontal acceleration}$$

$$a_y = \frac{\triangle v_y}{\triangle t} = \text{vertical acceleration}$$

Angular:

$$\theta = \arctan \frac{\triangle y}{\triangle x} = \text{angular disposition}$$

$$\omega = \frac{\triangle \theta}{\triangle t} = \text{angular velocity}$$

$$\alpha = \frac{\triangle \omega}{\triangle t} = \text{angular acceleration}$$

Rotational:

$$a_R = \frac{\triangle v}{\triangle t} = \frac{\omega \cdot r \cdot \triangle \theta}{\triangle \theta / \omega} = \omega^2 \cdot r = \text{centripetal acceleration}$$

$$a_T = \frac{\triangle v_T}{\triangle t} = \frac{\triangle \omega \cdot r}{\triangle t} = \alpha \cdot r = \text{tangential acceleration}$$

Forces and moments:

Static condition:

$$\sum F_x = m \cdot a_x = 0$$

$$\sum F_y = m \cdot a_y = 0$$

$$\sum M = 0$$

Dynamic condition:

$$\sum F_x = m \cdot a_x = \text{horizontal force}$$

$$\sum F_y = m \cdot a_y = \text{vertical force}$$

$$\sum M = I \cdot \alpha = \text{dynamic moment}$$

Energies:

$$E_{pot} = m \cdot g \cdot h = \text{potential energy}$$

$$E_{kin} = \frac{1}{2} \cdot m \cdot v^2 = \text{kinetic energy}$$

$$E_{rot} = \frac{1}{2} \cdot I \cdot \omega^2 = \text{rotational energy}$$

$$E_{tot} = E_{pot} + E_{kin} + E_{rot} = \text{total energy}$$

The specific calculations for the lower leg are shown in Appendix C: Definition of the Biomechanics.

Figure 4.2 illustrates flexion and extension of the segments of the lower leg.

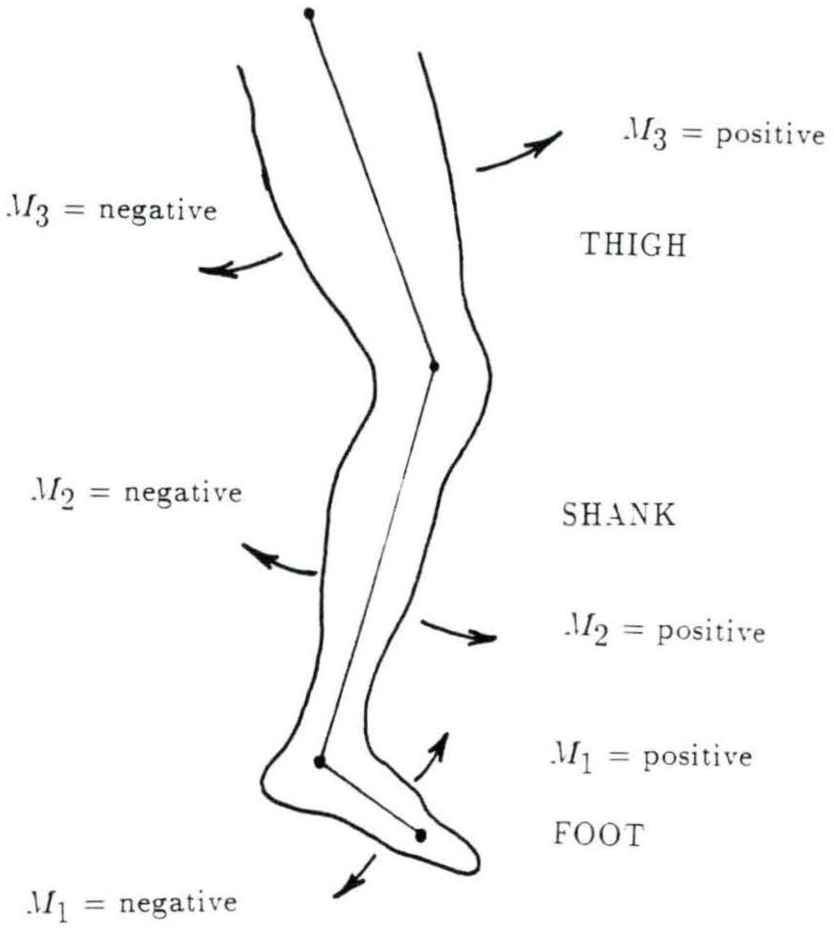

Figure 4.2: Flexion and extension of the lower leg

5 METHOD

5.1 Experimental Procedure

Electromyographic recording of the gastrocnemius and soleus muscle of the right leg were synchronized with high speed cinematography of the lower leg during extended treadmill running. Three male subjects currently involved in distance running and without any present injury were selected from the university student community on a strictly voluntary basis.

Two bipolar electrode pairs were used to obtain the EMG from the gastrocnemius and soleus muscle of the right leg. The electrodes should have good skin contact and be lightweight. As either small non-disposable electrodes (stick with double-sided adhesive rings) or pediatric size ECG electrodes are recommended (Hof, 1984), small non-disposable electrodes were used. Electrode gel was applied to the electrodes to ensure proper receiving of the EMG signals.

In order to obtain reliable EMG recordings, the skin resistance must be below 30 KΩ (O'Connell and Gardner, 1963; Hof, 1984). To accomplish this the calf of the right leg was shaved and washed with alcohol before placement of the electrodes to reduce the skin resistance to a minimum.

The gastrocnemius electrode pair was positioned vertically between the medial and lateral head of the muscle. The soleus electrode pair was positioned vertically on the medial aspect where the muscles protrudes from under the gastrocnemius. The electrode pairs were connected in bipolar fashion with a ground electrode placed on the ankle bone. Figure 5.1 shows the placement of the electrodes. A force transducer was placed on the shoe heel to indicate when heel strike occurred.

The subjects ran on a Quinton Instruments treadmill at a comfortable constant pace (8.25 mph) for an hour, which is a training pace for a good runner, but still slow enough that the running is aerobic (with oxygen).

The following additional equipment was used during the experiment:

- Apple-IIe computer
- A/D converter
- 631 Bio-Amplifiers, Phipps & Bird, Inc.
- Nova Super-8 camera (cine-8)
- Lights

Figure 5.2 shows the Nova Super-8 camera. The camera was set-up to film the lower leg. Small white spots were placed on the lower leg for use in later digitizing of the film. The spots were placed on the following locations: right hip, right knee, right ankle, right toe. A reference point was placed in the lower left hand corner in view of the camera, which placed all digitized values in the first quadrant. Figure 5.3 shows the view of the camera.

The electrodes were connected to a bioamplifier, where the signals were amplified 5000× and bandpass filtered in the spectrum 10- 1000 Hz. The signals were sent to an A/D converter, then to an Apple-IIe computer and stored in memory.

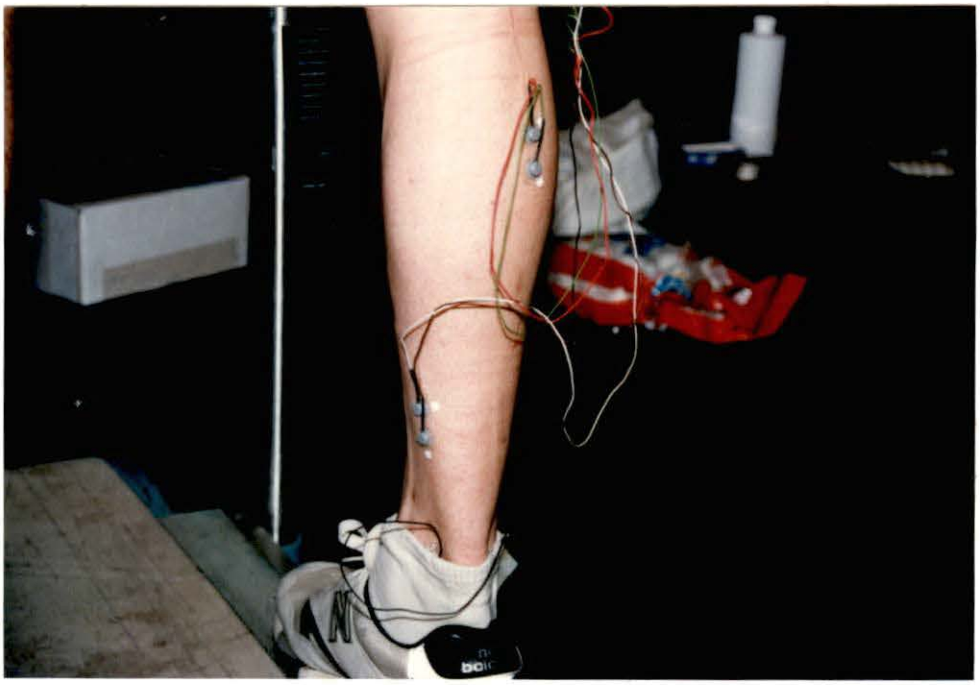

Figure 5.1: Placement of electrodes

Figure 5.2: Nova Super-8 camera

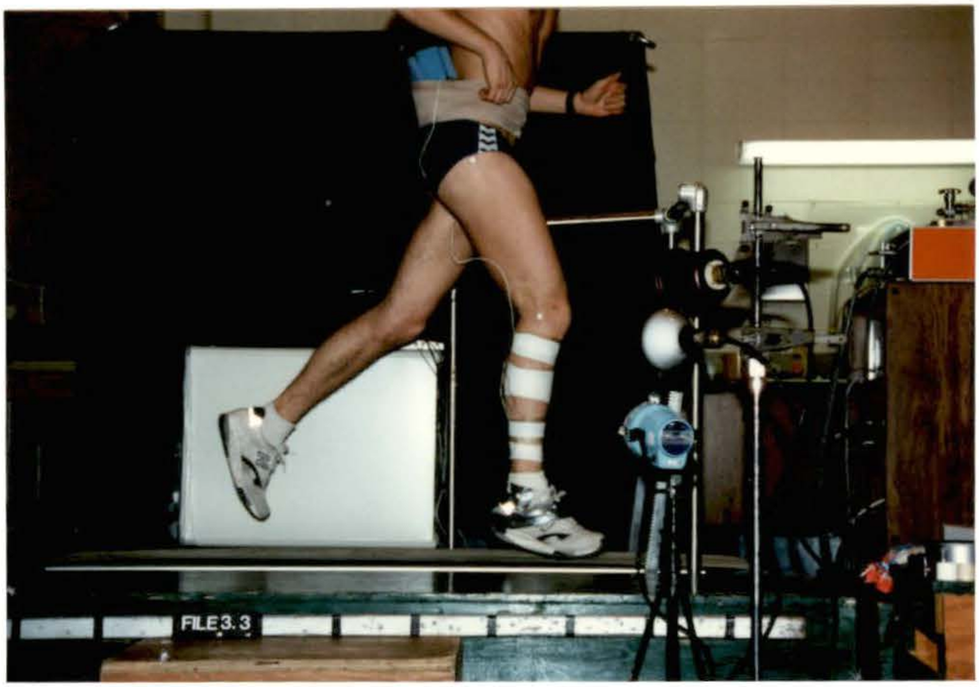

Figure 5.3: Runner and treadmill set-up

The A/D converter had a maximum of ±5 Volts, giving a maximum of 2 mV peak to peak of the EMG signal before cut-off. The signals were saved on diskettes for later analysis. The experimental set-up is shown in Figure 5.4.

The computer program to sample the EMG was designed to sample each millisecond for a time period of 2000 milliseconds. The program for the EMG sampling is shown in Appendix A: EMG Data Collection.

The following are the camera characteristics:

Film = Kodak Ektachrome 160 movie film

Frame rate = 250 frames/second

Shutter opening = 120°

Exposure time = $\frac{120^\circ}{360^\circ \cdot 250} = \frac{1}{750}$ second

Shutter factor = $\frac{360^\circ}{120^\circ} = 3$

f-stop = 1.8

The film speed was 250 frames/second, giving a time period between frames of 4 milliseconds. The length of the film record was 3600 frames, or 14.4 seconds/film. The filming took about 3 seconds including start and stop segments, so that 4 trials are included on each film. For each timeperiod there were 2 trials, giving 2 different trials/film.

The different trials were taken in intervals of 20 minutes with 2 films needed per subject, giving the following times at which records were analyzed: 0 - 20 - 40 - 60 minutes. Three male subjects and a total of 6 films resulted.

Figure 5.4: Illustration of experimental electronic and computer set-up

5.2 Experimental Output

In order to analyze changes in all the selected biomechanical parameters, the direct output obtained from the experiment included:

- raw EMG from gastrocnemius muscle (right leg)
- raw EMG from soleus muscle (right leg)
- film of the lower leg

The raw EMG from gastrocnemius and soleus muscle saved on diskettes on the Apple-IIe computer were transferred from the Apple-IIe to the IBM computer by using Kermit as decribed in Appendix A: EMG Data Collection. The EMG signals served as inputs for both the calculation of the elasticity of the calf muscle and the FFT-analysis as described later in this chapter. The film served as input for the analysis of biomechanics. The following equipment were used in analyzing the film:

- Numonics 1224-1 digitizer
- Tektronix 4051 computer
- Lafayette analyzer

In the present study the running cycle was analyzed from toe-off to toe-off for the right foot, in order to get optimal conditions for the FFT-analysis of the raw EMGs. Only one running cycle of each record was analyzed.The processed film was projected onto a white surface by the Lafayette analyzer. The following information was obtained directly from the film:

- 1. Framenumber for right toe off (reset to zero)
- 2. Framenumber for left heel strike
- 3. Framenumber for left toe off
- 4. Framenumber for right heel strike
- 5. Framenumber for next right toe off

The following could then be calculated (numbers refer to above):

- Running cycle time $= (5 - 1) \times 0.04$ seconds
- Support time $= ((5 - 4) + (3 - 2)) \times 0.04$ seconds
- Non-support time $= ((2 - 1) + (4 - 3)) \times 0.04$ seconds
- Stride rate = 1/running cycle time
- Stride length =speed of treadmill × running cycle time

The speed of the treadmill is measured in mph, so the following conversion factor allowed convertion to m/sec:

$$X \text{ mph} = X \cdot \frac{1609}{3600} \text{ m/sec.} = .447 \cdot X \text{ m/sec.}$$

A Tektronix 4051 computer was used in connection with a Numeric 1224-1 digitizer obtaining the x- and y- coordinates from the following points on the film:

- right hip
- right knee

- right ankle
- right toe

Figure 5.5 shows the Tektronix 4051 computer in connection with the Numeric 1224-1 digitizer. The program to obtain the x- and y- coordinates from the film is shown in Appendix B: Data from Digitizer.

Every eleventh frame (a time interval of 40 milliseconds) was digitized, with the resulting coordinates used as input to a biomechanical analysis program for IBM computers. The following parameters were determined:

- angle of right foot, shank, and thigh
- angle of right knee
- angle of right ankle
- velocity, acceleration, energy, and moments of lower leg

The program for the calculations of the biomechanics is shown in Appendix D: Biomechanics.

The elasticity of the calf muscle was determined by applying the EMG to muscle force processing method by Hof and Van den Berg (1981a, b, c, d) using Hill's muscle model.

Input:

- raw EMG from gastrocnemius and soleus muscle
- angle of ankle

Figure 5.5: Tektronix 4051 computer and Numeric 1224-1 digitizer

Output:

- the different components of the elasticity of the calf muscle

The program for the calculation of the elasticity of the calf muscle is shown in Appendix E: Elasticity of Calf Muscle.

The raw EMG from gastrocnemius and soleus muscle was additionally used as input to analyze its frequency spectrum (FFT-analyze). This analysis was done with a FORTRAN program on a PDP-11 computer. The program for the FFT-analysis is shown in Appendix F: FFT-Analysis.

All the obtained information was compared over the different timeperiods and analyzed to determine which might best indicate the onset of fatigue. To get a good visual comparison, the information was presented graphically by using Lotus 1-2-3.

6 RESULTS AND DISCUSSION

One running cycle, broken into four time periods, was analyzed for each of three subjects and compared to determine which of the changes (in biomechanics, EMG recording, elasticity and FFT-analysis) might best indicate the onset of fatigue. Subject 1 was an elite runner with a 10 km time of 30.25, while subjects 2 and 3 were good runners with 10 km times between 33-34 minutes. As the results obtained in the present study showed more or less the same pattern for all three subjects, the figures for only one of the subjects are included in this chapter. However, for completeness, the figures for the other two subjects may be found in Appendix G: Figures and Tables.

6.1 Biomechanics

6.1.1 Running Cycle

The most often reported parameters of the running cycle are running cycle time, support time, non-support time, stride rate, and stride length. The formulas used to calculate these parameters are shown in Chapter 5, Section 5.2. The factors used in the calculations of these key factors are shown in Table 6.1 for subject 1, in Table 6.2 for subject 2, and Table 6.3 for subject 3. The running cycle time is shown in Figure 6.1, support time in Figure 6.2, non-support time in Figure 6.3, stride rate in Figure 6.4, and stride length in Figure 6.5.

The literature indicates that as fatigue occurs support time increases, the non-support time decreases, stride rate increases, and stride length decreases (Bates and Osternig, 1977; Elliott and Ackland, 1981; Elliott and Roberts, 1980; Sparks, 1975). In the present study there were no observable changes in any of these parameters for any of the three subjects. However, when the three subjects were compared with each other, the results demonstrated that the better runner had a longer running cycle time, lower stride rate, and longer stride length than the other two runners. Biomechanical fatigue, defined as observable changes in the movement pattern due to changes in the runner's biomechanics, usually results in an increase in support time, a decrease in non-support time, an increase in stride rate, and a decrease in stride length (Bates and Osternig, 1977; Elliott and Ackland, 1981; Elliott and Roberts, 1980; Sparks, 1975). The present study did not confirm the changes in the running cycle as shown in the literature. This might be due to subjects not becoming biomechanically fatigued at the one hour 8.25 mph constant pace limiting the occurrence of changes in the running cycle. To better indicate changes in the running cycle due to fatigue, it appears that competitively trained subjects would either have to run for a longer period of time or run at a faster pace. It was concluded that in the present study the subjects showed no observable changes in any of running cycle parameters after one hour of running at a 8.25 mph pace.

Table 6.1: The factors used to determine the parameters of the running cycle for subject 1

	0 min.	20 min.	40 min.	60 min.
Right toe off [second]	0	0	0	0
Left heel strike [second]	0.144	0.180	0.172	0.136
Left toe off [second]	0.368	0.380	0.388	0.372
Right heel strike [second]	0.500	0.544	0.552	0.500
Right toe off [second]	0.732	0.784	0.792	0.768
Subject 1				

Table 6.2: The factors used to determine the parameters of the running cycle for subject 2

	0 min.	20 min.	40 min.	60 min.
Right toe off [second]	0	0	0	0
Left heel strike [second]	0.112	0.124	0.108	0.116
Left toe off [second]	0.312	0.344	0.324	0.328
Right heel strike [second]	0.440	0.464	0.440	0.460
Right toe off [second]	0.656	0.688	0.660	0.676
Subject 2				

Table 6.3: The factors used to determine the parameters of the running cycle for subject 3

	0 min.	20 min.	40 min.	60 min.
Right toe off [second]	0	0	0	0
Left heel strike [second]	0.132	0.148	0.152	0.160
Left toe off [second]	0.300	0.340	0.356	0.348
Right heel strike [second]	0.452	0.484	0.496	0.484
Right toe off [second]	0.652	0.708	0.700	0.704
Subject 3				

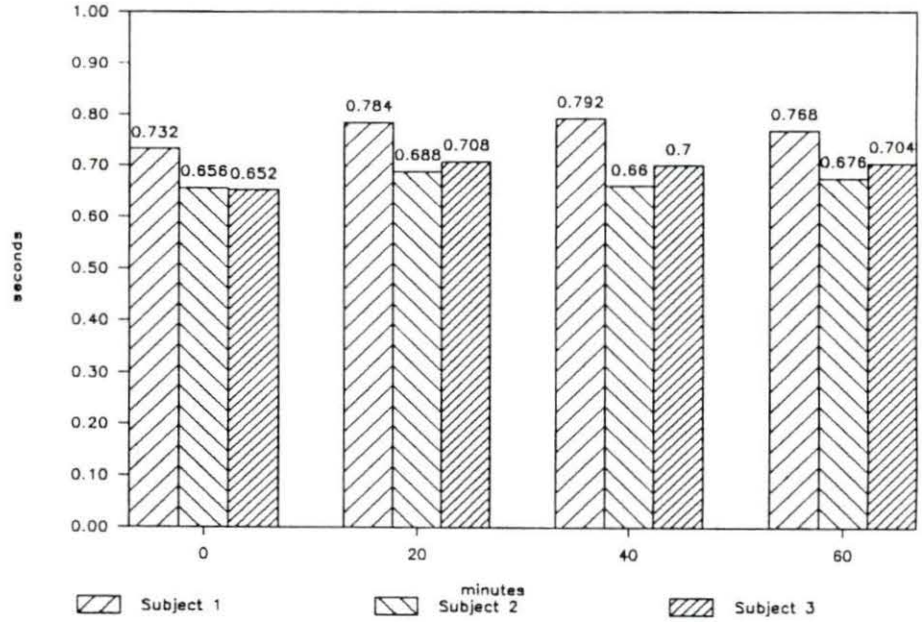

Figure 6.1: Running cycle time

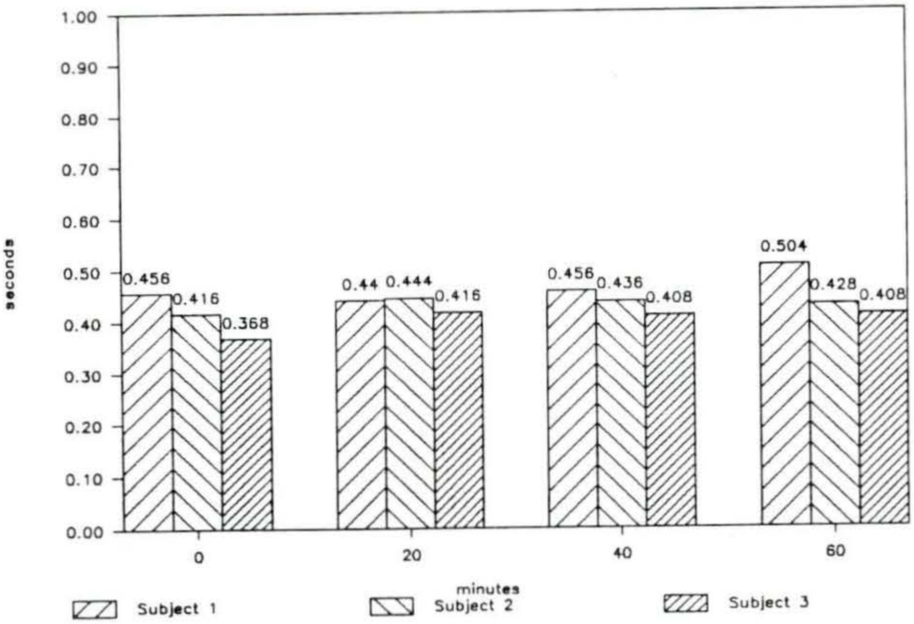

Figure 6.2: Support time

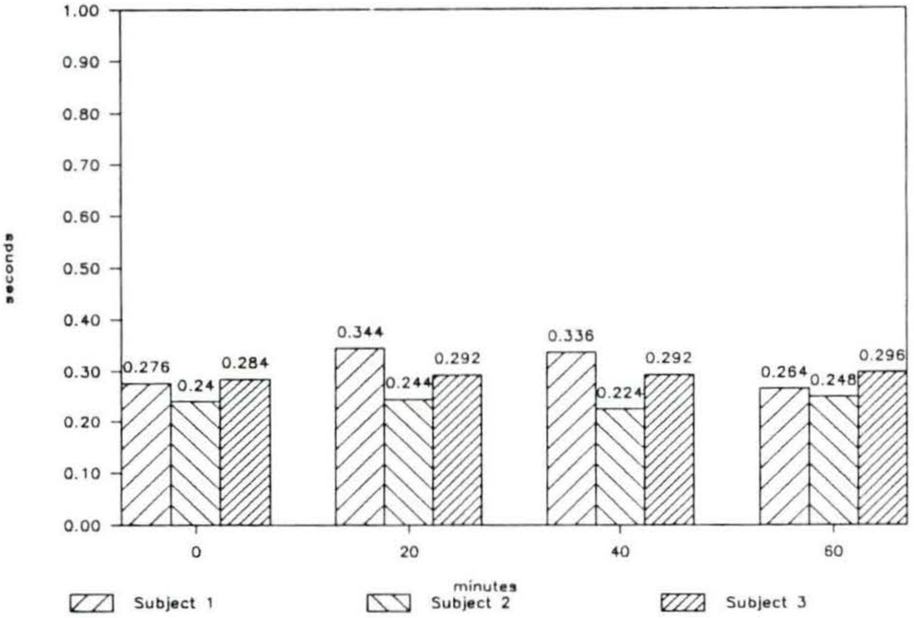

Figure 6.3: Non-support time

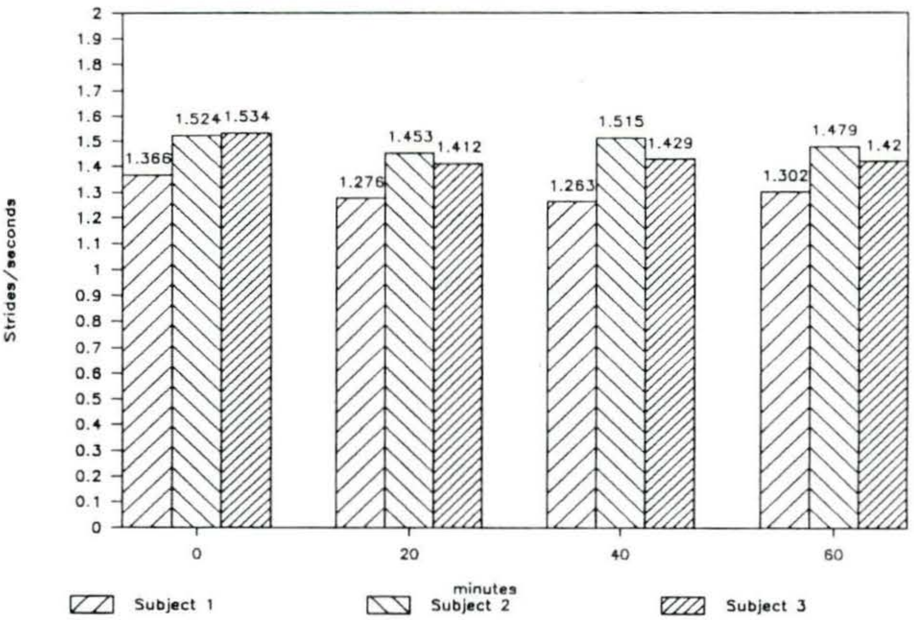

Figure 6.4: Stride rate

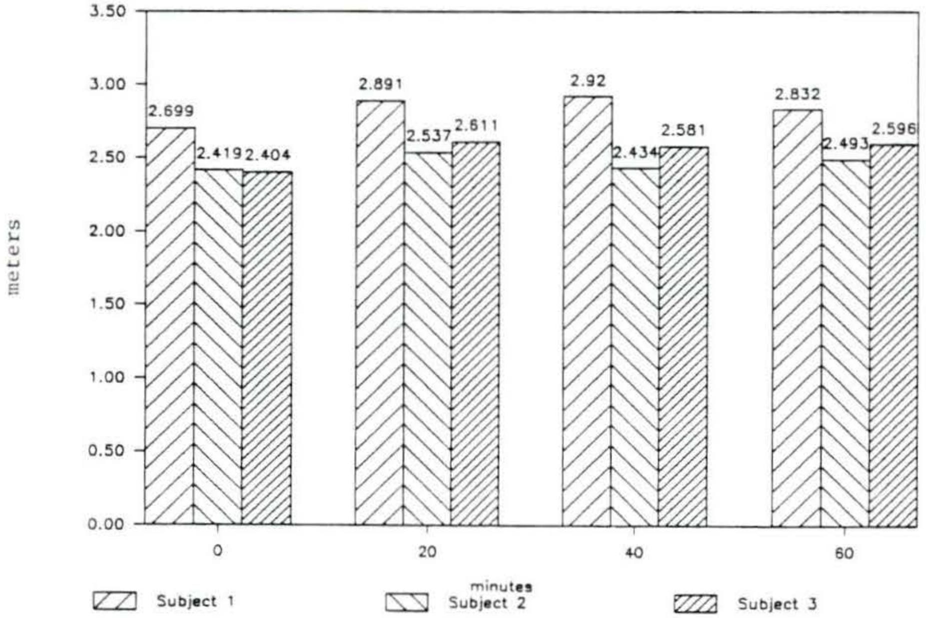

Figure 6.5: Stride length

6.1.2 Angles

The angles of both the ankle and the knee of the right leg throughout the cycle remained constant over time for all three subjects. Figure 6.6 shows the angle of the ankle, while Figure 6.7 shows the angle of the knee. However, due to changes in the running cycle time over the four time periods shown in Table 6.1, Table 6.2, and Table 6.3, the curves shifted to the left with a decrease in the running cycle time, and to the right with an increase in the running cycle time, and was most severe for subjects 1 and 3. The angle of the ankle had its minimum value in the stance phase close to push-off, while the maximum value occurred at toe-off. The angle of the knee had its minimum value in the swing phase, and had local maximums at toe-off and just before foot strike. For increased velocity it has been shown that knee extension decreases in the swing and support phases, while no changes occur in the ankle flexion and extension patterns (Sinning and Forsyth, 1970). Since fatigue causes a decrease in running velocity the opposite effects would therefore be expected. However, the present study did not demonstrate any observable changes in the angles of either the ankle or the knee. Again this might be due to subjects that were not yet biomechanically fatigued or that the subjects were able to keep the same running style as no external changes were seen. To better indicate significant changes in the angles due to fatigue, the subjects should either run for a longer period of time or at a faster pace. It can be concluded that in the present study the subjects showed no observable changes in ankle or knee angles after one hour of running at a 8.25 mph pace.

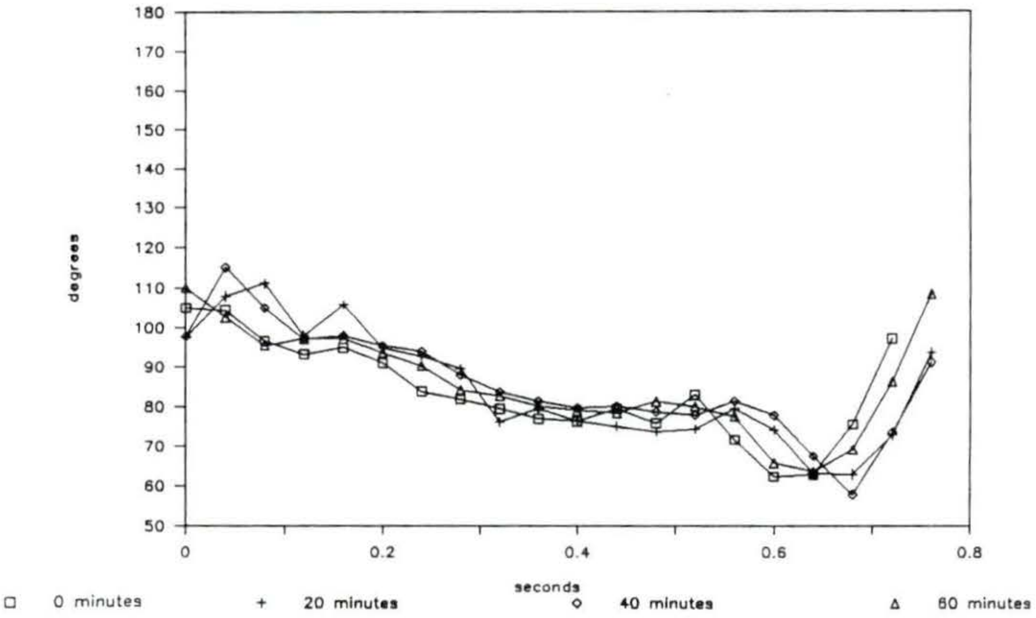

Figure 6.6: Angle of the ankle (subject 1)

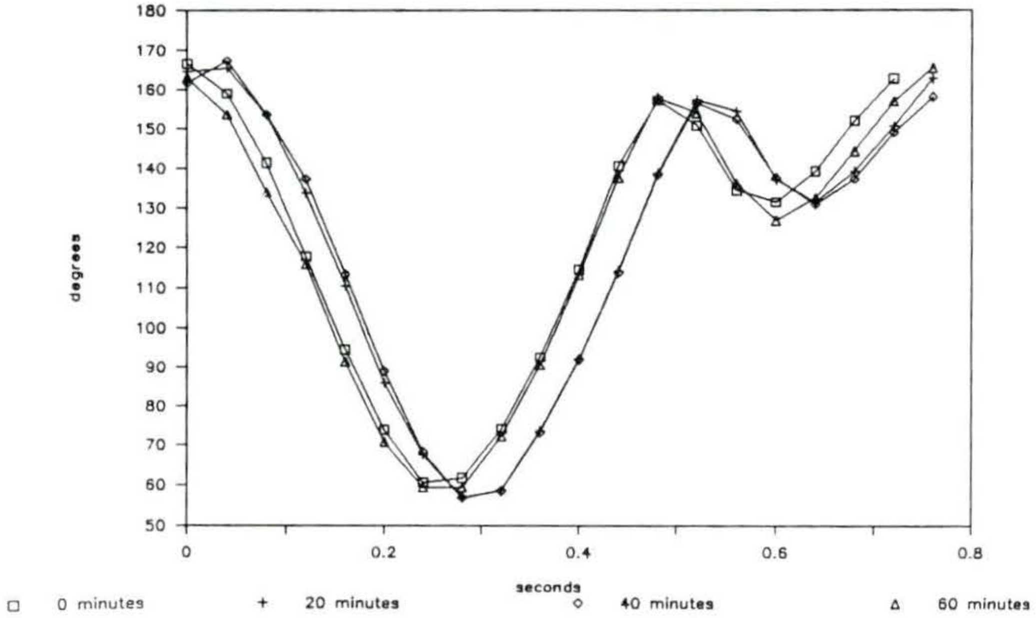

Figure 6.7: Angle of the knee (subject 1)

6.1.3 Dynamic Moments

The dynamic moments around the ankle, knee, and hip showed the same pattern for all three subjects and remained constant over time. Some phase shifting was evident because of changes in the running cycle time over the four time periods shown in Table 6.1, Table 6.2, and Table 6.3. Figure 6.8 shows the dynamic moment pattern around the ankle, Figure 6.9 shows the dynamic moment pattern around the knee, and Figure 6.10 shows the dynamic moment pattern around the hip. The dynamic moment around the ankle was minimal during the swing phase, while the maximum value occurred just prior to foot strike. The dynamic moment around the knee was minimal in the swing phase just before left toe- off, while local maximums occurred in the swing phase before left foot strike and in the stance phase with the foot stable. The dynamic moment around the hip was minimal in the swing phase, with the maximum value occurring during the stance phase with the foot stable. This agrees with the literature, where it has been shown that the forces across the knee and ankle are maximal at push-off (Winter, 1983). The present study did not demonstrate any observable changes over time in the dynamic moments. This again might be due to subjects who were not yet biomechanically fatigued or that the subjects were able to keep the same running style as no external changes were seen. The subjects might therefore have to run faster or for a longer period of time in order to demonstrate any changes in dynamic moments. It can therefore be concluded that in the present study the subjects showed no observable changes in the dynamic moments after one hour of continous running at a 8.25 mph pace.

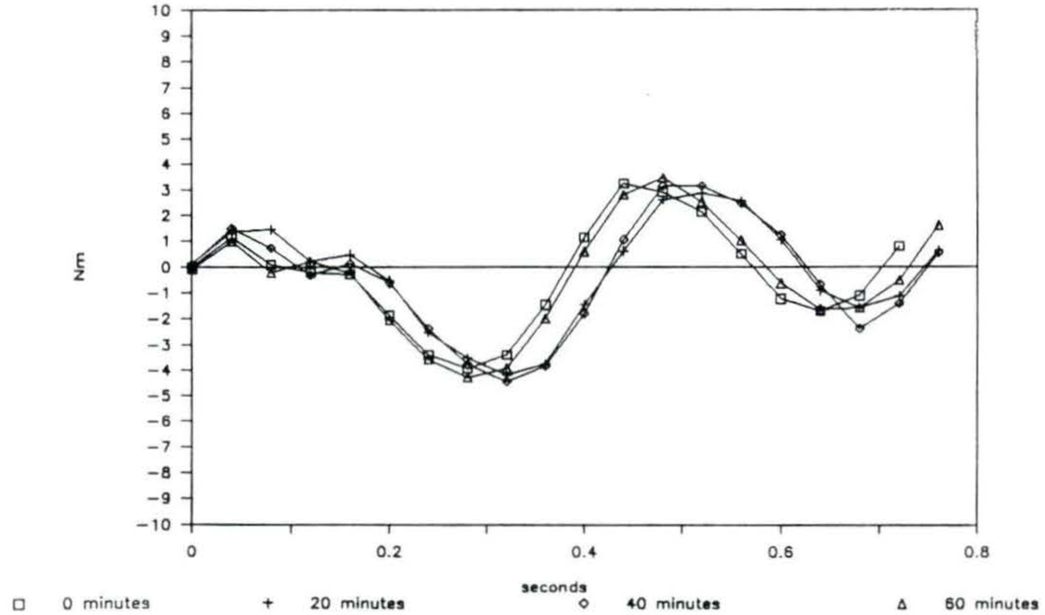

Figure 6.8: Dynamic moment around ankle (subject 1)

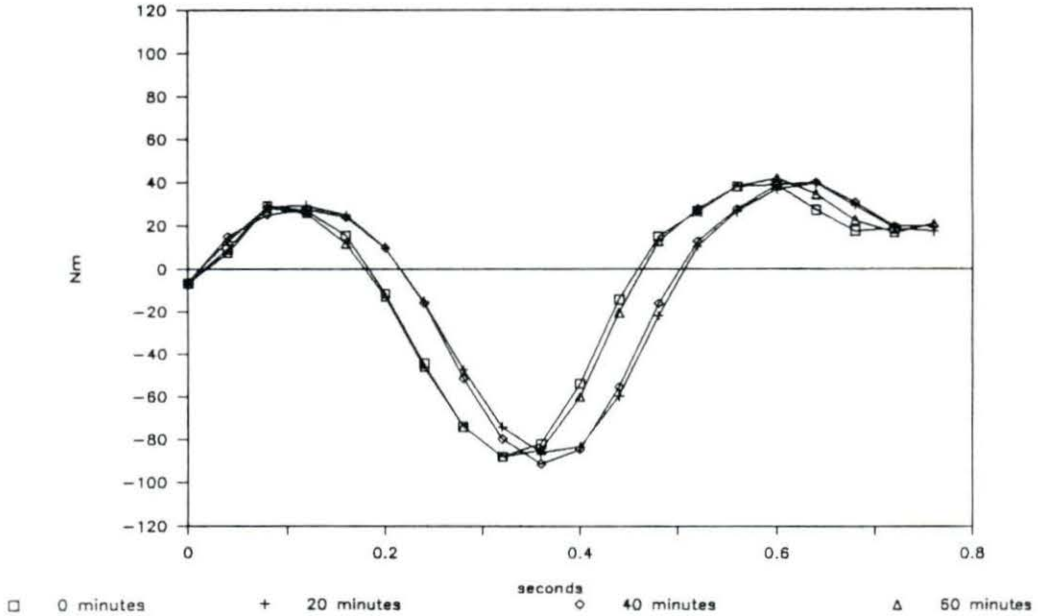

Figure 6.9: Dynamic moment around knee (subject 1)

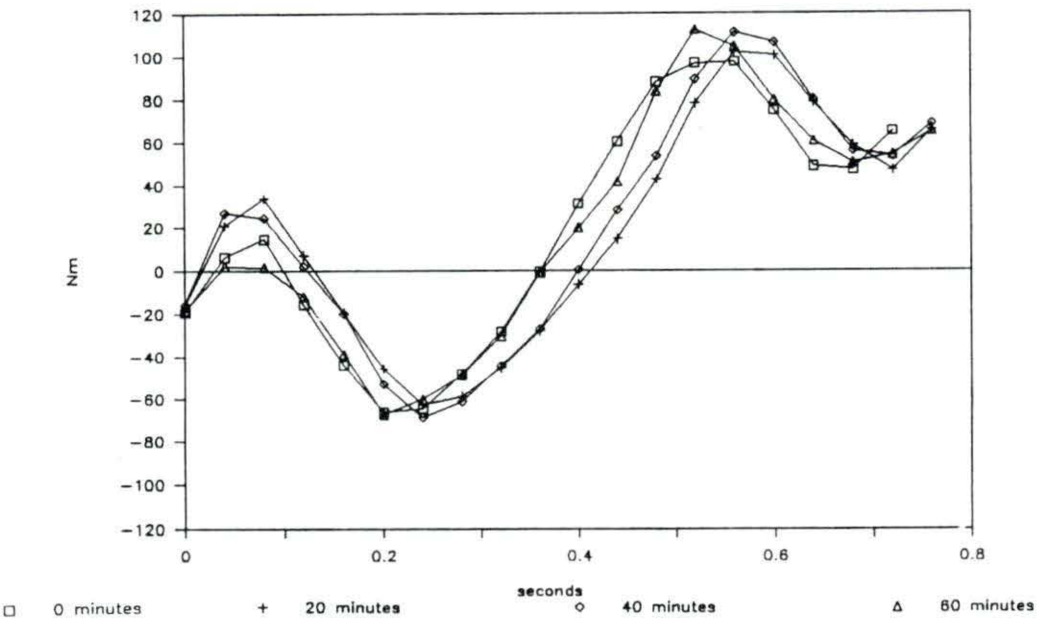

Figure 6.10: Dynamic moment around hip (subject 1)

6.1.4 Energy

The total energy for the foot, shank, and thigh remained constant over time for all three subjects. Figure 6.11 shows the energy of the foot, Figure 6.12 shows the energy of the shank, and Figure 6.13 shows the energy of the thigh. The maximum value for the energy of the foot occurred in the swing phase, while the minimum value occurred around foot strike. The energy of the shank showed the same pattern as the energy for the foot. The energy of the thigh had local minimums in the swing phase and in the stance phase, while the maximum value occurred in the swing phase. The present study did not demonstrate any observable changes in the total energies. This might be due to subjects who were not yet biomechanically fatigued or that the subjects were able to keep the same running style as no external changes were seen. The subjects therefore have to run for a longer period of time or at a faster pace in order to demonstrate any observable changes in the energies. It can therefore be concluded that in the present study the subjects showed no observable changes in the energies after one hour of running at a 8.25 mph pace.

In other biomechanical studies of fatigue in runners over time, only the parameters of the running cycle have been given much attention. For example, in one study on fatigue in a 3,000 meter race (Elliott and Roberts, 1980) the runners ran at a 11.6 mph pace for less than 10 minutes. In a study on fatigue in a 10,000 meter race (Elliott and Ackland, 1981) the subjects ran at a pace between 11.2-12.3 mph for about 30-33 minutes. Another study on fatigue in running a 4-minute mile (Sparks, 1975) the subjects ran at a 15 mph pace for 4 minutes. Each of the above studies all indicated biomechanical fatigue resulted in changes in the movement pattern. However, in the present study the subjects ran at a 8.25 mph pace for one hour with no change in the movement pattern. The subjects would therefore have to run for a longer period of time or at a faster pace in order to demonstrate any observable changes in the movement pattern.

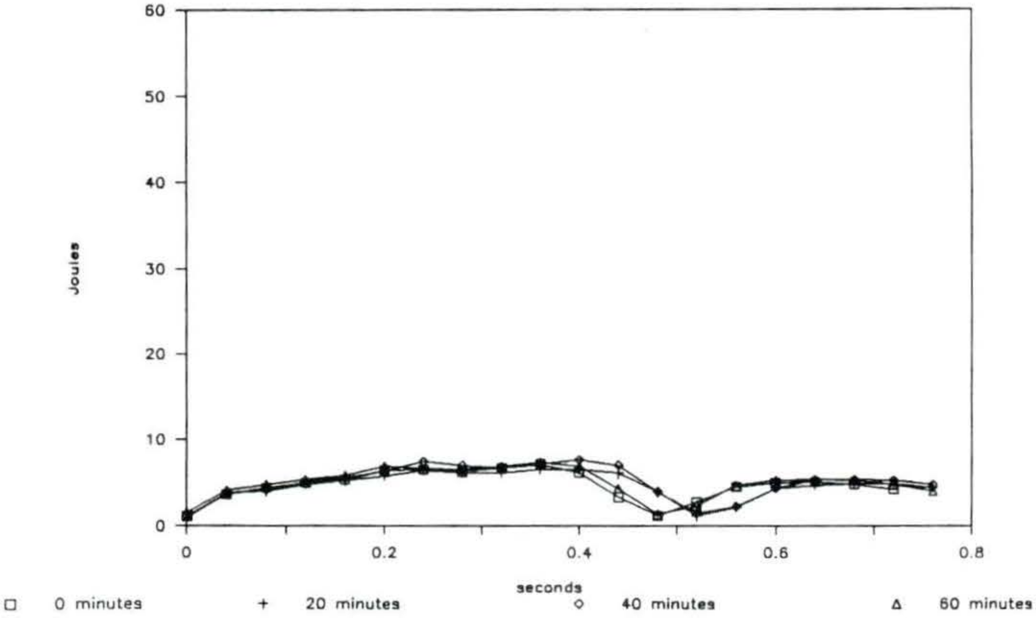

Figure 6.11: Total energy for foot (subject 1)

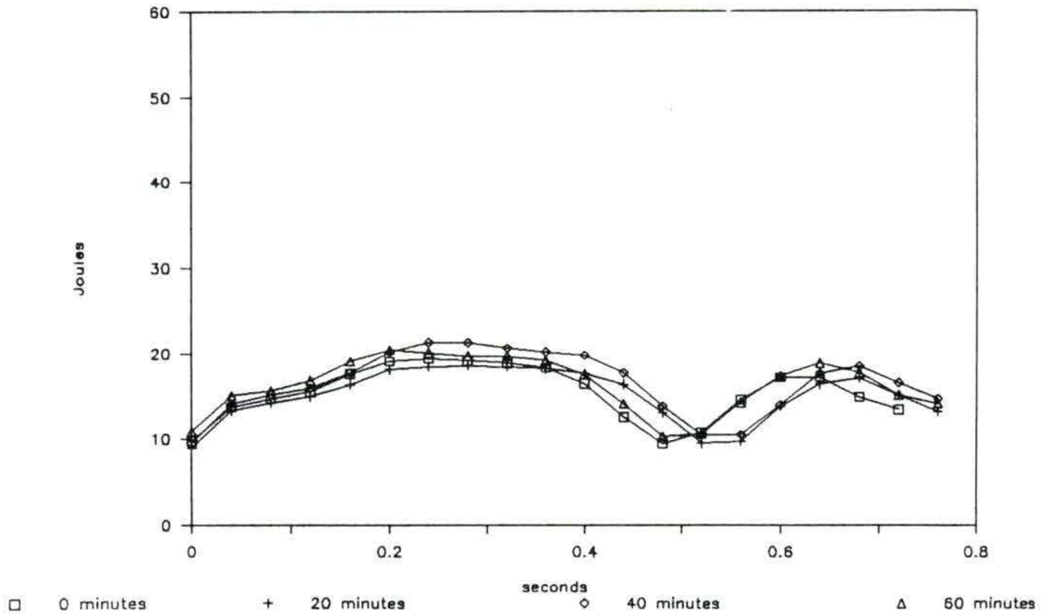

Figure 6.12: Total energy for shank (subject 1)

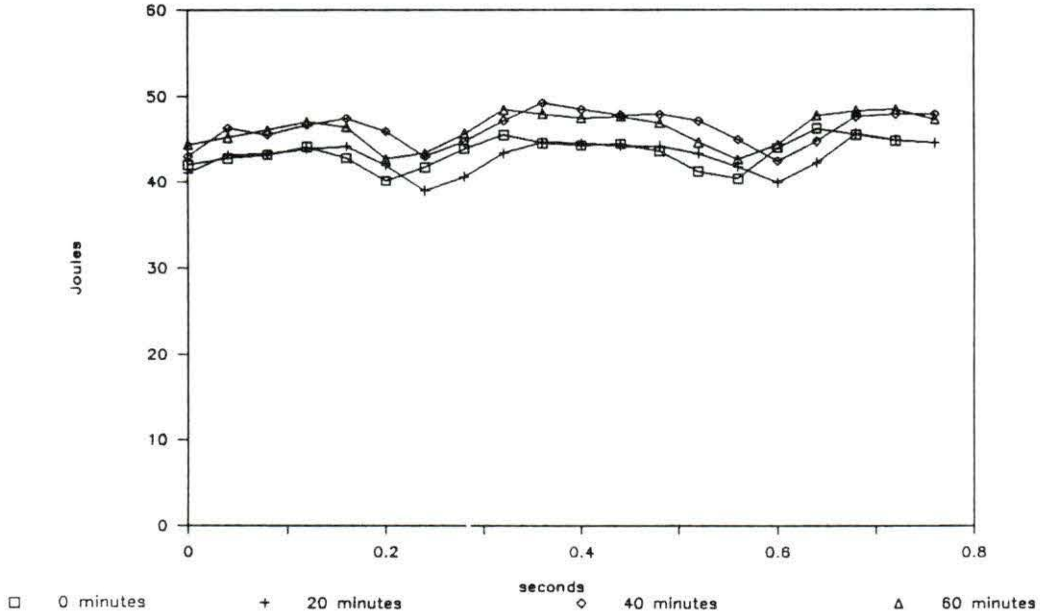

Figure 6.13: Total energy for thigh (subject 1)

6.2 EMG Recording

It has been shown that EMG activity increases with increased running speed. It has been suggested that with increased running speed increased neural activation occurs having a positive effect on the stride rate (Mero and Komi, 1986). The present study showed that even though there was a decrease in the amplitude of the EMG over time, this had no influence on the movement pattern. No external changes were seen in the movement pattern, however, the EMG recordings indicated that internal changes occurred. For all three subjects the amplitude of the EMG showed a decrease over time, with the most severe decrease occurring for subject 1. Figure 6.14 shows the EMG recording at the beginning of the trial, Figure 6.15 shows the EMG recording after 20 minutes, Figure 6.16 shows the EMG recording after 40 minutes, and Figure 6.17 shows the EMG recording after 60 minutes. Figures 6.16 and 6.17 show no EMG activity occurs in the swing phase until just prior to the foot striking the ground. The EMG activity then increases until the maximum occurs at push-off, after which the EMG activity decreases to zero. The present study confirms previous studies which demonstrated that the calf muscle is active only during the stance phase, with the maximum EMG occurring at push-off (Elliott and Blanksby, 1979a; Elliott and Blanksby, 1979b; Hof, Geelen, and Van den Berg, 1983; Mann et al., 1986; Schwab et al., 1983). The maximum EMG activity has been shown to occur when the muscle is closest to its anatomical length (Frigo et al., 1978). It can therefore be assumed that the muscle is closest to its anatomical length at push-off. Joint angles can be assumed to be proportional to muscle length (Hof and Van den Berg, 1981a). In the present study the joint angle of the ankle had its mimimum value in the stance phase close to push-off. This was close to where the maximum EMG activity occurred. It can therefore be concluded that the calf muscle was closest to its anatomical length when the angle of the ankle had its minimum value. In the present study the minimum value of the angle of the ankle remained fairly constant for all four time periods. The present study did not show any changes in the length of the calf muscle due to subjects who were not yet biomechanically fatigued.

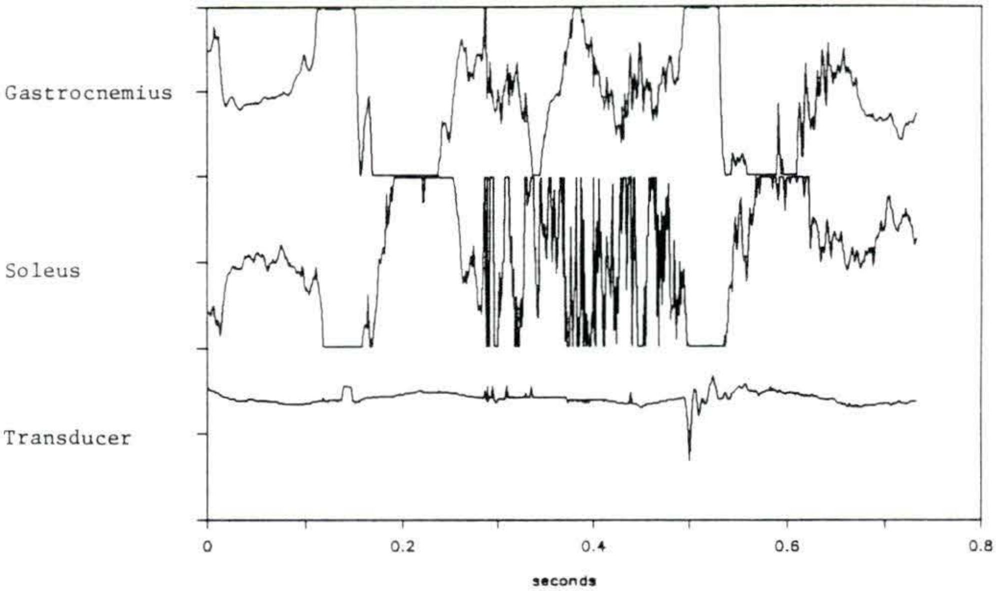

Figure 6.14: EMG recording after 0 minutes (subject 1)

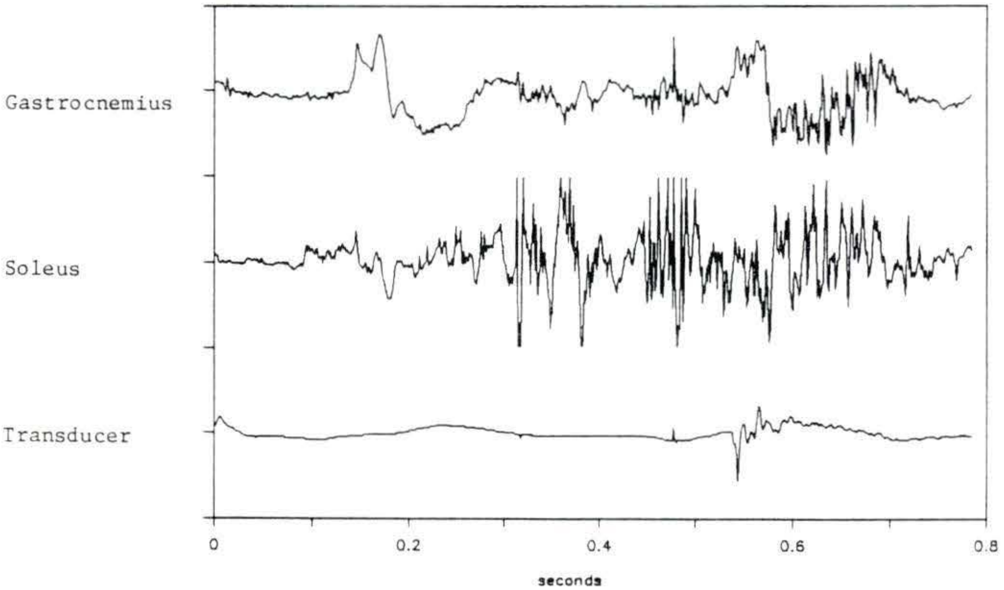

Figure 6.15: EMG recording after 20 minutes (subject 1)

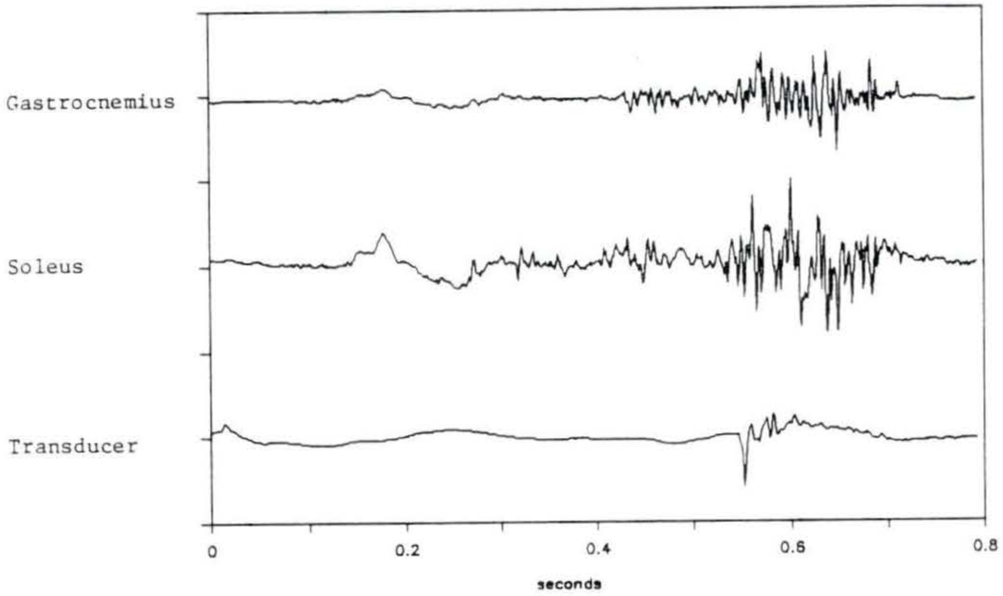

Figure 6.16: EMG recording after 40 minutes (subject 1)

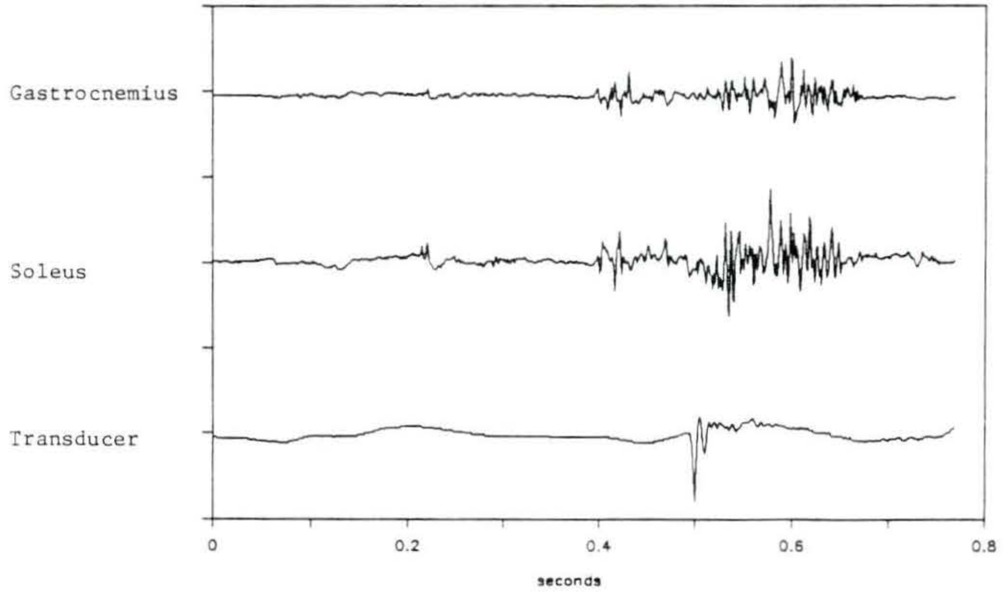

Figure 6.17: EMG recording after 60 minutes (subject 1)

6.3 Elasticity

The elasticity of the calf muscle was fairly constant over time for all three subjects. Figure 6.18 shows the angle of the ankle joint represented by ϕ, Figure 6.19 shows the SEC stretch represented by ϕ_e, Figure 6.20 shows the angle corresponding to CC length represented by ϕ_c, and Figure 6.21 shows the torque from the PEC represented by M_p. M_p (Figure 6.21) shows that there was no tension on the muscle when it was at its resting length or less. When the muscle began stretching, tension started to build up with M_p becoming maximum around push-off, thereafter decreasing to zero. ϕ_c (Figure 6.20), the length of the CC, seemed to depend primarily on the angle of the ankle ϕ (Figure 6.18), since the SEC stretch ϕ_e (Figure 6.19) only contributed a small amount in the calculation of ϕ_c. ϕ_c (Figure 6.20) followed the same pattern as ϕ (Figure 6.18), with an almost linear decrease from toe-off until the minimal value at push-off, with a subsequent increase from push-off until toe-off. The present study did not demonstrate any observable changes in the elasticity. This might be due to subjects not becoming biomechanically fatigued, since the elasticity parameters were depending primarily on the angle of the ankle. In order to see changes in the elasticity due to fatigue, the subjects would either have to run at a faster pace or for a longer period of time in order to cause biomechanical fatigue. It can therefore be concluded that in the present study the subjects showed no observable changes in the elasticity after one hour of running at a 8.25 mph pace.

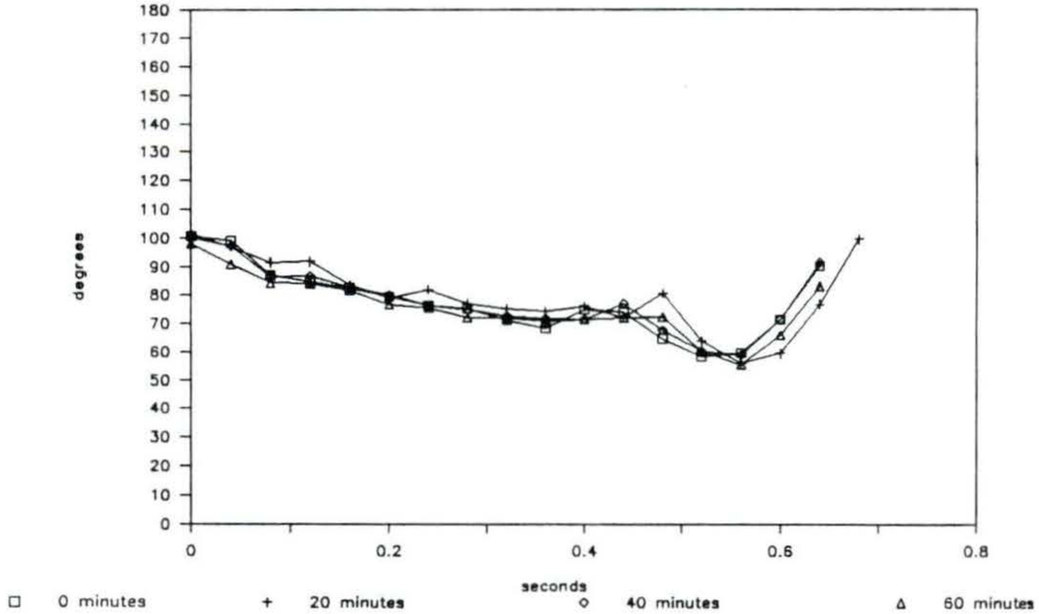

Figure 6.18: ϕ, angle of the ankle joint (subject 2)

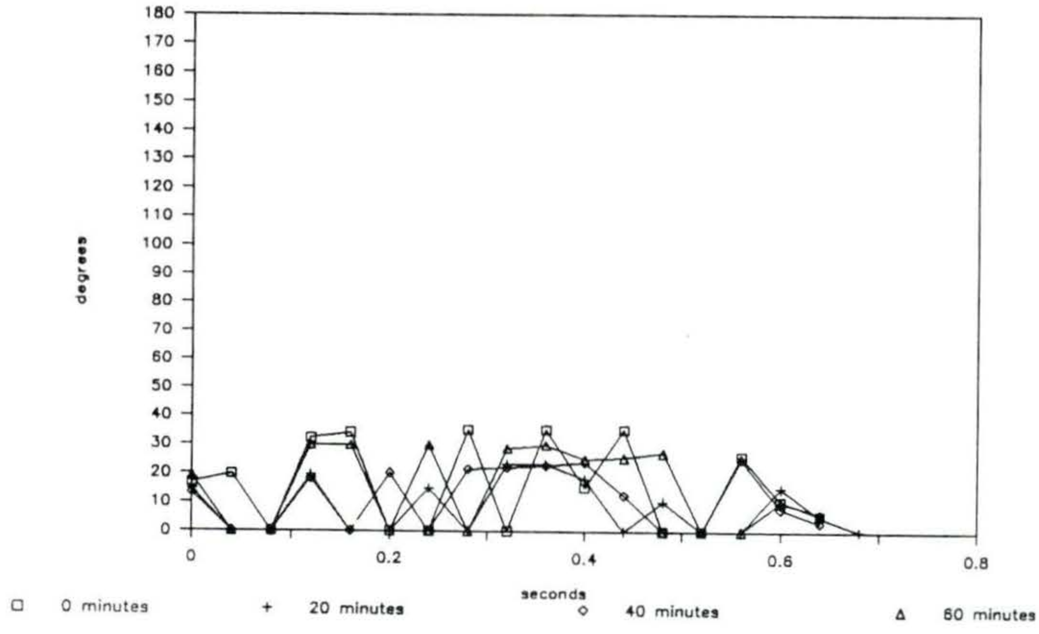

Figure 6.19: ϕ_e, SEC stretch (subject 2)

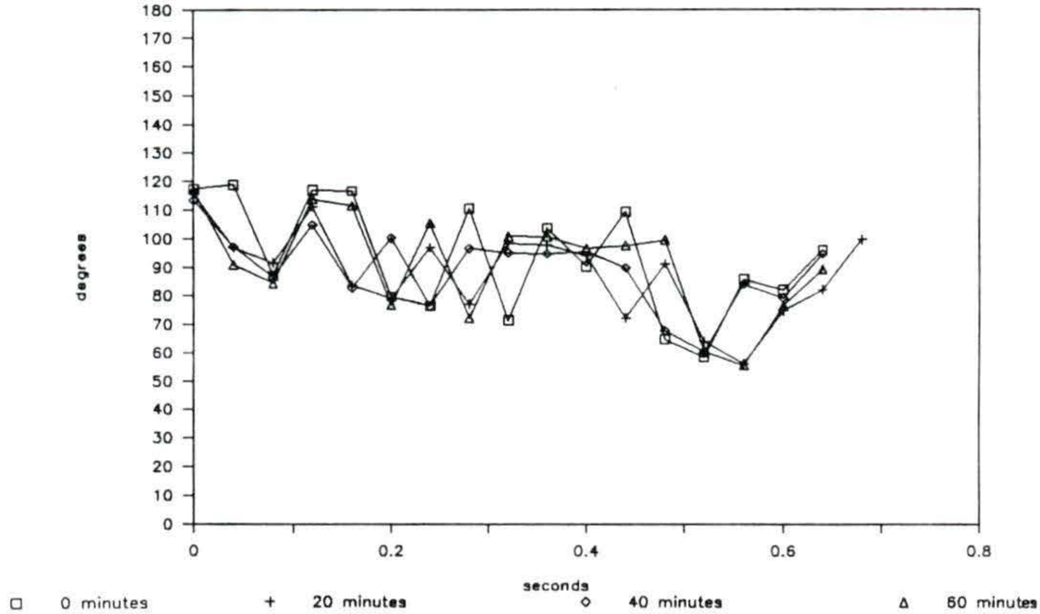

Figure 6.20: ϕ_c, angle corresponding to CC length (subject 2)

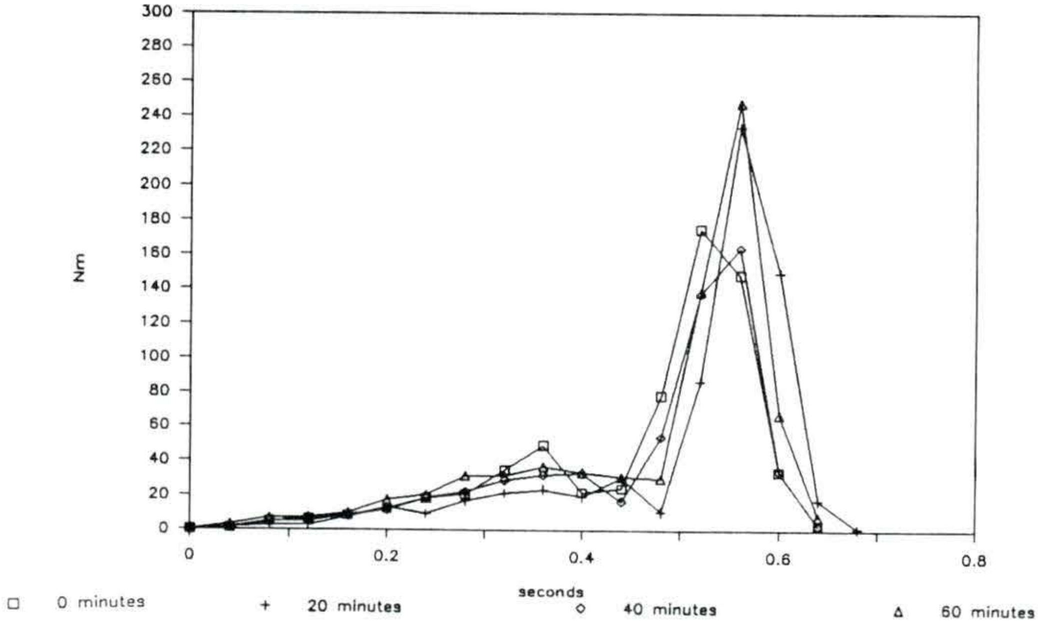

Figure 6.21: M_p, torque from the PEC (subject 2)

6.4 FFT-Analysis

It has been shown that a sustained, constant-force, isometric contraction shifts toward lower frequencies while the amplitude increases with fatigue (De Luca, 1984). However, fatigue under dynamic conditions has not yet been given much attention.

In the present study, which dealt with dynamic conditions, the magnitude of the power spectrum of the EMG signals showed a decrease over time as well as a shift towards lower frequencies. Figures 6.22 and 6.23 show the power spectrum for the gastrocnemius and soleus muscle at the beginning of the bout, Figures 6.24 and 6.25 show the spectrum after 20 minutes, Figures 6.26 and 6.27 show the spectrum after 40 minutes, and Figures 6.28 and 6.29 show the spectrum after 60 minutes. For subject 1 the magnitude of the power spectrum showed a continuous decrease over time as well as a shift toward lower frequencies for both muscles. For subject 2 the magnitude of the power spectrum for the gastrocnemius muscle remained constant, while the magnitude of the power spectrum for the soleus muscle increased in the beginning after which it decreased. However, the frequency shifted toward zero for both the gastrocnemius and soleus muscle. For subject 3 the frequency for the gastrocnemius muscle shifted toward zero in the beginning, after which it shifted toward higher frequencies. For the soleus muscle there was a continuous shift toward zero for the frequency, while the magnitude of the power spectrum decreased in the beginning, and then increased to a constant level.

The differences for the three subjects in the magnitude of the power spectrum and the frequencies may result from the recruiting of fast twitch fibers instead of slow twitch fibers as fatigue progresses. This agrees with the literature, where it has been shown that fatigue usually comes in stages as a result of the recruiting of muscle fibers (Costill, 1986). So, the magnitude of the power spectrum from EMG can be used in determining when local muscle fatigue occurs resulting from the recruitment of either the slow twitch, the fast twitch *a*, or the fast twitch *b* fibers.

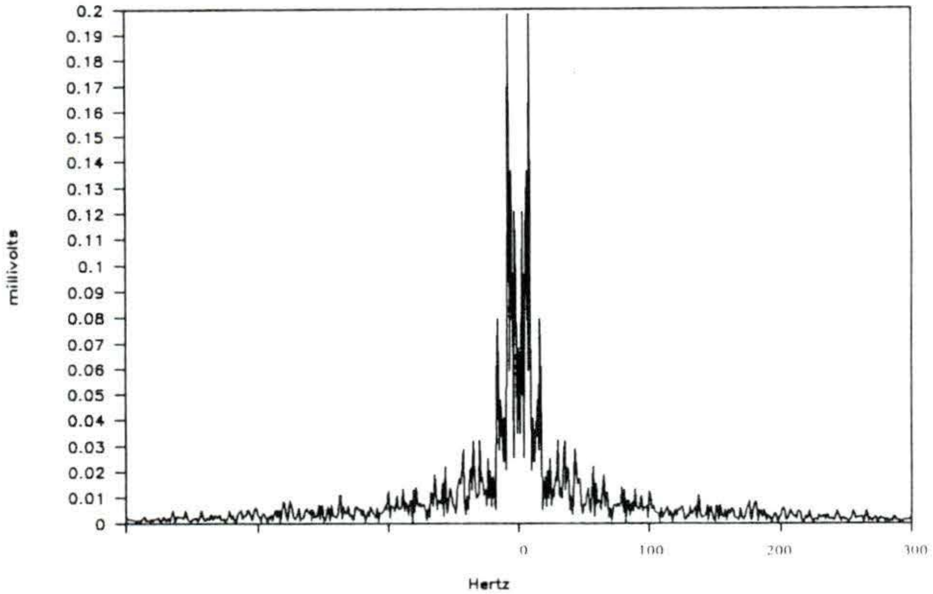

Figure 6.22: FFT-analysis for gastrocnemius muscle after 0 minutes (subject 1)

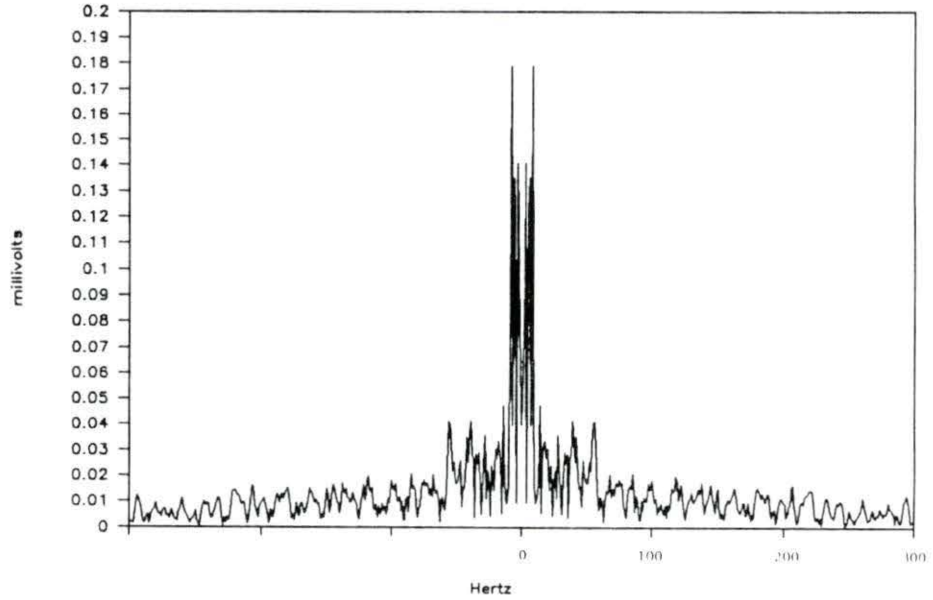

Figure 6.23: FFT-analysis for soleus muscle after 0 minutes (subject 1)

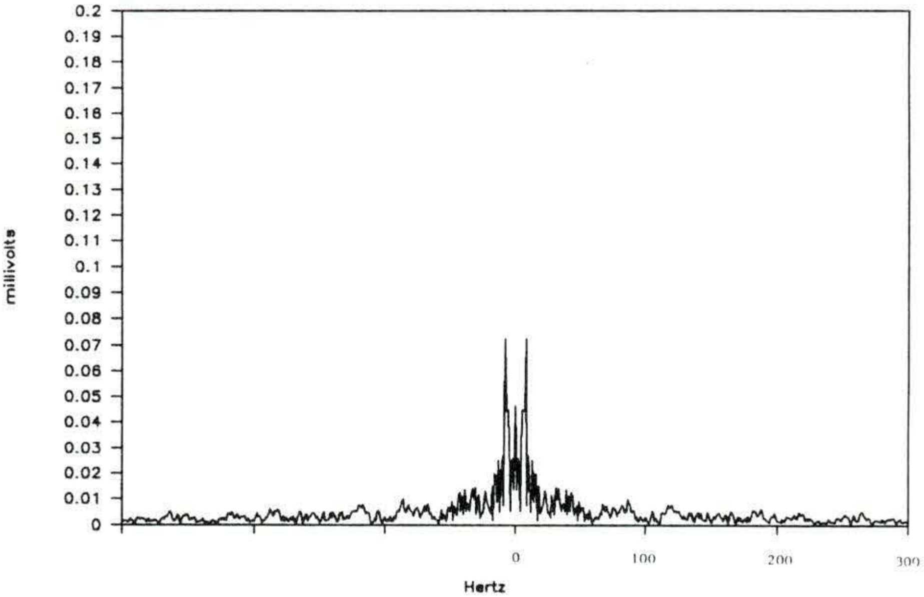

Figure 6.24: FFT-analysis for gastrocnemius muscle after 20 minutes (subject 1)

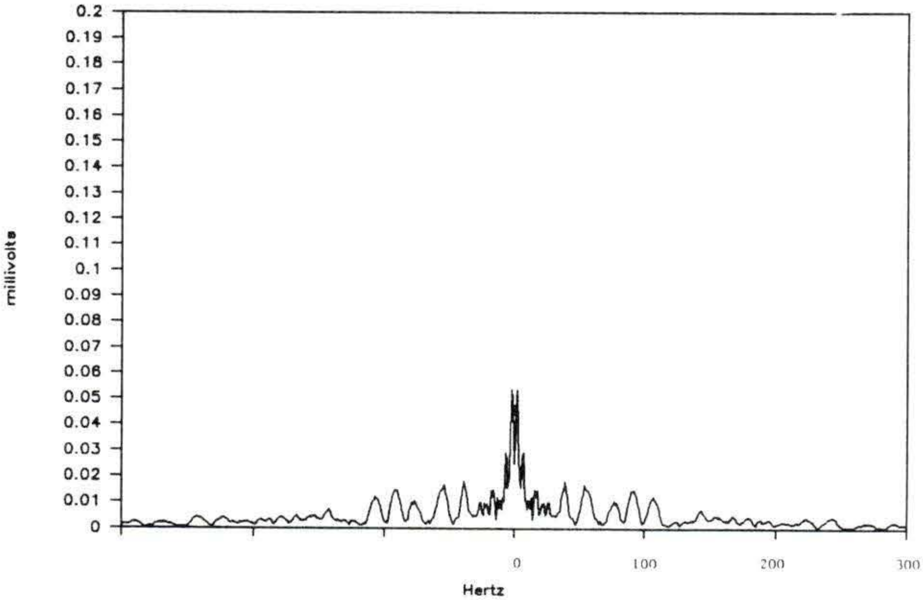

Figure 6.25: FFT-analysis for soleus muscle after 20 minutes (subject 1)

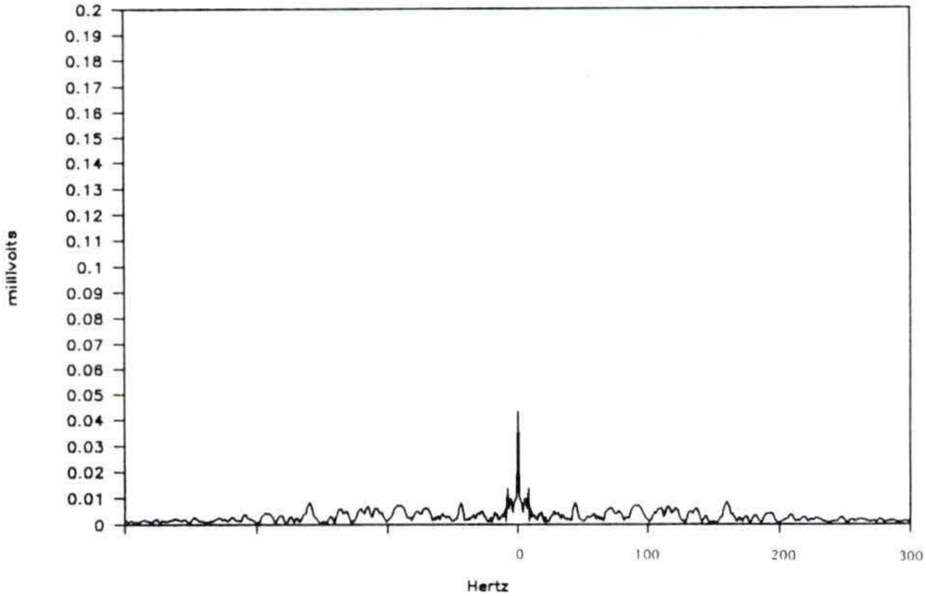

Figure 6.26: FFT-analysis for gastrocnemius muscle after 40 minutes (subject 1)

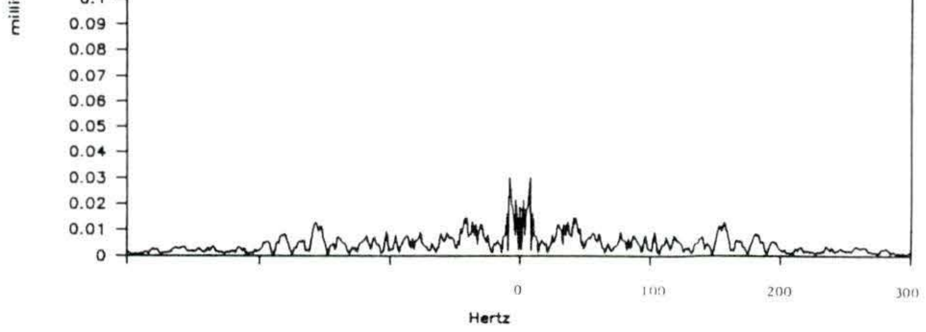

Figure 6.27: FFT-analysis for soleus muscle after 40 minutes (subject 1)

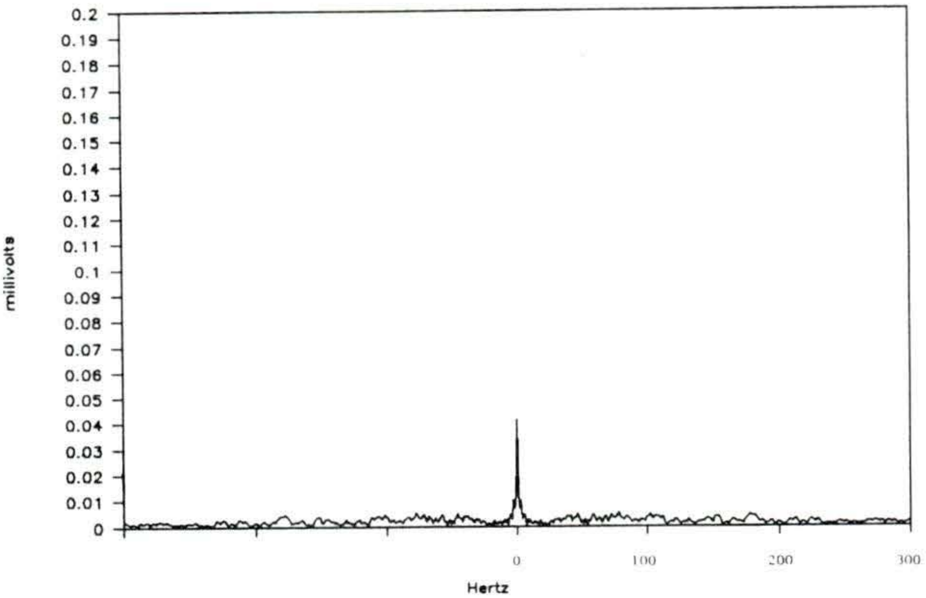

Figure 6.28: FFT-analysis for gastrocnemius muscle after 60 minutes (subject 1)

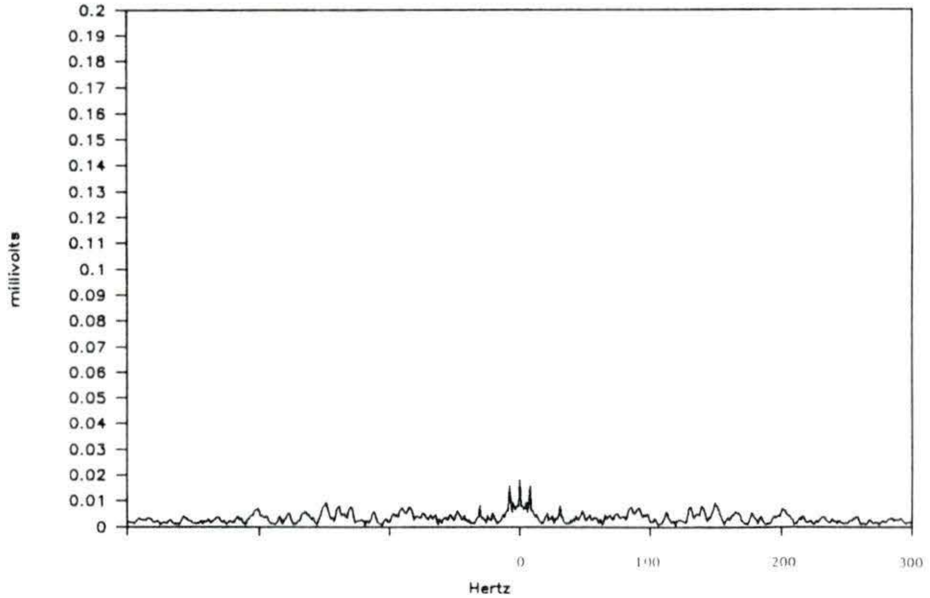

Figure 6.29: FFT-analysis for soleus muscle after 60 minutes (subject 1)

7 SUMMARY AND CONCLUSION

Three subjects ran on a Quinton Instruments treadmill for one hour in order to detect changes in biomechanics, EMG, elasticity, and FFT. The EMG recordings obtained from the gastrocnemius and soleus muscle of the right leg were synchronized with CMG of the lower leg.

7.1 Biomechanics

The results obtained in the present study indicated that there was no observable changes in any of the biomechanical parameters of the running cycle. However, the better runner had a longer running cycle time, lower stride rate, and higher stride length than the other two runners. For all three subjects there were no observable changes over time in other biomechanical parameters such as angles, dynamic moments, and energies.

7.2 EMG Recording

The amplitude of the EMG recordings decreased over time. No EMG activity was seen in the swing phase, and the maximum EMG activity occurred around push-off in the stance phase.

7.3 Elasticity

A method to determine the elasticity of the calf muscle was presented. The results obtained in the present study indicated that for all three subjects no observable changes occurred in the elasticity of the calf muscle. The length of the CC was mainly determined from the angle of the ankle.

7.4 FFT-Analysis

An FFT-analysis was performed on the EMG recordings from the gastrocnemius and soleus muscle. The results showed a decrease in the magnitude of the power spectra over time as well as a frequency shift towards lower frequencies for subject 1, while the results for subjects 2 and 3 did not show a definite pattern.

7.5 Conclusion

In the present study the best methods for detecting fatigue in runners over time were the amplitude of EMG recordings and the power spectra of FFT-analysis. No observable changes were found in the biomechanics and the elasticity. The elasticity parameters, which were determined from the EMG and the angle of the ankle, seemed to depend primarily on the angle of the ankle. The obtained results in the present study indicate that after the subjects ran for one hour at a 8.25 mph pace no biomechanical fatigue occurred as no observable changes were seen in the runner's biomechanics, but a decrease was seen in the amplitude of the EMG. In order to demonstrate biomechanical fatigue, elite subjects would either have to run at a faster pace or for a longer period of time. Usually when people think of runner's fatigue it is the changes in the movement pattern indicating biomechanical fatigue.

Since the present study was not able to indicate how fatigue influences the biomechanics of elite runners, future studies should include longer time periods of running and a variety of running speeds. The different parameters involved in the elasticity model should be determined individually for each person, with the model revised to include both shortening and stretching of the muscle. For the biomechanical aspects of future studies, a measurement of force should be incorporated. This could be done by using a force plate, and ground reaction forces could be measured. Another useful indicator of fatigue might be the subject's heart rate and should be included in future studies.

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The present study was approved by the University Committee on the Use of Human Subjects in Research.

10 APPENDIX A: EMG DATA COLLECTION

The following is a BASIC program that provides a menu at startup on the Apple-IIe computer. The program gives a choice of either: display old files on the screen, sample new EMG data, or transfer files from the Apple-IIe to the IBM.

```
10 D$ =  CHR$ (4)
20  HOME
30  VTAB (5): HTAB (1): PRINT "CHOOSE A/D ROUTINE FOR DATA
COLLECTION"
40  VTAB (8): HTAB (5): PRINT "1 - A.D.DISPLAY"
50  VTAB (10): HTAB (5): PRINT "2 - A.D.SKILL.NEW"
52  VTAB (12): HTAB (5): PRINT "3 - A.D.TRANSFER"
54  VTAB (14): HTAB (5): PRINT "4 - END"
60  VTAB (18): HTAB (10): PRINT "INPUT CHOICE : ";: GET A$
65  PRINT : HOME
66  IF A$ <  > "1" AND A$ <  > "2" AND.A$ <  > "3" AND A$ <
> "4" THEN
    10
70  IF  VAL (A$) < 1 AND  VAL (A$) > 4 THEN 60
80  ON  VAL (A$) GOTO 90,100,108,115
90  PRINT D$;"RUN A.D.DISPLAY"
92  GOTO 105
95  END
100  PRINT D$;"RUN A.D.SKILL.NEW"
105  END
108  REM
110  PRINT D$;"RUN A.D.TRANSFER"
115  END
```

The following is a BASIC program for the Apple-IIe computer to obtain EMG data every millisecond for 2000 milliseconds.

```
100  HOME
110 HIMEM = 16384
120  DIM Y(512),Z(5)
130  PRINT "DATE (MONTH-DAY-YEAR) : "
140  INPUT D%
150  INPUT E%
155  INPUT F%
160 V1 =  PEEK (Y):V2 =  PEEK (Y + 1)
170 NTRIAL = 100
180 D$ =  CHR$ (4)
185  HOME
190  PRINT "LOADING OBJECT FILES"
210  PRINT D$;"BLOAD A.D.12MSEC.OBJ0"
220  PRINT D$;"BLOAD INT.CLK.SET"
230  GOSUB 2000
250  GOSUB 3000
290 B = 0: GOSUB 4000
340  VTAB (23): PRINT "SAVE THIS TRIAL ? (W = DISPLAY
DATA)": GET A$
345  IF A$ = "W" GOTO 347
346  GOTO 350
347  VTAB (23)
348  PRINT "                                                  "
349  GOSUB 6000: GOTO 340
350  IF A$ <  > "Y" AND A$ <  > "N" THEN 340
360  IF  ASC (A$) = 89 THEN 380
370  GOTO 400
380 D$ =  CHR$ (4)
390  GOSUB 8000
400  HGR : HCOLOR= 0:ITRIAL = ITRIAL + 1
420  IF NTRIAL >  = ITRIAL THEN 290
425  HOME :
430  PRINT D$;"RUN STARTUP"
440  END
2000  REM
```

```
2005  HOME
2010 D$ =  CHR$ (4)
2020 XTRIAL = 0
2030  INPUT "SUBJECT CODE : ";SUBJ
2150  HOME
2160  IF ITRIAL > 1 THEN 2270
2170  INPUT "STARTING TRIAL : ";ITRIAL
2175  HOME
2180  INPUT "STARTING DISK STORE TRIAL : ";XTRIAL:XTRIAL =
XTRIAL - 1
2200  HOME
2280 MSEC = 2000
2310 CHAN = 4
2340 P1 = 1
2370  PRINT "SAMPLING TIME IS ";MSEC;" MILLISECONDS"
2375  PRINT
2380  PRINT "NUMBER OF CHANNELS IS ";CHAN - 1
2385  PRINT
2390  PRINT "SAMPLING INTERVAL IS ";P1;" MILLISECONDS"
2400  POKE 254,P1
2410  VTAB (23): GET K$
2420  RETURN
3000  POKE 16640,SUBJ
3010  POKE 16641,D%: POKE 16642,E%: POKE 16643,F%
3020  POKE 16644,ITRIAL: POKE 16645,P1
3030  POKE 16646,MSEC / 100: POKE 16647,CHAN
3050  RETURN
4000  REM
4003  HOME
4005  VTAB (21)
4010  PRINT : PRINT : PRINT " * * * * * TRIAL = ";ITRIAL;"
* * * * *"
4020  PRINT
4030  CALL 785
4040  POKE 255,04
4050  POKE 237,0
4060  CALL 768
4070  PRINT "TYPE CTRL G TO BEGIN ": GET A$
4080  POKE 07,00
```

```
4090  IF  ASC (A$) <  > 07 THEN 4070
4100  POKE 06,P1
4110  POKE 16563,00
4120  VTAB (23): PRINT "                    "
4130 D$ =  CHR$ (4)
4140  PRINT D$;"PR#1": PRINT D$;"IN#1"
4145  PRINT "B($FF)"
4147  PRINT "B#192"
4180  PRINT D$;"PR#0": PRINT D$;"IN#0"
4190  POKE 07,00
4200  CALL 16384
4201  PRINT D$;"PR#1": PRINT D$;"IN#1"
4202  PRINT "B($FF)"
4203  PRINT "B#128"
4204  PRINT "B#00"
4205  PRINT D$;"PR#0": PRINT D$;"IN#0"
4210 CK =  PEEK (16563)
4220  IF CK <  > 243 THEN  RETURN
4230  PRINT : PRINT " * * * * * DATA OVERRUN * * * * * "
4240  GOSUB 2280
4250  RETURN
6000  REM  DISPLAY ROUTINE
6020 Z = 16660
6030  GOSUB 6050
6040  RETURN
6050  REM
6060  HGR : HCOLOR= 3
6070 PL = 0
6080  FOR I = 1 TO CHAN
6090 PL = 0:Y = Z + I * 2
6100  FOR J = 1 TO 256
6110 PL = PL + 1
6120 Y = Y + (CHAN) * 4
6130 V1 =  PEEK (Y):V2 =  PEEK (Y + 1)
6140 Y(PL) = V1 * 256 + V2 - 2048
6150  NEXT J
6160  GOSUB 6190
6170  NEXT I
6180  RETURN
```

```
6190  REM  DISPLAY RESULTS
6195  IF I = 1 GOTO 6310
6200 HI = 0
6210  FOR K = 1 TO 256
6220 PL = PL + 1
6230  IF  ABS (Y(K)) > HI THEN HI =  ABS (Y(K))
6240  NEXT K
6250 SCF = HI / 15
6260 PL = 0
6265  IF B = 0 GOTO 6302
6270  FOR K = 1 TO 256
6280 PL = PL + 1
6285  IF I = 4 GOTO 6295
6290  HPLOT PL,((I - 1) * 60) - 40 - Y(K) / SCF
6293  GOTO 6300
6295  HPLOT PL,120 - Y(K) / 15
6300  NEXT K
6301  IF B = 1 GOTO 6310
6302  HPLOT 0,0
6304  HPLOT  TO 0,150 TO 257,150
6305  HPLOT  TO 257,0 TO 0,0
6309 B = 1: GOTO 6270
6310  RETURN
8000  REM
8005  HOME
8010 XTRIAL = XTRIAL + 1
8020 D$ =  CHR$ (4)
8025 S2$ =  STR$ (SUBJ)
8030 S3$ =  STR$ (XTRIAL)
8050 S0$ = "."
8060 S1$ = "FILE"
8070 SS$ = S1$ + S2$ + S0$ + S3$
8080  VTAB (23): PRINT SS$
8100  PRINT D$;"PREFIX/DATA"
8110  PRINT D$;"BSAVE";SS$;",A$411E,L16016"
8120 X =  FRE (0)
8130  PRINT D$;"PREFIX/AD.PRODOS"
8160  RETURN
```

The following is a BASIC program for the Apple-IIe computer to display EMG data.

```
100  HOME
105  HGR : HCOLOR= 0
110 HIMEM = 16384
120  DIM Y(512),Z(5)
125  GOSUB 4000
130  GOSUB 8100
140  GOSUB 6000
150  END
4000  REM
4010  VTAB (21): PRINT "FILTER ? "
4015  GET A$
4020  IF A$ <  > "Y" AND A$ <  > "N" THEN 4010
4045  VTAB (21): PRINT "            "
4050  RETURN
5000  REM  FILTER
5010 D$ =  CHR$ (4)
5020 PI = 3.1415926:DT = 0.01
5030  FOR L = 1 TO 256
5035 Y(L) =  ABS (Y(L))
5037  NEXT L
5038 T = 0.02
5040 ALPHA =  EXP ( - DT / T):Y = 0
5050  FOR L = 1 TO 256:Y = Y * AL + (1 - AL) * Y(L)
5055 Y(L) = Y: NEXT L
5060  RETURN
6000  REM  DISPLAY ROUTINE
6010 CHAN = 4
6020 Z = 16660
6025 R = 0
6030  GOSUB 6050
6040  RETURN
6050  REM
6052  HGR : HCOLOR= 7
6055  FOR Q = 1 TO 8
6070 PL = 0
```

```
6080  FOR I = 2 TO CHAN
6090 PL = 0:Y = Z + I * 2
6100  FOR J = 1 TO 256
6110 PL = PL + 1
6120 Y = Y + (CHAN) * 2
6130 V1 =  PEEK (Y):V2 =  PEEK (Y + 1)
6140 Y(PL) = V1 * 256 + V2 - 2048
6145  NEXT J
6150  IF A$ = "Y" THEN  GOSUB 5000
6160  GOSUB 6190
6170  NEXT I
6175 Z = Z + 2048:B = 0
6176  IF Q > 1 THEN  GOTO 6186
6177  VTAB (23): PRINT "DISPLAY MORE DATA ?": GET B$
6178  IF B$ = "Y" THEN  GOTO 6185
6179  IF B$ = "N" THEN  GOTO 6188
6180  IF B$ <  > "Y" AND B$ <  > "N" THEN  GOTO 6177
6185  VTAB (23): PRINT "                    "
6186  NEXT Q
6188  RETURN
6190  REM  DISPLAY RESULTS
6195  IF I = 1 GOTO 6310
6200 HI = 0
6210  FOR K = 1 TO 256
6220 PL = PL + 1
6230  IF  ABS (Y(K)) > HI THEN HI =  ABS (Y(K))
6240  NEXT K
6250 SCF = HI / 15
6260 PL = 0
6265  IF B = 0 GOTO 6302
6270  FOR K = 1 TO 256
6280 PL = PL + 1
6285  IF I = 4 GOTO 6295
6290  HPLOT PL,((I - 1) * 60) - 40 - Y(K) / SCF
6293  GOTO 6300
6295  HPLOT PL,120 - Y(K) / 30
6300  NEXT K
6301  IF B = 1 GOTO 6310
6302  HGR : HCOLOR= 3: HPLOT 0,0
```

```
6304  HPLOT  TO 0,150 TO 257,150
6305  HPLOT  TO 257,0 TO 0,0
6306  VTAB (21): HTAB (22): PRINT "";R;" TO  ";R + 256;"
MSEC."
6307 R = R + 257
6309 B = 1: GOTO 6270
6310  RETURN
8100  REM
8102 D$ =  CHR$ (4)
8105  VTAB (21): INPUT "DATA : ";F$
8107  PRINT D$;"PREFIX/DATA"
8110  PRINT D$;"BLOAD";F$;",A$411E"
8130  PRINT D$;"PREFIX/AD.PRODOS"
8160  RETURN
```

The following procedure using KERMIT transfers files from the Apple-IIe computer to the IBM computer.

```
1. Install "super-serial card" in the Apple-IIe in slot #1.

2. Set switches as follows: Mode: Terminal

                               SW1: OFF-OFF-OFF-ON-OFF-ON-ON
                               SW2: ON-OFF-OFF-ON-ON-OFF-OFF

3. Connect cable from the 25 pin output of serial card to
   the serial port of the IBM.

4. On the IBM type: C> MODE COM1:9600,N,8,1,P [RETURN]

5. Use disk with KERMIT in drive A on the IBM, and switch to
   drive A.

6. On the IBM type: A> KERMIT [RETURN]

7. Kermit-MS> LOG SESSION FILENAME.PRN [RETURN]
```

```
8. Kermit-MS> C [RETURN]

9. On the Apple-IIe type the following:

   PR#1 [RETURN]
   IN#1 [RETURN]
   LOAD A.D.TRANSFER
   RUN
   DATA: FILENAME

10. Do CTRL ] and ?

11. Command> R [RETURN]

12. Do CTRL ] and ?

13. Command> Q [RETURN]

14. Do CTRL ] and ?

15. Command> C [RETURN]

16. Do CTRL ] and ?

17. Kermit-MS> EXIT [RETURN]

18. A>
```

The following is a BASIC program for the Apple-IIe computer to transfer data from the Apple-IIe computer to the IBM computer.

```
100  HOME
110 HIMEM = 16384
120  DIM Y(512),Z(5)
130  GOSUB 8100
140  GOSUB 6000
150  END
```

```
6000  REM  DISPLAY ROUTINE
6010 CHAN = 4
6020 Z = 16660
6030 S = 1
6040 H = 0
6045  PRINT  CHR$ (4);"PR#1"
6050  FOR K = 1 TO 10
6060  FOR PL = S TO S + 199
6080  FOR I = 2 TO CHAN
6090 Y = Z + I * 2
6120 Y = Y + (CHAN) * 2
6130 V1 =  PEEK (Y):V2 =  PEEK (Y + 1)
6140 Y(I) = V1 * 256 + V2 - 2048
6150  NEXT I
6153  PRINT PL; CHR$ (44);Y(2); CHR$ (44);Y(3); CHR$
(44);Y(4)
6155 Z = Z + 8
6160  NEXT PL
6165 S = S + 200
6170  NEXT K
6260  RETURN
8100  REM
8102 D$ =  CHR$ (4)
8105  VTAB (21): INPUT "DATA : ";F$
8107  PRINT D$;"PREFIX/DATA"
8110  PRINT D$;"BLOAD";F$;",A$411E"
8130  PRINT D$;"PREFIX/AD.PRODOS"
8160  RETURN
9000  REM  FILTER
9010 T = 0.02
9020 DT = 0.01
9030 ALPHA =  EXP ( - DT / T)
9040 H = H * AL + (1 - AL) * Y(5)
9050 Y(5) = H
9060  RETURN
```

11 APPENDIX B: DATA FROM DIGITIZER

This BASIC program for the Tektronix 4051 gets the X and Y coordinates from the Numeric 1224-1 digitizer. The data can then be stored on data tape.

```
1 REM DATA MANIPULATION **********
2 INIT
3 GO TO 110
4 P9=1
5 GO TO 100
8 P9=2
9 REM DATA FROM DIGITIZER **********
10 GO TO 100
12 P9=3
13 REM DATA TO TAPE **********
14 GO TO 100
16 P9=4
17 REM CORRECT DATA **********
18 GO TO 100
20 P9=5
21 REM SHIFT DATA **********
22 GO TO 100
24 P9=6
25 REM SCALE DATA **********
26 GO TO 100
28 P9=7
29 REM ADJUST FOR REFERENCE POINT **********
30 GO TO 100
32 P9=8
33 REM PRINT AND GRAPH DATA **********
34 GO TO 100
```

```
36 P9=9
37 REM DATA FROM TAPE **********
38 GO TO 100
40 FIND 1
41 OLD
42 RUN
43 PAGE
44 PRINT "CHOOSE WHICH COMBINATION IS REQUIRED "
45 PRINT "NO OPTIONS ARE AVAILABLE OUTSIDE YOUR SELECTION "
46 PRINT "1   DIGITIZE then TO TAPE"
47 PRINT "2   FROM TAPE then CORRECT then TO TAPE"
48 PRINT "3   FROM TAPE then SHIFT then TO TAPE"
49 PRINT "4   FROM TAPE then SCALE then TO TAPE"
50 PRINT "5   FROM TAPE then ADJUST FOR REF PT then TO TAPE"
51 PRINT "6   FROM TAPE then PRINT/GRAPH"
52 PRINT "WHICH NUMBER IS YOUR CHOICE: ";
53 INPUT I5
54 DELETE 540,610
55 GO TO I5 OF 56,59,64,71,78,85
56 DELETE 16,38
57 DELETE 2600,5000
58 GO TO 110
59 DELETE 8,10
60 DELETE 20,34
61 DELETE 670,1570
62 DELETE 2770,3980
63 GO TO 110
64 DELETE 8,10
65 DELETE 16,18
66 DELETE 24,34
67 DELETE 670,1570
68 DELETE 2600,2490
69 DELETE 2930,3980
70 GO TO 110
71 DELETE 8,10
72 DELETE 16,22
73 DELETE 28,34
74 DELETE 670,1570
75 DELETE 2600,2690
```

```
76 DELETE 3090,3980
77 GO TO 110
78 DELETE 8,10
79 DELETE 16,26
80 DELETE 32,34
81 DELETE 670,1570
82 DELETE 2600,2890
83 DELETE 3260,3980
84 GO TO 110
85 DELETE 8,10
86 DELETE 16,30
87 DELETE 670,3090
88 GO TO 110
89 FIND @P4,27:2
90 DELETE 2,88
91 DELETE 100,5000
95 CALL "BAPPEND",[illegible];1
96 GO TO 1
100 GO TO P9 OF 110,670,1610,2600,2770,2930,3090,3260,4130
110 REM PRINTOUT ON PROGRAM **********
120 PRINT "MANIPULATION OF DATA IN COMPUTER"
130 PRINT "DATA FROM DIGITIZER          = KEY 2"
140 PRINT "STORE DATA ON TAPE           = KEY 3"
150 PRINT "CORRECTION OF DATA POINTS    = KEY 4"
160 PRINT "SHIFT ALL THE DATA POINTS    = KEY 5"
170 PRINT "SCALE ALL THE DATA POINTS    = KEY 6"
180 PRINT "ADJUST FOR REFERENCE POINT = KEY 7"
190 PRINT "PRINT OR GRAPH THE DATA      = KEY 8"
200 PRINT "DATA FROM A TAPE FILE        = KEY 9"
210 PRINT "TO END THIS PROGRAM          = KEY 10"
220 DATA "Right finger tip",1,"Right wrist",1,"Right elbow",1
230 DATA "Right shoulder",1,"Left shoulder",1,"Left elbow",1
240 DATA "Left wrist",1,"Left finger tip",1,"Right toe",1
250 DATA "Right ankle",1,"Right knee",1,"Right hip",1
260 DATA "Left hip",1,"Left knee",1,"Left ankle",1
270 DATA "Left toe",1,"Bottom of trunk",1,"Top of trunk",1
280 DATA "Special point #1",-1,"Special point #2",-1
290 DATA "Special point #3",-1,"Special point #4",-1
300 DATA "Special point #5",-1,"Special point #6",-1
```

```
310 data "Object - Reference point",1
320 RESTORE 220
330 DIM P$(625),I$(25),L((25)
340 P$=""
350 PRINT "Is the standard body acceptable? (Y/N) ";
360 INPUT H$
370 P=0
380 FOR I=1 TO 25
390 P$=P$&"
400 READ I$,L9(I)
410 IF H$="Y" THEN 480
420 L9(I)=1
430 PRINT "Include ";I$;"? (Y/N) ";
440 INPUT G$
450 IF G$="Y" THEN 480
460 IF G$<>"N" THEN 430
470 L9(I)=-1
480 IF L9(I)=-1 THEN 510
490 P=P+1
500 P$=REP(I$,1+(P-1)*25,LEN(I$))
501 REM -- REPLACED 12-12-88 -- 500 P$=REP(I$,1+(I-1)*25,LEN(I$))
510 NEXT I
520 P3=33
530 P4=33
540 PRINT ""
550 PRINT "This program occupies much of the unit's memory."
560 PRINT "If you will be manipulating a large data base,"
570 PRINT "you may elect to swap parts of the program in"
580 PRINT "and out of memory to leave extra space for data."
590 PRINT "However, you will trade off memory for time."
595 PRINT "Do you elect to make this trade? (Y/N) ";
600 INPUT S$
610 IF S$="Y" THEN 43
620 DELETE 220,610
630 PRINT "Press the appropriate key when ready"
640 PRINT "If you run into problems in the middle of the"
650 PRINT "program press the break key twice then press key"
655 PRINT "1 to begin again."
660 END
```

```
670 REM DATA FROM DIGITIZER **********
680 PAGE
690 PRINT "DATA FROM DIGITIZER"
700 PRINT "REFERENCE POINT (IF USED) MUST BE LAST"
710 PRINT "POINT FOR EACH FRAME"
720 N9=INT(MEMORY/(2*(P+1)*9))
730 IF N9<200 THEN 750
740 N9=200
750 PRINT "FRAME LIMIT= ";N9
760 DIM T$(25)
770 PRINT "INPUT TITLE TO FILE (up to 25 characters): ";
780 INPUT T$
790 PRINT "DO YOU WISH TO AVERAGE DATA POINTS ? (Y OR N): ";
800 INPUT A$
810 IF A$="N" THEN 850
820 PRINT "INPUT NUMBER OF FRAMES TO BE AVERAGED: ";
830 INPUT A
840 GO TO 870
850 A=1
860 GO TO 1260
870 DIM X(N9,P),Y(N9,P),X1(A,P),Y1(A,P),T(N9)
880 LET N1=1
890 PRINT "Begin Digitizing"
900 FOR I=N1 TO N9
910 PAGE
920 PRINT "Enter TIME sequence number as X coordinate."
930 INPUT @14,32:T(I),T1
940 IF T(I)>99 THEN 1480
950 T(I)=INT(T(I))
960 PRINT USING 970:I,T(I)
970 IMAGE 3X,"Frame number ',4D,30T,"Time sequence number ",3D
980 FOR K=1 TO A
990 FOR J1=1 TO P
1000 X1(K,J1)=0
1010 Y1(K,J1)=0
1020 IF L9(J1)<0 THEN 1070
1030 I$=SEG(P$,1+(J1-1)*25,25)
1040 PRINT I$;
1050 INPUT @14,32:X1(K,J1),Y1(K,J1)
```

```
1060 PRINT X1(K,J1),Y1(K,J1)
1070 NEXT J1
1080 IF K=A THEN 1100
1090 PRINT "Repeat Frame ";I;" again"
1100 NEXT K
1110 FOR J2=1 TO P
1120 X(I,J2)=0
1130 Y(I,J2)=0
1140 FOR J3=1 TO A
1150 X(I,J2)=X(I,J2)+X1(J3,J2)
1160 Y(I,J2)=Y(I,J2)+Y1(J3,J2)
1170 NEXT J3
1180 X(I,J2)=X(I,J2)/A
1190 Y(I,J2)=Y(I,J2)/A
1200 NEXT J2
1210 N=I
1220 PRINT "FRAME ";I;" COMPLETE"
1230 NEXT I
1240 DELETE X1,Y1
1250 GOTO 1480
1260 DIM X(N9,P),Y(N9,P),T(N9)
1270 PRINT "Begin Digitizing"
1280 LET N1=1
1290 FOR I=N1 TO N9
1300 PAGE
1310 PRINT "Enter TIME sequence number as X coordinate."
1320 INPUT @14,32:T(I),T(I)
1330 PRINT USING 1340:I,T(I)
1340 IMAGE 3X,"Frame number ",4D,30T,"Time sequence number ",3D
1350 IF T(I)>99 THEN 1480
1360 T(I)=INT(T(I))
1370 FOR J=1 TO P
1380 X(I,J)=0
1390 Y(I,J)=0
1400 REM -- REMOVED 12-12-88 -- IF L9(J)<0 THEN 1450
1410 I$=SEG(P$,1+(J-1)*25,25)
1420 PRINT I$;
1430 INPUT @14,32:X(I,J),Y(I,J)
1440 PRINT X(I,J),Y(I,J)
```

```
1450 NEXT J
1460 N=I
1470 NEXT I
1480 PRINT "IS THIS A CORRECTION (Y OR N):";
1490 INPUT G$
1500 IF G$="N" THEN 1560
1510 PRINT "INPUT NEW STARTING POINT: ";
1520 INPUT N1
1530 PRINT "Begin Digitizing Frame ";N1;" again"
1540 IF A=1 THEN 1290
1550 GO TO 900
1560 PRINT "DATA ENTERED INTO MEMORY"
1570 PRINT "INSERT DATA TAPE"
1580 PRINT "Press return to continue";
1590 INPUT G$
1600 GO TO 110
1610 REM STORE DATA **********
1620 PRINT "STORE THE DATA ON TAPE"
1630 PRINT "INSERT DATA TAPE"
1640 PRINT "STATED ID IS: ";T4
1650 PRINT "Is this the correct ID. (Y OR N): ";
1660 INPUT G$
1670 IF G$="Y" THEN 1710
1680 IF G$<>"N" THEN 1640
1690 PRINT "New correct ID. = ";
1700 INPUT T$
1710 PRINT "DO YOU WISH TO CORRECT FOR TIME FACTOR? (Y OR N): ";
1720 INPUT G$
1730 IF G$="Y" THEN 2540
1740 PRINT "IS DATA TO BE STORED IN (A):SINGLE FILE OR "
1750 PRINT "                        (B):SEPARATE FILES ?";
1760 INPUT G$
1770 IF G$="B" THEN 2040
1780 PRINT "INPUT FILE NUMBER FOR DATA STORAGE: ";
1790 INPUT F
1800 PRINT "IS THIS A NEW DATA FILE? (Y OR N): ";

1810 INPUT G$
1820 IF G$="N" THEN 1860
1830 FIND @P3,27:F
```

```
1840 M=((2*P+1)*N+N)*17+LEN(T$)+LEN(P$)+50
1850 MARK @P3,28:1,M
1860 FIND @P3,27:F
1870 WRITE @P3,12:T$
1880 WRITE @P3,12:N,P
1890 WRITE @P3,12:P$
1900 FOR J=1 TO P
1910 WRITE @P3,12:L9(J)
1920 NEXT J
1930 FOR I=1 TO N
1940 FOR J=1 TO P
1950 REM -- REMOVED 2-23-89 --IF L9(J)<0 THEN 1970
1960 WRITE @P3,12:X(I,J),Y(I,J)
1970 NEXT J
1980 NEXT I
1990 FOR I=1 TO N
2000 WRITE @P3,12:T(I)
2010 NEXT I
2020 CLOSE
2030 GO TO 2460
2040 PRINT "NOTE: THIS ROUTINE ERASES ALL FILES FOLLOWING"
2045 PRINT "INITIAL FILE"
2050 PRINT "INPUT INITIAL DATA STORAGE FILE NUMBER: ";
2060 INPUT F
2070 M=24*(N+2)
2080 FOR I=1 TO P
2090 FIND @P3,27:F
2100 MARK @P3,28:2,M
2110 FIND @P3,27:F
2120 WRITE @P3,15:I$,N
2130 FOR J=1 TO N
2140 WRITE @P3,15:T(I),X(J,I)
2150 NEXT J
2160 IF P3=33 THEN 2190
2170 PRINT @P3,2:
2180 GO TO 2200
2190 CLOSE
2200 FIND @P3,27:F
2210 READ @P3,14:I$,N5
```

```
2220 FOR J=1 TO N5
2230 READ @P3,14:X5,Y5
2240 NEXT J
2250 F=F+1
2260 FIND @P3,27:F
2270 WRITE @P3,15:I$,N
2280 FOR J=1 TO N
2290 WRITE @P3,15:T(I),Y(J,I)
2300 NEXT J
2310 IF P3=33 THEN 2340
2330 GO TO 2350
2340 CLOSE
2350 FIND @P3,27:F
2360 READ @P3,14:I$,N5
2370 FOR J=1 TO N5
2380 READ @P3,14:X5,Y5
2390 NEXT J
2400 F=F+1
2410 NEXT I
2420 PRINT "DATA STORED ON TAPE"
2430 PRINT "FORM: ";2*P; FILES: I$,N,T1,X1,T2,X2,..."
2440 PRINT "                   OR: I$,N,T1,Y1,T2,Y2,..."
2450 GO TO 2490
2460 PRINT "DATA STORED ON TAPE"
2470 PRINT "FORM: I$,N,P,X1,Y1,X2,Y2,..."
2480 PRINT "        ...,XN,YN,T1,T2,...,TN"
2490 PRINT "Press return to continue";
2510 INPUT G$
2520 IF S$="Y" THEN 88
2530 GO TO 110
2540 PRINT "INPUT TIME CORRECTION FACTOR: ";
2550 INPUT T9
2560 FOR I=1 TO N
2570 T(I)=T(I)*T9
2580 NEXT I
2590 GO TO 1740
2600 REM CORRECT DATA **********
2610 PAGE
2620 PRINT "CORRECTION OF DATA"
```

```
2630 FOR I=1 TO 22*N
2640 PRINT "INPUT DATA POINT TO BE CORRECTED: (FRAME, DATA POINT): ";
2650 INPUT N1,P1
2660 PRINT "",X(N1,P1),Y(N1,P1)
2670 PRINT "INPUT CORRECT VALUES: ";
2680 INPUT X(N1,P1),Y(N1,P1)
2690 PRINT "DO YOU WISH TO MAKE ANY MORE CORRECTIONS? (Y OR N): ";
2700 INPUT G$
2710 IF G$="Y" THEN 2640
2720 NEXT I
2730 PRINT "ALL CORRECTIONS ENTERED"
2740 PRINT "Press return to continue";
2750 INPUT G$
2760 GO TO 110
2770 REM SHIFT DATA **********
2780 PAGE
2790 PRINT "SHIFT THE DATA POINTS"
2800 PRINT "INPUT X,Y COORDINATES TO BE ADDED TO ALL DATA POINTS: ";
2810 INPUT X1,Y1
2820 PRINT ""
2830 FOR I=1 TO N
2840 FOR J=1 TO P
2850 X(I,J)=X(I,J)+X1
2860 Y(I,J)=Y(I,J)+Y1
2870 NEXT J
2880 NEXT I
2890 PRINT "DATA SHIFT COMPLETED"
2900 PRINT "Press return key to continue";
2910 INPUT G$
2920 GO TO 110
2930 REM SCALE DATA **********
2940 PAGE
2950 PRINT "SCALE THE DATA"
2960 PRINT "INPUT CONVERSION FACTOR C"
2970 PRINT "1 SCALE UNIT= C METERS C= ";
2980 INPUT C5
2990 FOR I=1 TO N
3000 FOR J=1 TO P
3010 X(I,J)=X(I,J)*C5
```

```
3020 Y(I,J)=Y(I,J)*C5
3030 NEXT J
3040 NEXT I
3050 PRINT "DATA SCALING COMPLETE"
3060 PRINT "Press return to continue";
3070 INPUT G$
3080 GO TO 110
3090 REM ADJUST FOR REFERENCE POINT **********
3100 PAGE
3110 PRINT 'ADJUST DATA FOR REFERENCE POINT"
3120 LET X1=INT(X(1,P)+2
3130 LET Y1=INT(Y(1,P)+2
3140 FOR I=1 TO N
3150 FOR J=1 TO P
3160 X(I,J)=X(I,J)-X(I,P)+X1
3170 Y(I,J)=Y(I,J)-Y(I,P)+Y1
3180 NEXT J
3190 NEXT I
3200 P=P-1
3210 PRINT "REFERENCE POINT ADJUSTMENT COMPLETED AND"
3220 PRINT "REFERENCE POINT DELETED"
3230 PRINT "Press return to continue";
3240 INPUT G$
3250 GO TO 110
3260 REM PRINT &/OR GRAPH DATA POINTS **********
3270 PAGE
3280 PRINT "PRINT OR GRAPH THE DATA"
3290 P1=2*P
3300 FOR I=1 TO P1
3310 F9=0
3320 PRINT "DO YOU WANT TO PRINT DATA? (Y OR N): ";
3330 INPUT G$
3340 IF G$="N" THEN 3370
3350 GOSUB 3480
3360 GO TO 3410
3370 PRINT "DO YOU WANT TO GRAPH DATA? (Y OR N): ";
3380 INPUT G$
3390 IF G$="N" THEN 3410
3400 GOSUB 3650
```

```
3410 PAGE
3420 PRINT "DO YOU WANT TO REPEAT THIS ROUTINE? (Y OR N): ";
3430 INPUT G$
3440 IF G$="N" THEN 3470
3450 NEXT I
3460 IF S$="Y" THEN 88
3470 GO TO 110
3480 REM PRINT DATA **********
3490 PRINT "THE ANALYSIS CONTAINS ";P;" DATA POINTS"
3500 PRINT "IDENTIFY THE DATA POINT TO BE PRINTED: ";
3510 INPUT P2
3520 PAGE
3530 I$=SEG(P$,1+(P2-1)*25,25)
3540 PRINT USING 3550:"DATA POINT ";P2;I$
3550 IMAGE10T,11A,2D,";  ",25A/
3560 PRINT USING 3570: "TIME/FRAME","X-COORDINATE","Y-COORDINATE"
3570 IMAGE7T,10A,20T,12A,37T,12A,/
3580 FOR K=1 TO N
3590 PRINT USING 3600:K,X(K,P2),Y(K,P2)
3600 IMAGE 11T,2D,24T,3D.2D,41T,3D.2D
3610 NEXT K
3620 INPUT G$
3630 F9=1
3640 GO TO 3370
3650 REM GRAPH DATA **********
3660 IF F9=1 THEN 3700
3670 PRINT "THE ANALYSIS CONTAINS ";P;" DATA POINTS"
3680 PRINT "IDENTIFY THE DATA POINT TO BE GRAPHED: ";
3690 INPUT P2
3700 PAGE
3710 VIEWPORT 20,110,5,95
3720 M1,INT(X(1,P2))
3730 M2=INT(Y(1,P2))
3740 M3=M1
3750 M4=M2
3760 FOR J=1 TO N
3770 M1=X(J,P2) MAX M1
3780 M2=Y(J,P2) MAX M2
3790 M3=X(J,P2) MIN M3
```

```
3800 M4=Y(J,P2) MIN M4
3810 NEXT J
3820 M1=INT(M1+1)
3830 M2=INT(M2+1)
3840 M3=INT(M3)
3850 M4=INT(M4)
3860 IF M1-M3>M2-M4 THEN 3910
3870 M1=M3+(M2-M4)
3880 WINDOW M3,M1,M4,M2
3890 GO TO 3920
3900 M2=M4+(M1-M3)
3910 WINDOW M3,M1,M4,M2
3920 FOR K=1 TO N
3930 MOVE X(K,P2),Y(K,P2)
3940 PRINT "*"
3950 VIEWPORT 20,110,3,93
3960 MOVE X(K,P2),Y(K,P2)
3970 PRINT K
3980 VIEWPORT 20,110,5,95
3990 NEXT K
4000 AXIS 1,1
4010 VIEWPORT 17,107,2,95
4020 FOR I=M3 TO M1 STEP 5
4030 MOVE I,M4
4040 PRINT I;
4050 NEXT I
4060 VIEWPORT 13,110,4,94
4070 FOR I=M4 TO M2 STEP 5
4080 MOVE M3,I
4090 PRINT I
4100 NEXT I
4110 INPUT G$
4120 GO TO 3420
4130 REM FROM TAPE **********
4140 PAGE
4150 INIT
4160 PRINT "DATA FROM TAPE"
4170 P3=33
4180 PRINT "INSERT DATA TAPE"
```

```
4190 PRINT "INPUT DATA FILE NUMBER: ";
4200 INPUT F
4210 FIND @P3,27:F
4220 DIM T$(25),P$(625)
4230 READ @P3,13:T$
4240 PRINT "STATED ID IS:    ";T$
4250 PRINT "Is this the correct ID. (Y OR N): ";
4260 INPUT G$
4270 IF G$="Y" THEN 4310
4280 IF G$<>"N" THEN 4240
4290 PRINT "New correct ID. = ";
4300 INPUT T$
4310 READ @P3,13:N,P
4320 DIM X(N,P),Y(N,P),T(N),L9(P)
4330 READ @P3,13:P$
4340 FOR J=1 TO P
4350 READ @P3,13:L9(J)
4360 NEXT J
4370 FOR I=1 TO N
4380 FOR J=1 TO P
4390 X(I,J)=0
4400 Y(I,J)=0
4410 REM -- REMOVED 2-23-89 -- IF L9(J)<0 THEN 4430
4420 READ@P3,13:X(I,J),Y(I,J)
4430 NEXT J
4440 NEXT I
4450 FOR I=1 TO N
4460 READ @P3,13:T(I)
4470 NEXT I
4480 PRINT "DATA ENTERED"
4490 PRINT "INSERT DATA TAPE"
4500 PRINT "Press return to continue";
4510 INPUT G$
4520 GO TO 110
4530 END
```

12 APPENDIX C: DEFINITION OF THE BIOMECHANICS

12.1 Angles

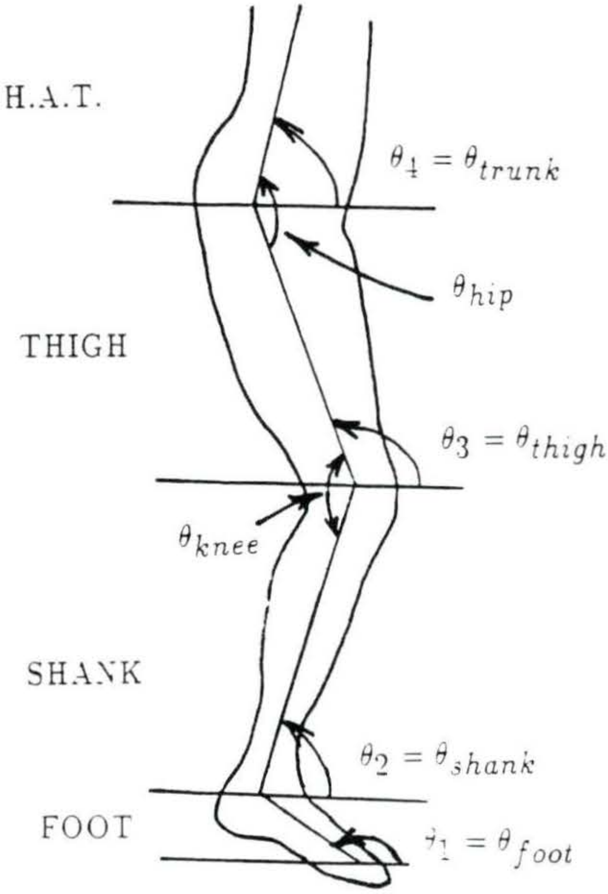

Figure 12.1: Definition of angles

A sagittal view of the foot is shown in Figure 12.2, where the foot is lifted from the ground. However, ψ_0 can also be found when the person is standing with the foot flat on the ground. With the foot flat on the ground, ψ_0 can be determined as follows:

$$\psi_0 = \arccos(\frac{d}{LS(1)})$$

where d = horizontal distance from toe to ankle

and LS(1) = distance between toe and ankle

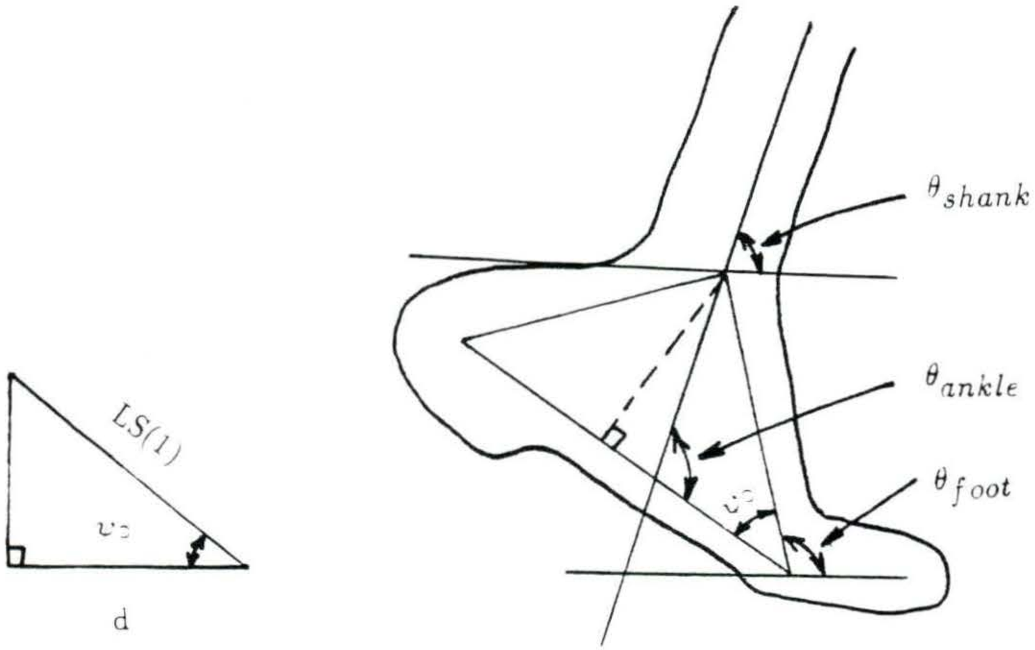

Figure 12.2: Sagittal view of the foot

The angles of the hip, knee, and ankle were defined the following way:

$$\begin{aligned}
\theta_{hip} &= 180^\circ - \theta_{thigh} + \theta_{trunk} \\
\theta_{knee} &= 180^\circ - \theta_{thigh} + \theta_{shank} \\
\theta_{ankle} &= 180^\circ - (\theta_{foot} + \psi_\circ) + \theta_{shank}
\end{aligned}$$

12.2 Accelerations

The rotational accelerations were defined as:

Horizontal:

$$\begin{aligned}
a_{Rx1} &= \omega_1^2 \cdot r_1 \cdot \cos(180^\circ - \theta_1) \\
a_{Rx2} &= \omega_2^2 \cdot r_2 \cdot \cos(\theta_2) \\
a_{Rx3} &= \omega_3^2 \cdot r_3 \cdot \cos(180^\circ - \theta_3) \\
a_{Tx1} &= \alpha_1 \cdot r_1 \cdot \sin(180^\circ - \theta_1) \\
a_{Tx2} &= \alpha_2 \cdot r_2 \cdot \sin(\theta_2) \\
a_{Tx3} &= \alpha_3 \cdot r_3 \cdot \sin(180^\circ - \theta_3)
\end{aligned}$$

Vertical:

$$\begin{aligned}
a_{Ry1} &= \omega_1^2 \cdot r_1 \cdot \sin(180^\circ - \theta_1) \\
a_{Ry2} &= \omega_2^2 \cdot r_2 \cdot \sin(\theta_2) \\
a_{Ry3} &= \omega_3^2 \cdot r_3 \cdot \sin(180^\circ - \theta_3) \\
a_{Ty1} &= \alpha_1 \cdot r_1 \cdot \cos(180^\circ - \theta_1) \\
a_{Ty2} &= \alpha_2 \cdot r_2 \cdot \cos(\theta_2) \\
a_{Ty3} &= \alpha_3 \cdot r_3 \cdot \cos(180^\circ - \theta_3)
\end{aligned}$$

Angular acceleration of center of mass:

Horizontal:

$$a_{x1} = -a_{Rx1} + a_{Tx1} - a_{x1cm}$$

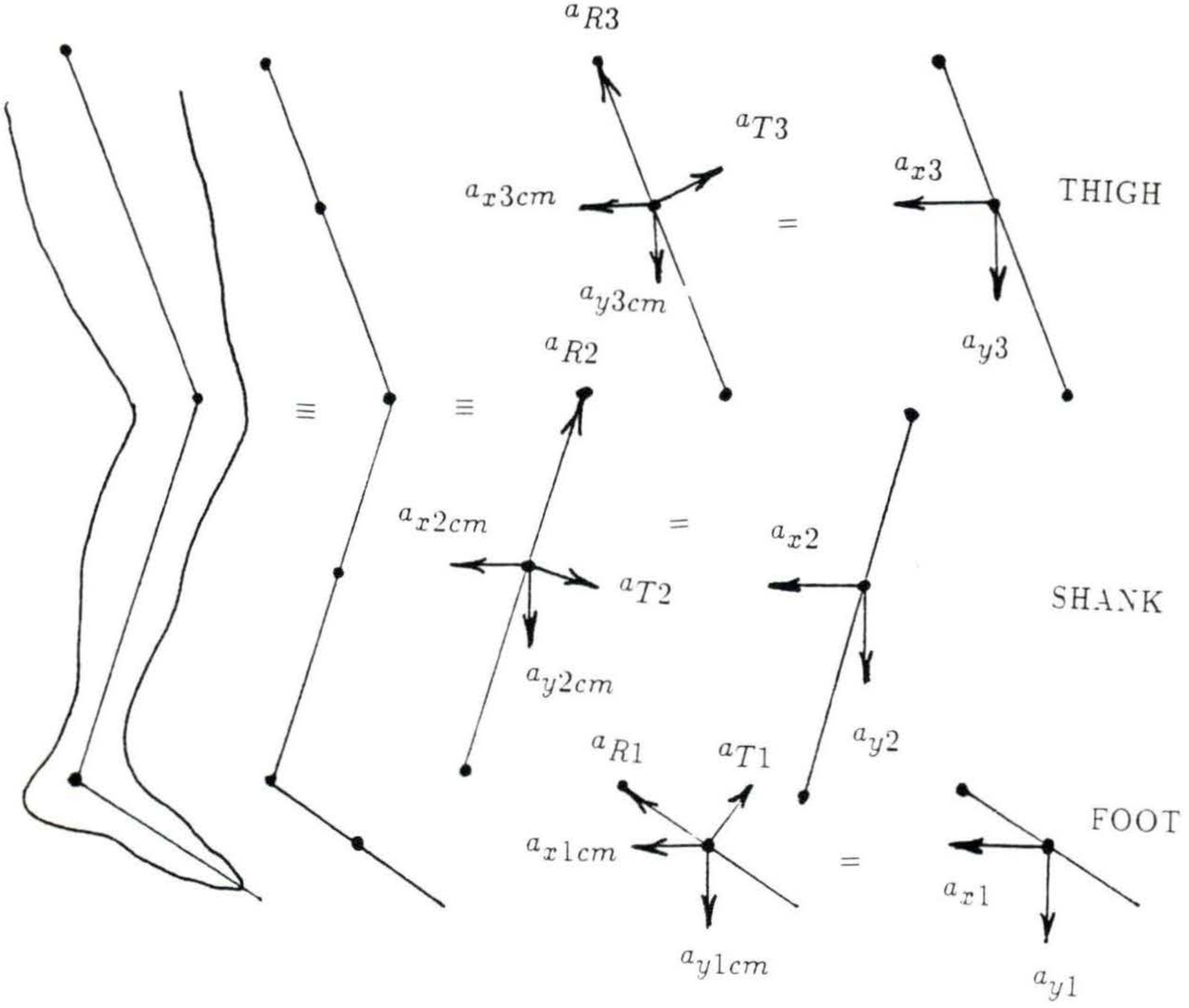

Figure 12.3: Definition of accelerations

$$a_{x2} = a_{Rx2} + a_{Tx2} - a_{x2cm}$$

$$a_{x3} = -a_{Rx3} + a_{Tx3} - a_{x3cm}$$

Vertical:

$$a_{y1} = a_{Ry1} + a_{Ty1} - a_{y1cm}$$

$$a_{y2} = a_{Ry2} - a_{Ty2} - a_{y2cm}$$

$$a_{y3} = a_{Ry3} + a_{Ty3} - a_{y3cm}$$

The radii were defined as:

$$r_1 = JCM(1) \cdot LS(1)$$

$$r_2 = JCM(2) \cdot LS(2)$$

$$r_3 = JCM(3) \cdot LS(3)$$

12.3 Forces and Moments

General formulas for static condition:

$$\sum F_x = 0$$

$$\sum F_y = 0$$

$$\sum M = 0$$

Static reactive forces:

Horizontal:

$$Rx_1 = Rx_2 = Rx_3 = 0$$

Vertical:

$$Ry_1 - m_1 \cdot g = 0 \Rightarrow Ry_1 = m_1 \cdot g$$

$$-Ry_1 - m_2 \cdot g - Ry_2 = 0 \Rightarrow Ry_2 = Ry_1 - m_2 \cdot g = (m_1 - m_2) \cdot g$$

$$-Ry_2 - m_3 \cdot g - Ry_3 = 0 \Rightarrow Ry_3 = Ry_2 - m_3 \cdot = (m_1 + m_2 = m_3) \cdot g$$

Static moments:

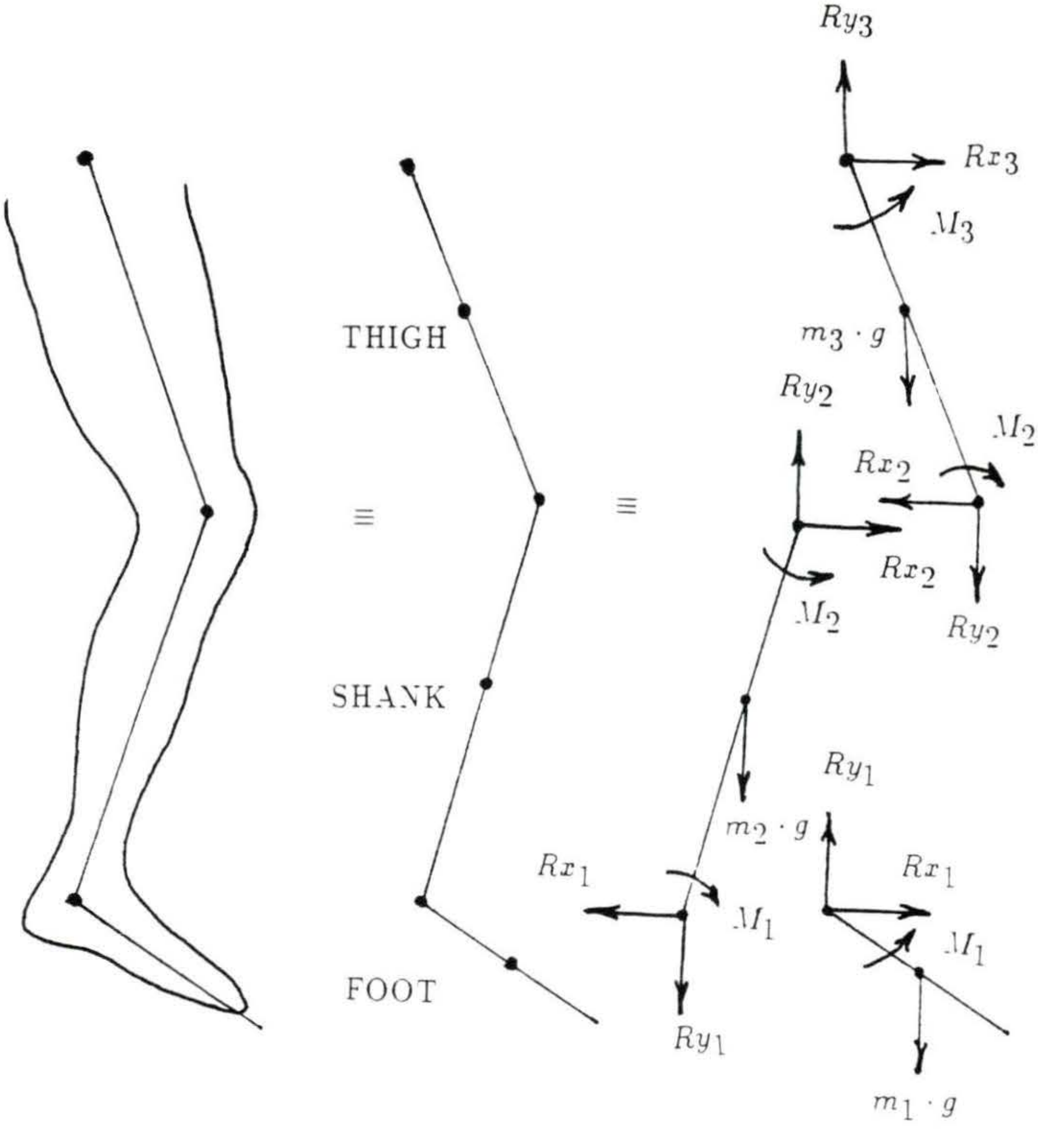

Figure 12.4: Static reactive forces and moments

$$M_1 - m_1 \cdot g \cdot JCM(1) \cdot LS(1) \cdot \cos(180^\circ - \theta_1) = 0 \Rightarrow$$
$$M_1 = m_1 \cdot g \cdot JCM(1) \cdot LS(1) \cdot \cos(180^\circ - \theta_1)$$

$$M_2 - M_1 + Ry_1 \cdot LS(2) \cdot \cos(\theta_2) + m_2 \cdot g \cdot JCM(2) \cdot LS(2) \cdot \cos(\theta_2) = 0 \Rightarrow$$
$$M_2 = M_1 - (Ry_1 + m_2 \cdot g \cdot JCM(2)) \cdot \cos(\theta_2) \cdot LS(2)$$

$$M_3 - M_2 - Ry_2 \cdot \cos(180^\circ - \theta_3)$$
$$-m_3 \cdot g \cdot LS(3) \cdot JCM(3) \cdot \cos(180^\circ - \theta_3) = 0 \Rightarrow$$
$$M_3 = M_2 + (Ry_2 + m_3 \cdot g \cdot JCM(3)) \cdot \cos(180 - \theta_3) \cdot LS(3)$$

General formulas for dynamic condition:

$$\sum F_x = m \cdot a_x$$
$$\sum F_y = m \cdot a_y$$
$$\sum M = I \cdot \alpha$$

Dynamic reactive forces:

Horizontal:

$$Rx_1 = m_1 \cdot a_{x1}$$
$$Rx_2 - Rx_1 = m_2 \cdot a_{x2} \Rightarrow Rx_2 = m_2 \cdot a_{x2} - Rx_1$$
$$Rx_3 - Rx_2 = m_3 \cdot a_{x3} \Rightarrow R_{x3} = m \cdot a_{x3} + Rx_2$$

Vertical:

$$Ry_1 - m_1 \cdot g = m_1 \cdot a_{y1} \Rightarrow Ry_1 = m_1 \cdot (g + a_{y1})$$
$$Ry_2 - Ry_1 - m_2 \cdot g = m_2 \cdot a_{y2} \Rightarrow Ry_2 = m_2 \cdot (g + a_{y2}) - Ry_1$$
$$Ry_3 - Ry2 - m_3 \cdot g = m_3 \cdot a_{y3} \Rightarrow Ry_3 = m_3 \cdot (g + ay3) + Ry2$$
$$M_1 - JCM(1) \cdot LS(1) \cdot \cos(180^\circ - \theta_1) \cdot m_1 \cdot (g + a_{y1})$$
$$-JCM(1) \cdot LS(1) \cdot \sin(180^\circ - \theta_1) \cdot m_1 \cdot a_{x1} = I_1 \cdot \alpha_1 \Rightarrow$$

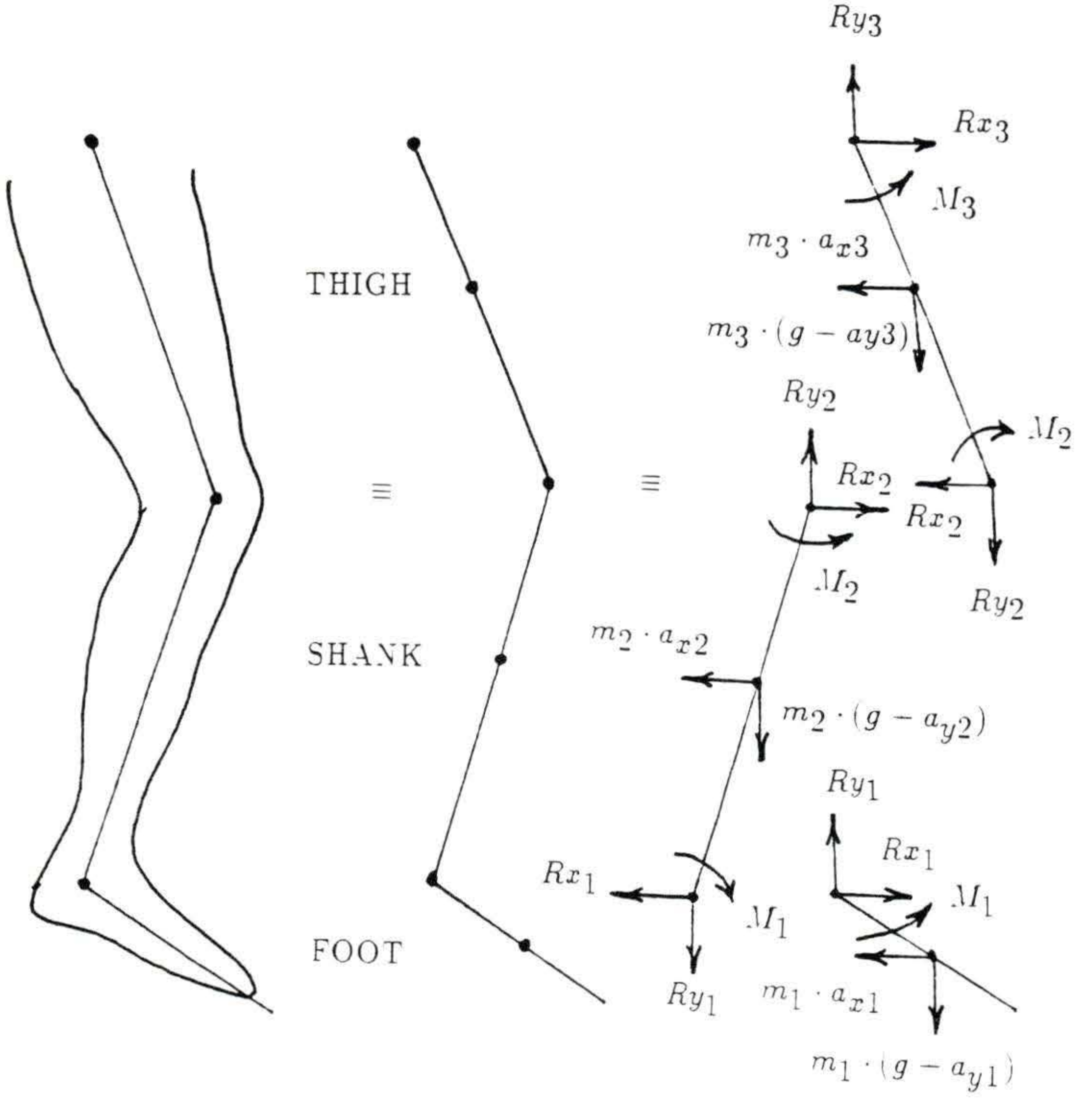

Figure 12.5: Dynamic reactive forces and moments

$$M_1 = JCM(1) \cdot LS(1) \cdot \cos(180^\circ - \theta_1) \cdot m_1 \cdot (g + a_{y1})$$
$$+JCM(1) \cdot LS(1) \cdot \sin(180 -^\circ \theta_1) \cdot m_1 \cdot a_{x1}$$

$$M_2 - M_1 + JCM(2) \cdot LS(2) \cdot \cos(\theta_2) \cdot m_2 \cdot (g + a_{y2})$$
$$-JCM(2) \cdot LS(2) \cdot \sin(\theta_2) \cdot m_2 \cdot a_{x2} + Ry_1 \cdot LS(2) \cdot \cos(\theta_2)$$
$$-Rx_1 \cdot LS(2) \cdot \sin(\theta_2) = I_2 \cdot \alpha_2 \Rightarrow$$
$$M_2 = M_1 - JCM(2) \cdot LS(2) \cdot \cos(\theta_2) \cdot m_2 \cdot (g + a_{y2})$$
$$+JCM(2) \cdot LS(2) \cdot \sin(\theta_2) \cdot m_2 \cdot a_{x2} - LS(2) \cdot \cos(\theta_2) \cdot Ry_1$$
$$+LS(2) \cdot \sin(\theta_2) \cdot Rx_1 + I_2 \cdot \alpha_2$$

$$M_3 - M_2 - JCM(3) \cdot LS(3) \cdot \cos(180^\circ - \theta_3) \cdot m_3 \cdot (g + a_{y3})$$
$$-JCM(3) \cdot LS(3) \cdot m_3 \cdot a_{x3} \cdot \sin(180^\circ - \theta_3)$$
$$-Rx_2 \cdot LS(3) \cdot \sin(180^\circ - \theta_3) - Ry_2 \cdot LS(3) \cdot \cos(180^\circ - \theta_3) = I_3 \cdot \alpha_3 \Rightarrow$$
$$M_3 = M_2 + JCM(3) \cdot LS(3) \cdot \cos(180^\circ - \theta_3) \cdot m_3 \cdot (g + a_{y3})$$
$$+JCM(3) \cdot LS(3) \cdot m_3 \cdot a_{x3} \cdot \sin(180^\circ - \theta_3)$$
$$+Rx_2 \cdot LS(3) \cdot \sin(180^\circ - \theta_3) + Ry_2 \cdot LS(3) \cdot \cos(180 - \theta_3) + I_3 \cdot \alpha_3$$

13 APPENDIX D: BIOMECHANICS

The following BASIC program for the IBM computer calculates two dimensional angles, velocities, acceleration, moments, and energies for the lower leg. The program listing is as follows:

```
1  REM *****************************************************
2  REM *                                                   *
3  REM * THIS PROGRAM CALCULATES VELOCITIES, ACCELERATION, *
4  REM * ANGLES, FORCES, MOMENTS, AND ENERGIES OF THE      *
5  REM * LOWER LEG IN RUNNING.                             *
9  REM *                                                   *
10 REM *****************************************************
11 REM
12 REM
15 REM MAIN MENU
20 KEY OFF
30 DIM HV(5, 30), HA(5, 30), VV(5, 30), VA(5, 30), STRF(3), STMOM(3,
30), DYNMOM(3, 30)
31 DIM XADJ(30), YADJ(30)
40 DIM THETA(4, 30), OMEGA(4, 30), ALPHA(4, 30), DEG(4, 30), HRF(5,
30), VRF(5, 40), BRE(30)
41 DIM X(6, 30), Y(6, 30), DEGA(30), DEGK(30), DEGH(30)
45 DIM XCM(4, 30), YCM(4, 30), HVCM(4, 30), VVCM(4, 30), HLACM(4, 30),
VLACM(4,30)
50 DIM HACM(4, 30), VACM(4, 30), JCM(4), LS(4), RG(4), WPCT(4),
TBE(30), BPE(30), BKE(30)
60 DIM JOINT$(5), SEGMT$(4), PE(4, 30), HKE(4, 30), VKE(4, 30), TKE(4,
```

```
30), RE(4, 30), TE(4, 30)
65 SEGMT$(1) = "FOOT": SEGMT$(2) = "SHANK": SEGMT$(3) = "THIGH"
66 SEGMT$(4) = "H.A.T."
70 FOR I = 1 TO 4
80     READ JCM(I)
90 NEXT I
100 FOR I = 1 TO 4
110     READ WPCT(I)
120 NEXT I
130 FOR I = 1 TO 4
140     READ RG(I)
150 NEXT I
160 DATA .500,.433,.433,.626
170 DATA .0145,.0465,.100,.339
180 DATA .475,.302,.323,.496
190 CLS
195 Z = 0
200 LOCATE 2, 22
210 PRINT "**************** MAIN MENU ********************"
220 LOCATE 4, 25: PRINT " 1 - CREATE NEW DATA SET"
230 LOCATE 5, 25: PRINT " 2 - LOAD EXISTING DATA SET"
240 LOCATE 6, 25: PRINT " 3 - VIEW VEL. AND ACC. OF CURRENT DATA SET"
245 LOCATE 7, 25: PRINT " 4 - VIEW TOTAL CURRENT DATA SET"
250 LOCATE 8, 25: PRINT " 5 - SAVE CURRENT DATA SET"
255 LOCATE 9, 25: PRINT " 6 - SAVE TOTAL CURRENT DATA SET AS FILE"
260 LOCATE 10, 25: PRINT " 7 - PRINT VEL. AND ACC. OF CURRENT DATA
SET"
265 LOCATE 11, 25: PRINT " 8 - PRINT TOTAL CURRENT DATA SET"
270 LOCATE 12, 25: PRINT " 9 - ALTER CURRENT DATA SET"
280 LOCATE 13, 25: PRINT "10 - CALCULATE MOMENTS OF CURRENT DATA SET"
290 LOCATE 14, 25: PRINT "11 - CALCULATE ENERGIES OF CURRENT DATA SET"
300 LOCATE 15, 25: PRINT "12 - RETURN TO DOS"
310 LOCATE 17, 22: PRINT
"**********************************************"
320 INPUT "CHOICE"; CHOICE
330 IF CHOICE < 1 AND CHOICE > 12 THEN GOTO 190
340 IF CHOICE = 0 THEN GOTO 190
350 ON CHOICE GOTO 360, 1390, 1580, 1665, 2300, 3215, 2500, 2595,
3870, 4000, 6520, 6490
```

```
360 CLS
370 LOCATE 2, 20: PRINT "************** NEW DATA SET MENU
******************"
380 LOCATE 4, 25: PRINT "1 - CREATE A NEW DATA SET"
390 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
400 LOCATE 8, 20: PRINT
"***************************************************"
410 PRINT : INPUT "CHOICE"; CHOICE
420 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 360
430 ON CHOICE GOTO 440, 190
440 CLS
450 LOCATE 2, 10: PRINT "********** CREATE NEW DATA SET
**************"
460 LOCATE 4, 15: INPUT "SUBJECT NUMBER: ", LT$
470 LOCATE 6, 15: INPUT "TOTAL DURATION OF ACTIVITY (SEC): ", TIME
480 LOCATE 7, 15: INPUT "HORIZONTAL DISTANCE FROM TOE TO ANKLE (M): ",
D
490 LOCATE 8, 15: INPUT "WEIGHT OF SUBJECT (KG): ", WEIGHT
500 LOCATE 9, 15: INPUT "DISTANCE FROM TOE TO ANKLE (M): ", LS(1)
510 LOCATE 10, 15: INPUT "DISTANCE FROM ANKLE TO KNEE (M): ", LS(2)
520 LOCATE 11, 15: INPUT "DISTANCE FROM KNEE TO HIP (M): ", LS(3)
530 LOCATE 12, 15: INPUT "DISTANCE FROM HIP TO SHOULDER (M): ", LS(4)
550 LOCATE 13, 15: INPUT "TOTAL NUMBER OF FRAMES: ", TNF
560 LOCATE 14, 15: INPUT "NUMBER OF UNITS PER METER FOR GRID SCALE
(UNITS/M): ", NU
565 GS = 1/NU
570 PRINT : INPUT "ARE THE ABOVE DATA CORRECT (Y/N)? ", A$
580 IF A$ = "N" THEN GOTO 360
590 CLS
600 LOCATE 1, 17: PRINT "************* INPUT JOINT COORDINATES
*************"
610 PRINT
620 FOR I = 0 TO 5
630 IF I = 0 THEN PRINT "JOINT = TOE"
640 IF I = 1 THEN PRINT "JOINT = ANKLE"
650 IF I = 2 THEN PRINT "JOINT = KNEE"
660 IF I = 3 THEN PRINT "JOINT = HIP"
670 IF I = 4 THEN PRINT "JOINT = SHOULDER"
680 IF I = 5 THEN PRINT "ABSOLUT REFERENCE POINT"
```

```
685 IF I <> 4 THEN GOTO 700
687 PI = 3.14159265#
690 PRINT
691 FOR J = 1 TO TNF
692 PRINT "FRAME "; J; " (DEG)": INPUT DEG(4,J)
693 THETA(4,J) = DEG(4,J) * PI/180
694 X(4,J) = X(3,J) + (LS(4) * COS(THETA(4,J))) / GS
695 Y(4,J) = Y(3,J) + (LS(4) * SIN(THETA(4,J))) / GS
696 NEXT J
697 GOTO 740
700 PRINT
701 IF I <> 5 THEN GOTO 710
702 IF I=5 THEN INPUT"IS ABSOLUT REFERENCE POINT (0,0) (Y/N)? ", A$
703 IF A$ = "N" THEN GOTO 710
704 FOR J=1 TO TNF
705 X(5,J) = 0
706 Y(5,J) = 0
707 NEXT J
708 GOTO 740
710 FOR J = 1 TO TNF
720 PRINT "FRAME "; J; " (X,Y)": INPUT X(I, J), Y(I, J)
730 NEXT J
740 PRINT
750 PRINT : INPUT "ARE THE ABOVE DATA CORRECT (Y/N)? ", A$
760 IF A$ = "N" THEN GOTO 630
770 PRINT
780 NEXT I
790 REM **** DATA SMOOTHING ****
810 FOR I = 2 TO TNF
820     XADJ(I) = X(5, 1) - X(5, I)
830     YADJ(I) = Y(5, 1) - Y(5, I)
840 NEXT I
850 FOR I = 0 TO 5
860     FOR J = 2 TO TNF
870     X(I, J) = X(I, J) + XADJ(J)
880     Y(I, J) = Y(I, J) + YADJ(J)
890     NEXT J
900 NEXT I
910 REM **** HORIZONTAL AND VERTICAL VELOCITIES AND ACCELERATIONS ****
```

```
920 TINT = TIME / (TNF - 1)
930 FOR I = 0 TO 4
940     FOR J = 2 TO TNF - 1
950        HV(I, J) = (X(I, J + 1) - X(I, J - 1)) / (2 * TINT) * GS
960        VV(I, J) = (Y(I, J + 1) - Y(I, J - 1)) / (2 * TINT) * GS
970     NEXT J
980     HV(I, TNF) = (X(I, TNF) - X(I, TNF - 1)) / (TINT) * GS
990     VV(I, TNF) = (Y(I, TNF) - Y(I, TNF - 1)) / (TINT) * GS
1000 NEXT I
1010 FOR I = 0 TO 4
1020     FOR J = 2 TO TNF - 1
1030         HA(I, J) = (HV(I, J+1) - HV(I, J-1)) / (2 * TINT)
1040         VA(I, J) = (VV(I, J+1) - HV(I, J-1)) / (2 * TINT)
1050     NEXT J
1060     HA(I, TNF) = (HV(I, TNF) - HV(I, TNF - 1)) / TINT
1070     VA(I, TNF) = (VV(I, TNF) - VV(I, TNF - 1)) / TINT
1080 NEXT I
1090 REM **** ANGULAR VELOCITIES AND ACCELERATIONS ****
1100 PI = 3.14159265#
1110 FOR I = 1 TO 4
1120     FOR J = 1 TO TNF
1130         IF X(I - 1, J) > X(I, J) THEN GOTO 1190
1140         IF X(I - 1, J) = X(I, J) THEN GOTO 1170
1150         THETA(I, J) = ATN((Y(I - 1, J) - Y(I, J)) / (X(I - 1, J)
- X(I, J)))
1160         GOTO 1200
1170         IF Y(I - 1, J) > Y(I, J) THEN THETA(I, J) = -1 * PI / 2:
GOTO 1200
1180         THETA(I, J) = PI / 2: GOTO 1200
1190         THETA(I, J) = PI + ATN((Y(I - 1, J) - Y(I, J)) / (X(I -
1, J) - X(I, J)))
1200     DEG(I, J) = THETA(I, J) * 180 / PI
1210 NEXT J
1220 NEXT I
1221 PHIO = ATN(SQR(LS(1)^2 - D^2)/D)*180/PI
1223 FOR J = 1 TO TNF
1224 DEGH(J) = 180 - DEG(3,J) + DEG(4,J)
1225 DEGK(J) = 180 - DEG(3,J) + DEG(2,J)
1226 DEGA(J) = 180 - (DEG(1,J) + PHIO) + DEG(2,J)
```

```
1227 NEXT J
1230 FOR I = 1 TO 4
1240     FOR J = 2 TO TNF - 1
1250         OMEGA(I, J) = (THETA(I, J + 1) - THETA(I, J - 1)) / (2 *
TINT)
1260         ALPHA(I, J) = (OMEGA(I, J + 1) - OMEGA(I, J - 1)) / (2 *
TINT)
1270     NEXT J
1275     OMEGA(I, TNF) = (THETA(I, TNF) - THETA(I, TNF - 1)) / TINT
1280     ALPHA(I, TNF) = (OMEGA(I, TNF) - OMEGA(I, TNF - 1)) / TINT
1285 NEXT I
1286 FOR I = 1 TO 4
1287     FOR J = 1 TO TNF
1288         XCM(I, J) = X(I, J) - (JCM(I) * LS(I) * COS(THETA(I, J))
/ GS)
1289         YCM(I, J) = Y(I, J) - (JCM(I) * LS(I) * SIN(THETA(I, J))
/ GS)
1290     NEXT J
1291 NEXT I
1292 FOR I = 1 TO 4
1293     FOR J = 2 TO TNF - 1
1294         HVCM(I, J) = (XCM(I, J + 1) - XCM(I, J - 1)) / (2 * TINT)
* GS
1295         VVCM(I, J) = (YCM(I, J + 1) - YCM(I, J - 1)) / (2 * TINT)
* GS
1296     NEXT J
1297     HVCM(I, TNF) = (XCM(I, TNF) - XCM(I, TNF - 1)) / (TINT) * GS
1298     VVCM(I, TNF) = (YCM(I, TNF) - YCM(I, TNF - 1)) / (TINT) * GS
1299 NEXT I
1300 FOR I = 1 TO 4
1301     FOR J = 2 TO TNF - 1
1302         HLACM(I, J) = (HVCM(I, J+1) - HVCM(I, J-1)) / (2 * TINT)
1303         VLACM(I, J) = (VVCM(I, J+1) - HVCM(I, J-1)) / (2 * TINT)
1304     NEXT J
1305     HLACM(I, TNF) = (HVCM(I, TNF) - HVCM(I, TNF - 1)) / TINT
1306     VLACM(I, TNF) = (VVCM(I, TNF) - VVCM(I, TNF - 1)) / TINT
1307 NEXT I
1310 REM *** ACCELERATIONS AT CENTER OF MASS ***
1320 FOR I = 1 TO 4
```

```
1330      FOR J = 1 TO TNF
1340           HACM(I, J) = JCM(I) * LS(I) * ((OMEGA(I, J)^2) *
COS(THETA(I, J)) + ALPHA(I, J) * SIN(THETA(I, J))) - HLACM(I, J)
1350           VACM(I, J) = JCM(I) * LS(I) * ((OMEGA(I, J)^2) *
SIN(THETA(I, J)) - ALPHA(I, J) * COS(THETA(I, J))) - VLACM(I, J)
1360      NEXT J
1370 NEXT I
1380 GOTO 190
1390 REM ************* LOAD A CURRENT FILE ******************
1400 CLS
1410 LOCATE 2, 20: PRINT "**************** LOAD MENU
********************"
1420 LOCATE 4, 25: PRINT "1 - LOAD AN EXISTING FILE"
1430 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
1440 LOCATE 8, 20: PRINT
"***********************************************"
1450 PRINT : INPUT "CHOICE"; CHOICE
1460 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 1400
1470 ON CHOICE GOTO 1471, 190
1471 PRINT : PRINT : FILES "B:*.DAT"
1480 PRINT : INPUT "NAME OF FILE TO LOAD (WITHOUT EXTENSION):", F$
1481 FILE$ = F$ + ".DAT"
1490 OPEN FILE$ FOR INPUT AS #2
1491 ON ERROR GOTO 1480
1500 INPUT #2, LT$, TIME, D, WEIGHT, LS(1), LS(2), LS(3), LS(4), TNF,
NU, GS
1510 FOR I = 0 TO 5
1520      FOR J = 1 TO TNF
1530           INPUT #2, X(I, J), Y(I, J)
1540      NEXT J
1550 NEXT I
1560 CLOSE #2
1570 GOTO 790
1580 REM ************* VIEW A CURRENT FILE ******************
1590 CLS
1600 LOCATE 2, 20: PRINT "**************** VIEW MENU
********************"
1610 LOCATE 4, 25: PRINT "1 - VIEW AN EXISTING FILE"
1620 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
```

```
1630 LOCATE 8, 20: PRINT
"***********************************************"
1640 PRINT : INPUT "CHOICE"; CHOICE
1650 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 1590
1660 ON CHOICE GOTO 1670, 190
1665 Z = 1
1670 CLS
1680 LOCATE 5, 15: PRINT "SUBJECT NUMBER: "; LT$
1690 LOCATE 6, 15: PRINT "TOTAL DURATION OF ACTIVITY (SEC): "; TIME
1700 LOCATE 7, 15: PRINT "HORIZONTAL DISTANCE FROM TOE TO ANKLE (M):
"; D
1710 LOCATE 8, 15: PRINT "WEIGHT OF SUBJECT (KG): "; WEIGHT
1720 LOCATE 9, 15: PRINT "DISTANCE FROM TOE TO ANKLE (M): "; LS(1)
1730 LOCATE 10, 15: PRINT "DISTANCE FROM ANKLE TO KNEE (M): "; LS(2)
1740 LOCATE 11, 15: PRINT "DISTANCE FROM KNEE TO HIP (M): "; LS(3)
1750 LOCATE 12, 15: PRINT "DISTANCE FROM HIP TO SHOULDER (M): "; LS(4)
1770 LOCATE 13, 15: PRINT "TOTAL NUMBER OF FRAMES: "; TNF
1780 LOCATE 14, 15: PRINT "NUMBER OF UNITS PER METER FOR GRID SCALE
(UNITS/M): "; NU
1790 PRINT : PRINT : INPUT "HIT RETURN TO CONTINUE", A$
1800 CLS : PRINT "     JOINT    FRAME     X-COORD      Y-COORD    "
1810 PRINT "    --------   -----     -------       -------    "
1820 PRINT
1830 JOINT$(0) = "TOE": JOINT$(1) = "ANKLE": JOINT$(2) = "KNEE"
1840 JOINT$(3) = "HIP": JOINT$(4) = "SHOULDER"
1850 FOR I = 0 TO 4
1860     FOR J = 1 TO TNF
1862         PRINT "    "; JOINT$(I),
1863         PRINT USING "#####"; J;
1864         PRINT USING "##########.##"; X(I, J), Y(I, J)
1865     NEXT J
1866 PRINT
1867 NEXT I
1868 PRINT : PRINT : INPUT "HIT RETURN TO CONTINUE", A$
1869 CLS :PRINT "      MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
JOINTS"
1870 PRINT "     --------------------------------------------------"
1871 FOR I = 0 TO 4
1872 PRINT "   NAME OF JOINT: "; JOINT$(I): PRINT: PRINT
```

```
1874 PRINT "          HORIZ.    VERTICAL    HORIZ.    VERTICAL
HORIZ.   VERTICAL"
1875 PRINT "         POSITION   POSITION   VELOCITY   VELOCITY
ACCEL.     ACCEL."
1876 PRINT "FRAME   (UNITS)    (UNITS)    (M/SEC)    (M/SEC)
(M/S^2)    (M/S^2)"
1877 PRINT "-----   --------   --------   --------   --------   ------
--   --------"
1878 FOR J = 1 TO TNF
1879 PRINT USING "#####"; J;
1880 PRINT USING "######.####"; X(I, J), Y(I, J), HV(I, J), VV(I, J),
HA(I, J), VA(I, J)
1891 NEXT J
1892 PRINT: PRINT
1893 NEXT I
1905 SEGMT$(1) = "FOOT": SEGMT$(2) = "SHANK": SEGMT$(3) = "THIGH"
1906 SEGMT$(4) = "H.A.T."
1910 PRINT : PRINT : INPUT "HIT RETURN TO CONTINUE", A$
1920 CLS : PRINT "      MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
SEGMENTS"
1930 PRINT "      ----------------------------------------------------
-"
1940 FOR I = 1 TO 4
1950 PRINT "  NAME OF SEGMENT: "; SEGMT$(I): PRINT
1960 PRINT "      *** HORIZONTAL MOVEMENTS AND VELOCITIES ***": PRINT
1970 PRINT SPC(51); "HORIZ."
1980 PRINT SPC(15); " HORIZ.    HORIZ.    HORIZ.      ACCEL."
1990 PRINT SPC(15); "POSITION   VELOCITY   ACCEL.    @ C OF G"
2000 PRINT "    FRAME     (UNITS)     (M/SEC)    (M/S^2)     (M/S^2)"
2010 PRINT "    ------    -------    ---------   --------   ---------
"
2020 FOR J = 1 TO TNF
2030 PRINT USING "###########"; J;
2040 PRINT USING "######.####"; XCM(I, J), HVCM(I, J), HLACM(I, J),
HACM(I, J)
2050 NEXT J
2060 PRINT
2070 PRINT "      *** VERTICAL MOVEMENTS AND VELOCITIES ***": PRINT
2080 PRINT SPC(49); "VERTICAL"
```

```
2090 PRINT SPC(15); "VERTICAL   VERTICAL    VERTICAL      ACCEL."
2100 PRINT SPC(15); "POSITION   VELOCITY     ACCEL.    @ C OF G"
2110 PRINT "     FRAME     (UNITS)     (M/SEC)     (M/S^2)     (M/S^2)"
2120 PRINT "     ------    -------    ---------    --------    ---------
"
2130 FOR J = 1 TO TNF
2140 PRINT USING "###########"; J;
2150 PRINT USING "######.####"; YCM(I, J), VVCM(I, J), VLACM(I, J),
VACM(I, J)
2160 NEXT J
2170 PRINT
2180 PRINT "      *** ANGULAR VELOCITIES AND ACCELERATIONS ***": PRINT
2190 PRINT SPC(14); "  THETA       THETA      OMEGA        ALPHA"
2200 PRINT "     FRAME      (DEG)     (RADIANS)  (RAD/SEC)
(RAD/S^2)"
2210 PRINT "     ------    -------    ---------    --------    ---------
"
2220 FOR J = 1 TO TNF
2230 PRINT USING "###########"; J;
2240 PRINT USING "######.####"; DEG(I, J), THETA(I, J), OMEGA(I, J),
ALPHA(I, J)
2250 NEXT J
2260 PRINT
2265 NEXT I
2270 PRINT
2271 PRINT "      *** ANGLES OF ANKLE, KNEE, AND HIP ***": PRINT
2272 PRINT SPC(14); "  ANKLE       KNEE        HIP "
2273 PRINT "     FRAME      (DEG)       (DEG)      (DEG) "
2274 PRINT "     ------    -------    ---------    -------- "
2275 FOR J = 1 TO TNF
2276 PRINT USING "###########"; J;
2277 PRINT USING "######.####"; DEGA(J), DEGK(J), DEGH(J)
2278 NEXT J
2279 PRINT
2285 PRINT : INPUT "HIT RETURN TO CONTINUE", A$
2287 IF Z=1 GOTO 4090
2290 GOTO 190
2300 REM ******* SAVING CURRENT DATA SET *******
2310 CLS
```

```
2320 LOCATE 2, 20: PRINT "******************* SAVE MENU
*******************"
2330 LOCATE 4, 25: PRINT "1 - SAVE CURRENT DATA TO FILE"
2340 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
2350 LOCATE 8, 20: PRINT
"************************************************"
2360 PRINT : INPUT "CHOICE"; CHOICE
2370 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 2310
2380 ON CHOICE GOTO 2390, 190
2390 CLS
2400 PRINT : PRINT : INPUT "NAME OF FILE TO BE SAVED (WITHOUT
EXTENSION)"; F$
2401 FILE$ = F$ + ".DAT"
2410 OPEN FILE$ FOR OUTPUT AS #1
2420 WRITE #1, LT$, TIME, D, WEIGHT, LS(1), LS(2), LS(3), LS(4), TNF,
NU, GS
2430 FOR I = 0 TO 5
2440     FOR J = 1 TO TNF
2450         WRITE #1, X(I, J), Y(I, J)
2460     NEXT J
2470 NEXT I
2480 CLOSE #1
2490 GOTO 190
2500 REM *** PRINT AN EXISTING FILE ***
2510 CLS
2520 LOCATE 2, 20: PRINT "***************** PRINT MENU
*****************"
2530 LOCATE 4, 25: PRINT "1 - PRINT TO PRINTER"
2540 LOCATE 6, 25: PRINT "2 - PRINT TO FILE"
2550 LOCATE 8, 25: PRINT "3 - RETURN TO MAIN MENU"
2560 LOCATE 10, 20: PRINT
"********************************************"
2570 PRINT : INPUT "CHOICE"; CHOICE
2580 IF CHOICE <> 1 AND CHOICE <> 2 AND CHOICE <> 3 THEN GOTO 2510
2590 ON CHOICE GOTO 2610, 3220, 190
2595 Z = 2
2600 CLS
2610 LPRINT "SUBJECT NUMBER: "; LT$
2620 LPRINT "TOTAL DURATION OF ACTIVITY (SEC): "; TIME
```

```
2630 LPRINT "HORIZONTAL DISTANCE FROM TOE TO ANKLE (M): "; D
2640 LPRINT "WEIGHT OF SUBJECT (KG): "; WEIGHT
2650 LPRINT "DISTANCE FROM TOE TO ANKLE (M): "; LS(1)
2660 LPRINT "DISTANCE FROM ANKLE TO KNEE (M): "; LS(2)
2670 LPRINT "DISTANCE FROM KNEE TO HIP (M): "; LS(3)
2680 LPRINT "DISTANCE FROM HIP TO SHOULDER (M): "; LS(4)
2700 LPRINT "TOTAL NUMBER OF FRAMES: "; TNF
2710 LPRINT "NUMBER OF UNITS PER METER FOR GRID SCALE (UNITS/M): "; NU
2720 LPRINT : LPRINT
2730 LPRINT "     JOINT     FRAME      X-COORD       Y-COORD    "
2740 LPRINT "    --------   -----      -------       -------    "
2750 LPRINT
2760 JOINT$(0) = "TOE": JOINT$(1) = "ANKLE": JOINT$(2) = "KNEE"
2770 JOINT$(3) = "HIP": JOINT$(4) = "SHOULDER"
2780 FOR I = 0 TO 4
2790     FOR J = 1 TO TNF
2795        LPRINT "    "; JOINT$(I),
2798        LPRINT USING "#####"; J;
2800        LPRINT USING "###########.##"; X(I, J), Y(I, J)
2801     NEXT J
2802     LPRINT
2803     IF I<>0 AND I<>2 AND I<>4 THEN LPRINT CHR$(12)
2804 NEXT I
2809 LPRINT : LPRINT CHR$(12)
2810 LPRINT "     MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
JOINTS"
2811 LPRINT "     --------------------------------------------------
"
2812 FOR I = 0 TO 4
2813 LPRINT "  NAME OF JOINT: "; JOINT$(I): LPRINT: LPRINT
2815 LPRINT "        HORIZ.    VERTICAL    HORIZ.   VERTICAL
HORIZ.   VERTICAL"
2816 LPRINT "       POSITION   POSITION   VELOCITY   VELOCITY
ACCEL.    ACCEL."
2817 LPRINT "FRAME   (UNITS)    (UNITS)    (M/SEC)    (M/SEC)
(M/S^2)    (M/S^2)"
2818 LPRINT "-----  --------   --------   --------   --------   -----
---   --------"
2819 FOR J = 1 TO TNF
```

```
2820 LPRINT USING "#####"; J;
2821 LPRINT USING "######.####"; X(I, J), Y(I, J),HV(I, J), VV(I, J),
HA(I, J), VA(I, J)
2822 NEXT J
2825 IF I<>0 AND I<>2 AND I<>4 THEN LPRINT CHR$(12)
2830 LPRINT: LPRINT
2834 NEXT I
2835 SEGMT$(1) = "FOOT": SEGMT$(2) = "SHANK": SEGMT$(3) = "THIGH"
2836 SEGMT$(4) = "H.A.T."
2840 LPRINT : LPRINT CHR$(12)
2850 LPRINT "      MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
SEGMENTS"
2860 LPRINT "      ---------------------------------------------------
--"
2870 FOR I = 1 TO 4
2880 LPRINT "   NAME OF SEGMENT: "; SEGMT$(I): LPRINT
2890 LPRINT "      *** HORIZONTAL MOVEMENTS AND VELOCITIES ***":
LPRINT
2900 LPRINT SPC(51); "HORIZ."
2910 LPRINT SPC(15); " HORIZ.     HORIZ.     HORIZ.       ACCEL."
2920 LPRINT SPC(15); "POSITION   VELOCITY    ACCEL.     @ C OF G"
2930 LPRINT "     FRAME     (UNITS)     (M/SEC)     (M/S^2)
(M/S^2)"
2940 LPRINT "     ------    -------     ---------   --------   --------
-"
2950 FOR J = 1 TO TNF
2960 LPRINT USING "############"; J;
2970 LPRINT USING "######.####"; XCM(I, J), HVCM(I, J), HLACM(I, J),
HACM(I, J)
2980 NEXT J
2990 LPRINT
2995 IF I<>1 AND I<>3 THEN LPRINT CHR$(12)
3000 LPRINT "      *** VERTICAL MOVEMENTS AND VELOCITIES ***": LPRINT
3010 LPRINT SPC(49); "VERTICAL"
3020 LPRINT SPC(15); "VERTICAL   VERTICAL    VERTICAL     ACCEL."
3030 LPRINT SPC(15); "POSITION   VELOCITY     ACCEL.    @ C OF G"
3040 LPRINT "     FRAME     (UNITS)     (M/SEC)     (M/S^2)
(M/S^2)"
3050 LPRINT "     ------    -------     ---------   --------   --------
```

```
-"
3060 FOR J = 1 TO TNF
3070 LPRINT USING "############"; J;
3080 LPRINT USING "######.####"; YCM(I, J), VVCM(I, J), VLACM(I, J),
VACM(I, J)
3090 NEXT J
3100 LPRINT
3105 IF I<>2 AND I<>4 THEN LPRINT CHR$(12)
3110 LPRINT "    *** ANGULAR VELOCITIES AND ACCELERATIONS ***": LPRINT
3120 LPRINT SPC(14); "  THETA       THETA      OMEGA       ALPHA"
3130 LPRINT "     FRAME      (DEG)     (RADIANS)  (RAD/SEC)
(RAD/S^2)"
3140 LPRINT "     ------    -------    ---------   --------   --------
-"
3150 FOR J = 1 TO TNF
3160 LPRINT USING "############"; J;
3170 LPRINT USING "######.####"; DEG(I, J), THETA(I, J), OMEGA(I, J),
ALPHA(I, J)
3180 NEXT J
3190 LPRINT
3192 IF I<>1 AND I<>3 THEN LPRINT CHR$(12)
3195 NEXT I
3200 LPRINT
3201 LPRINT "      *** ANGLES OF ANKLE, KNEE, AND HIP ***": LPRINT
3202 LPRINT SPC(14); "  ANKLE       KNEE        HIP "
3203 LPRINT "     FRAME      (DEG)       (DEG)      (DEG) "
3204 LPRINT "     ------    -------    ---------   -------- "
3205 FOR J = 1 TO TNF
3206 LPRINT USING "############"; J;
3207 LPRINT USING "######.####"; DEGA(J), DEGK(J), DEGH(J)
3208 NEXT J
3209 LPRINT
3210 IF Z=2 GOTO 4090
3211 LPRINT CHR$(12)
3212 GOTO 190
3215 Z = 3
3220 REM ************* PRINT TO A FILE *****************
3230 CLS : A$ = ""
3240 PRINT : INPUT "NAME OF OUTPUT FILE"; FILE$
```

```
3250 OPEN FILE$ FOR OUTPUT AS #1
3260 LOCATE 4, 15: PRINT #1, "SUBJECT NUMBER: "; LT$
3270 LOCATE 6, 15: PRINT #1, "TOTAL DURATION OF ACTIVITY (SEC): ";
TIME
3275 LOCATE 7, 15: PRINT #1, "HORIZONTAL DISTANCE FROM TOE TO ANKLE
(M): "; D
3280 LOCATE 8, 15: PRINT #1, "WEIGHT OF SUBJECT (KG): "; WEIGHT
3290 LOCATE 9, 15: PRINT #1, "DISTANCE FROM TOE TO ANKLE (M): "; LS(1)
3300 LOCATE 10, 15: PRINT #1, "DISTANCE FROM ANKLE TO KNEE (M): ";
LS(2)
3310 LOCATE 11, 15: PRINT #1, "DISTANCE FROM KNEE TO HIP (M): "; LS(3)
3320 LOCATE 12, 15: PRINT #1, "DISTANCE FROM HIP TO SHOULDER (M): ";
LS(4)
3340 LOCATE 14, 15: PRINT #1, "TOTAL NUMBER OF FRAMES: "; TNF
3350 LOCATE 15, 15: PRINT #1, "NUMBER OF UNITS PER METER FOR GRID
SCALE (UNITS/M): "; NU
3360 PRINT #1, A$: PRINT #1, A$
3370 PRINT #1, "      JOINT     FRAME      X-COORD        Y-COORD    "
3380 PRINT #1, "     --------   -----      -------        -------    "
3390 PRINT #1, A$
3400 JOINT$(0) = "TOE": JOINT$(1) = "ANKLE": JOINT$(2) = "KNEE"
3410 JOINT$(3) = "HIP": JOINT$(4) = "SHOULDER"
3420 FOR I = 0 TO 4
3430     FOR J = 1 TO TNF
3435         PRINT #1, "    "; JOINT$(I),
3437         PRINT #1, USING "#####"; J;
3440         PRINT #1, USING "###########.##"; X(I, J), Y(I, J)
3442     NEXT J
3443     PRINT #1, A$
3444 NEXT I
3445 PRINT #1, A$: PRINT #1, A$
3446 PRINT #1, "      MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
JOINTS"
3447 PRINT #1, "      ------------------------------------------------
---"
3448 FOR I = 0 TO 4
3449 PRINT #1, "   NAME OF JOINT: "; JOINT$(I): PRINT #1, A$
3451 PRINT #1, "          HORIZ.   VERTICAL   HORIZ.  VERTICAL
HORIZ.   VERTICAL"
```

```
3452 PRINT #1, "         POSITION   POSITION   VELOCITY  VELOCITY
ACCEL.     ACCEL."
3453 PRINT #1, "FRAME    (UNITS)    (UNITS)    (M/SEC)    (M/SEC)
(M/S^2)    (M/S^2)"
3454 PRINT #1, "------   --------   --------   --------   --------   -
-------   --------"
3455 FOR J = 1 TO TNF
3456 PRINT #1, USING "#####"; J;
3457 PRINT #1, USING "######.####"; X(I, J), Y(I, J), HV(I, J), VV(I,
J), HA(I, J), VA(I, J)
3458 NEXT J
3469 PRINT #1, A$: PRINT #1, A$
3470 NEXT I
3475 SEGMT$(1) = "FOOT": SEGMT$(2) = "SHANK": SEGMT$(3) = "THIGH"
3476 SEGMT$(4) = "H.A.T."
3480 PRINT #1, A$: PRINT #1, A$
3490 PRINT #1, "      MOVEMENTS, VELOCITIES, AND ACCELERATIONS FOR
SEGMENTS"
3500 PRINT #1, "      --------------------------------------------
-----"
3510 FOR I = 1 TO 4
3520 PRINT #1, "   NAME OF SEGMENT: "; SEGMT$(I): PRINT #1, A$
3530 PRINT #1, "    *** HORIZONTAL MOVEMENTS AND VELOCITIES ***":
PRINT #1, A$
3540 PRINT #1, SPC(51); "HORIZ."
3550 PRINT #1, SPC(15); " HORIZ.     HORIZ.     HORIZ.      ACCEL."
3560 PRINT #1, SPC(15); "POSITION   VELOCITY    ACCEL.    @ C OF G"
3570 PRINT #1, "     FRAME     (UNITS)     (M/SEC)    (M/S^2)
(M/S^2)"
3580 PRINT #1, "     ------    -------    ---------   --------   -----
----"
3590 FOR J = 1 TO TNF
3600 PRINT #1, USING "###########"; J;
3610 PRINT #1, USING "######.####"; XCM(I, J), HVCM(I, J), HLACM(I,
J), HACM(I, J)
3620 NEXT J
3630 PRINT #1, A$
3640 PRINT #1, "      *** VERTICAL MOVEMENTS AND VELOCITIES ***":
PRINT #1, A$
```

```
3650 PRINT #1, SPC(49); "VERTICAL"
3660 PRINT #1, SPC(15); "VERTICAL   VERTICAL   VERTICAL     ACCEL."
3670 PRINT #1, SPC(15); "POSITION   VELOCITY     ACCEL.    @ C OF G"
3680 PRINT #1, "     FRAME     (UNITS)     (M/SEC)    (M/S^2)
(M/S^2)"
3690 PRINT #1, "     ------    -------    ---------   --------   -----
----"
3700 FOR J = 1 TO TNF
3710 PRINT #1, USING "###########"; J;
3720 PRINT #1, USING "######.####"; YCM(I, J), VVCM(I, J), VLACM(I,
J), VACM(I, J)
3730 NEXT J
3740 PRINT #1, A$
3750 PRINT #1, "    *** ANGULAR VELOCITIES AND ACCELERATIONS ***":
PRINT #1, A$
3760 PRINT #1, SPC(14); "  THETA       THETA      OMEGA       ALPHA"
3770 PRINT #1, "     FRAME      (DEG)     (RADIANS)  (RAD/SEC)
(RAD/S^2)"
3780 PRINT #1, "     ------    -------    ---------   --------   -----
----"
3790 FOR J = 1 TO TNF
3800 PRINT #1, USING "###########"; J;
3810 PRINT #1, USING "######.####"; DEG(I, J), THETA(I, J), OMEGA(I,
J), ALPHA(I, J)
3820 NEXT J
3830 PRINT #1, A$
3835 NEXT I
3840 PRINT #1, A$
3841 PRINT #1, "      *** ANGLES OF ANKLE, KNEE, AND HIP ***": PRINT
#1, A$
3842 PRINT #1, SPC(14); "  ANKLE       KNEE        HIP "
3843 PRINT #1, "     FRAME      (DEG)       (DEG)      (DEG) "
3844 PRINT #1, "     ------    -------    ---------   -------- "
3845 FOR J = 1 TO TNF
3846 PRINT #1, USING "###########"; J;
3847 PRINT #1, USING "######.####"; DEGA(J), DEGK(J), DEGH(J)
3848 NEXT J
3849 PRINT #1, A$
3850 IF Z = 3 GOTO 4090
```

```
3855 CLOSE #1
3860 GOTO 190
3870 REM **** ALTER EXISTING DATA SET ****
3880 CLS
3890 LOCATE 4, 15: PRINT "********** ALTER EXISTING DATA SET
**********"
3900 LOCATE 6, 20: PRINT "1 - TOTAL DURATION OF ACTIVITY (SEC): ";
TIME
3920 LOCATE 8, 20: PRINT "2 - RECALCULATE WITH NEW VALUES"
3930 LOCATE 10, 20: PRINT "3 - RETURN TO MAIN MENU "
3940 LOCATE 12, 15: PRINT
"*********************************************"
3950 PRINT : PRINT : INPUT "CHOICE"; CHOICE
3960 IF CHOICE <> 1 AND CHOICE <> 2 AND CHOICE <> 3 THEN GOTO 3880
3970 ON CHOICE GOTO 3980, 920, 190
3980 PRINT : INPUT "ENTER NEW DURATION"; TIME: GOTO 3880
4000 REM ******************* MOMENT CALCULATIONS
****************************
4010 CLS
4020 LOCATE 2, 20: PRINT "*************** MOMENT CALCULATIONS
***************"
4030 LOCATE 4, 25: PRINT "1 - CALCULATE MOMENTS FOR CURRENT DATA SET"
4040 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
4050 LOCATE 8, 20: PRINT
"***************************************************"
4060 PRINT : INPUT "CHOICE"; CHOICE
4070 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 4010
4080 ON CHOICE GOTO 4090, 190
4090 G = 9.810001
4100 REM ******* VERTICAL STATIC REACTIVE FORCES *********
4120 FOR I = 1 TO 3
4130     STRF(I) = STRF(I - 1) + (WPCT(I) * WEIGHT) * G
4140 VRF(I, 1) = STRF(I)
4150 NEXT I
4160 REM ******* STATIC MOMENTS ********
4170 FOR I = 1 TO 3
4180     FOR J = 1 TO TNF
4190         STMOM(I, J) = STMOM(I - 1, J) - JCM(I) * LS(I) *
COS(THETA(I, J)) * WEIGHT * WPCT(I) * G - LS(I) * COS(THETA(I, J)) *
```

```
STRF(I - 1)
4200         NEXT J
4210 NEXT I
4220 REM ***** HORIZONTAL DYNAMIC REACTIVE FORCES ******************
4260 FOR I = 1 TO 3
4270     FOR J = 1 TO TNF
4280         HRF(I, J) = HRF(I - 1, J) + WEIGHT * WPCT(I) * HACM(I, J)
4290     NEXT J
4300 NEXT I
4310 REM ***** VERTICAL DYNAMIC REACTIVE FORCES **************
4350 FOR I = 1 TO 3
4360     FOR J = 1 TO TNF
4370         VRF(I, J) = VRF(I - 1, J) + WEIGHT * WPCT(I) * (G +
VACM(I, J))
4380     NEXT J
4390 NEXT I
4400 REM ****** DYNAMIC MOMENTS AT SEGMENTS ************
4410 FOR I = 1 TO 3
4420     FOR J = 1 TO TNF
4430 PART1 = -JCM(I) * LS(I) * COS(THETA(I, J)) * WEIGHT * WPCT(I) *
(G + VACM(I, J))
4440 PART2 =  JCM(I) * LS(I) * SIN(THETA(I, J)) * WEIGHT * WPCT(I) *
HACM(I, J)
4450 PART3 = -LS(I) * COS(THETA(I, J)) * VRF(I - 1, J)
4460 PART4 =  LS(I) * SIN(THETA(I, J)) * HRF(I - 1, J)
4470 PART5 =  ALPHA(I, J) * WEIGHT * WPCT(I) * (((RG(I)*LS(I))^2) +
((JCM(I) * LS(I))^2))
4480 DYNMOM(I, J) = DYNMOM(I - 1, J) + PART1 + PART2 + PART3 + PART4 +
PART5
4490     NEXT J
4500 NEXT I
4505 IF Z=1 GOTO 5860
4506 IF Z=2 GOTO 5260
4507 IF Z=3 GOTO 4650
4510 REM ******** PRINT CURRENT MOMENTS **************
4520 CLS :A$ = ""
4530 LOCATE 2, 20: PRINT "*********** PRINT MOMENTS MENU
**************"
4540 LOCATE 4, 25: PRINT "1 - PRINT TO FILE"
```

```
4550 LOCATE 6, 25: PRINT "2 - PRINT TO PRINTER"
4560 LOCATE 8, 25: PRINT "3 - PRINT TO SCREEN"
4570 LOCATE 10, 25: PRINT "4 - RETURN TO MAIN MENU"
4580 LOCATE 12, 20: PRINT
"*******************************************"
4590 PRINT : INPUT "CHOICE"; CHOICE
4600 IF CHOICE <> 1 AND CHOICE <> 2 AND CHOICE <> 3 AND CHOICE <> 4
THEN GOTO 4520
4610 ON CHOICE GOTO 4620, 5260, 5860, 190
4620 REM ***** PRINT TO FILE ******
4630 PRINT : INPUT "NAME OF FILE TO OUTPUT TO"; FILE$
4640 OPEN FILE$ FOR OUTPUT AS #1
4650 PRINT #1, "STATIC REACTIVE FORCES IN NEWTONS"
4660 PRINT #1, "--------------------------------"
4662 PRINT #1, A$
4664 PRINT #1, "FRAME     R1X         R2X         R3X         R1Y
R2Y         R3Y"
4666 PRINT #1, "-----  ---------  ---------  ---------  ---------  ---
------  ---------"
4670 PRINT #1, "  ALL";
4672 FOR I = 1 TO 3
4673     PRINT #1, "     0.0000";
4674 NEXT I
4680 FOR I = 1 TO 3
4700     PRINT #1, USING "######.####"; STRF(I);
4710 NEXT I
4720 PRINT #1, A$: PRINT #1, A$: PRINT #1, A$
4730 PRINT #1, "STATIC MOMENTS IN NEWTON METERS"
4740 PRINT #1, "------------------------------"
4750 PRINT #1, A$
4760 PRINT #1, "FRAME     M1          M2          M3 "
4770 PRINT #1, "-----  ---------  ---------  --------- "
4780 FOR J = 1 TO TNF
4790         PRINT #1, USING "#####"; J;
4800     FOR I = 1 TO 3
4810         PRINT #1, USING "######.####"; STMOM(I, J);
4820 NEXT I
4830 PRINT #1, A$
4840 NEXT J
```

```
4850 PRINT #1, A$: PRINT #1, A$
4860 PRINT #1, "DYNAMIC REACTIVE FORCES IN NEWTONS"
4870 PRINT #1, "----------------------------------"
4880 PRINT #1, A$
4890 PRINT #1, "FRAME     R1X        R2X        R3X        R1Y
R2Y        R3Y"
4900 PRINT #1, "-----  ---------  ---------  ---------  ---------  ---
------  ---------"
4910 FOR J = 1 TO TNF
4920         PRINT #1, USING "#####"; J;
4930     FOR I = 1 TO 3
4940         PRINT #1, USING "######.####"; HRF(I, J);
4950 NEXT I
4952     FOR I = 1 TO 3
4954         PRINT #1, USING "######.####"; VRF(I, J);
4956 NEXT I
4960 PRINT #1, A$
4970 NEXT J
5110 PRINT #1, A$: PRINT #1, A$
5120 PRINT #1, "DYNAMIC MOMENTS IN NEWTON METERS"
5130 PRINT #1, "--------------------------------"
5140 PRINT #1, A$
5150 PRINT #1, "FRAME     M1         M2         M3 "
5160 PRINT #1, "-----  ---------  ---------  --------- "
5170 FOR J = 1 TO TNF
5180         PRINT #1, USING "#####"; J;
5190     FOR I = 1 TO 3
5200         PRINT #1, USING "######.####"; DYNMOM(I, J);
5210 NEXT I
5220 PRINT #1, A$
5230 NEXT J
5235 IF Z = 3 GOTO 6610
5240 CLOSE 1
5250 GOTO 4520
5260 IF Z = 2 THEN LPRINT CHR$(12)
5265 LPRINT "STATIC REACTIVE FORCES IN NEWTONS"
5270 LPRINT "---------------------------------"
5280 LPRINT
5284 LPRINT "FRAME     R1X        R2X        R3X        R1Y        R2Y
```

```
R3Y"
5285 LPRINT "-----  ---------  ---------  ---------  ---------  ------
---  ---------"
5286 LPRINT "  ALL";
5287 FOR I = 1 TO 3
5288     LPRINT "      0.0000";
5289 NEXT I
5290 FOR I = 1 TO 3
5310     LPRINT USING "######.####"; STRF(I);
5320 NEXT I
5330 LPRINT : LPRINT : LPRINT
5340 LPRINT "STATIC MOMENTS IN NEWTON METERS"
5350 LPRINT "-------------------------------"
5360 LPRINT
5370 LPRINT "FRAME     M1         M2         M3 "
5380 LPRINT "-----  ---------  ---------  --------- "
5390 FOR J = 1 TO TNF
5400         LPRINT USING "#####"; J;
5410     FOR I = 1 TO 3
5420         LPRINT USING "######.####"; STMOM(I, J);
5430 NEXT I
5440 LPRINT
5450 NEXT J
5460 LPRINT : LPRINT
5465 LPRINT CHR$(12)
5470 LPRINT "DYNAMIC REACTIVE FORCES IN NEWTONS"
5480 LPRINT "----------------------------------"
5490 LPRINT A$
5500 LPRINT "FRAME     R1X        R2X        R3X        R1Y        R2Y
R3Y"
5510 LPRINT "-----  ---------  ---------  ---------  ---------  ------
---  ---------"
5520 FOR J = 1 TO TNF
5530         LPRINT USING "#####"; J;
5540     FOR I = 1 TO 3
5550         LPRINT USING "######.####"; HRF(I, J);
5560 NEXT I
5670     FOR I = 1 TO 3
5680         LPRINT USING "######.####"; VRF(I, J);
```

```
5690 NEXT I
5700 LPRINT
5710 NEXT J
5720 LPRINT : LPRINT
5730 LPRINT "DYNAMIC MOMENTS IN NEWTON METERS"
5740 LPRINT "--------------------------------"
5750 LPRINT
5760 LPRINT "FRAME     M1         M2         M3 "
5770 LPRINT "-----  ---------  ---------  --------- "
5780 FOR J = 1 TO TNF
5790         LPRINT USING "#####"; J;
5800     FOR I = 1 TO 3
5810         LPRINT USING "######.####"; DYNMOM(I, J);
5820 NEXT I
5830 LPRINT
5840 NEXT J
5845 IF Z=2 GOTO 6610
5847 LPRINT CHR$(12)
5850 GOTO 4520
5860 REM ***** PRINT TO SCREEN *****
5870 CLS
5880 PRINT "STATIC REACTIVE FORCES IN NEWTONS"
5890 PRINT "---------------------------------"
5900 PRINT A$
5904 PRINT "FRAME     R1X        R2X        R3X        R1Y        R2Y
R3Y"
5906 PRINT "-----  ---------  ---------  ---------  ---------  -------
--  ---------"
5908 PRINT "  ALL";
5910 FOR I = 1 TO 3
5915     PRINT "     0.0000";
5920 NEXT I
5925 FOR I = 1 TO 3
5930     PRINT USING "######.####"; STRF(I);
5940 NEXT I
5950 PRINT A$: PRINT A$: PRINT A$
5960 PRINT "STATIC MOMENTS IN NEWTON METERS"
5970 PRINT "-------------------------------"
5980 PRINT A$
```

```
5990 PRINT "FRAME     M1         M2         M3 "
6000 PRINT "-----  ---------  ---------  --------- "
6010 FOR J = 1 TO TNF
6020         PRINT USING "#####"; J;
6030     FOR I = 1 TO 3
6040         PRINT USING "######.####"; STMOM(I, J);
6050 NEXT I
6060 PRINT A$
6070 NEXT J
6080 PRINT A$: PRINT A$
6090 PRINT "DYNAMIC REACTIVE FORCES IN NEWTONS"
6100 PRINT "----------------------------------"
6110 PRINT A$
6120 PRINT "FRAME     R1X        R2X        R3X        R1Y        R2Y
R3Y"
6130 PRINT "-----  ---------  ---------  ---------  ---------  -------
--  ---------"
6140 FOR J = 1 TO TNF
6150         PRINT USING "#####"; J;
6160     FOR I = 1 TO 3
6170         PRINT USING "######.####"; HRF(I, J);
6180 NEXT I
6290     FOR I = 1 TO 3
6300         PRINT USING "######.####"; VRF(I, J);
6310 NEXT I
6320 PRINT A$
6330 NEXT J
6340 PRINT A$: PRINT A$
6350 PRINT "DYNAMIC MOMENTS IN NEWTON METERS"
6360 PRINT "--------------------------------"
6370 PRINT A$
6380 PRINT "FRAME     M1         M2         M3 "
6390 PRINT "-----  ---------  ---------  --------- "
6400 FOR J = 1 TO TNF
6410         PRINT USING "#####"; J;
6420     FOR I = 1 TO 3
6430         PRINT USING "######.####"; DYNMOM(I, J);
6440 NEXT I
6450 PRINT A$
```

```
6460 NEXT J
6470 PRINT : INPUT "HIT RETURN TO CONTINUE", I$
6475 IF Z=1 GOTO 6610
6480 GOTO 4520
6485 REM *******EXIT TO DOS **************
6490 PRINT : INPUT "ARE YOU SURE (Y/N)"; ANS$
6500 IF ANS$ <> "Y" AND ANS$ <> "y" THEN GOTO 190
6510 SYSTEM
6520 REM ******** CALCULATE ENERGIES OF THE CURRENT DATA SET
************
6530 CLS
6540 LOCATE 2, 20: PRINT "*************** ENERGY CALCULATIONS
***************"
6550 LOCATE 4, 25: PRINT "1 - CALCULATE ENERGIES FOR CURRENT DATA SET"
6560 LOCATE 6, 25: PRINT "2 - RETURN TO MAIN MENU"
6570 LOCATE 8, 20: PRINT
"****************************************************"
6580 PRINT : INPUT "CHOICE"; CHOICE
6590 IF CHOICE <> 1 AND CHOICE <> 2 THEN GOTO 4010
6600 ON CHOICE GOTO 6610, 190
6610 G = 9.810001
6620 REM *******  POTENTIAL ENERGY CALCULATIONS *******
6660 FOR I = 1 TO 4
6670     FOR J = 1 TO TNF
6680      PE(I, J) = WPCT(I) * WEIGHT * G * (Y(I,J) - (SIN(THETA(I,
J)) * LS(I) * JCM(I)) / GS) * GS
6690     NEXT J
6700 NEXT I
6710 REM **** HORIZONTAL AND VERTICAL KINETIC ENERGIES ****
6760 FOR I = 1 TO 4
6770     FOR J = 1 TO TNF
6780         HKE(I, J) = .5 * WEIGHT * WPCT(I) * HVCM(I, J) ^ 2
6790         VKE(I, J) = .5 * WEIGHT * WPCT(I) * VVCM(I, J) ^ 2
6800     NEXT J
6810 NEXT I
6820 REM **** TOTAL KINETIC ENERGY ****
6830 FOR I = 1 TO 4
6840     FOR J = 1 TO TNF
6850         TKE(I, J) = SQR(HKE(I, J) ^ 2 + VKE(I, J) ^ 2)
```

```
6860     NEXT J
6870 NEXT I
6880 REM **** ROTATIONAL ENERGY ******
6890 FOR I = 1 TO 4
6900     FOR J = 1 TO TNF
6910         RE(I, J) = .5 * OMEGA(I, J) ^ 2 * WEIGHT * WPCT(I) *
((LS(I) * RG(I))^2)
6920     NEXT J
6930 NEXT I
6940 REM **** TOTAL ENERGY FOR EACH SEGMENT ****
6950 FOR I = 1 TO 4
6960     FOR J = 1 TO TNF
6970         TE(I, J) = PE(I, J) + TKE(I, J) + RE(I, J)
6980     NEXT J
6990 NEXT I
7000 REM ***** TOTAL BODY ENERGY *****
7010 FOR J = 1 TO TNF
7020 FOR I = 1 TO 4
7030         TBE(J) = TE(I, J) + TBE(J)
7040     NEXT I
7050 NEXT J
7055 IF Z=1 GOTO 7170
7056 IF Z=2 GOTO 8870
7057 IF Z=3 GOTO 8050
7060 REM ******** PRINT CURRENT ENERGIES **************
7070 CLS
7080 LOCATE 2, 20: PRINT "*********** PRINT ENERGIES MENU
**************"
7090 LOCATE 4, 25: PRINT "1 - PRINT TO FILE"
7100 LOCATE 6, 25: PRINT "2 - PRINT TO PRINTER"
7110 LOCATE 8, 25: PRINT "3 - PRINT TO SCREEN"
7120 LOCATE 10, 25: PRINT "4 - RETURN TO MAIN MENU"
7130 LOCATE 12, 20: PRINT
"*****************************************"
7140 PRINT : INPUT "CHOICE"; CHOICE
7150 IF CHOICE <> 1 AND CHOICE <> 2 AND CHOICE <> 3 AND CHOICE <> 4
THEN GOTO 7070
7160 ON CHOICE GOTO 8020, 8870, 7170, 190
7170 REM ***** PRINT TO SCREEN *****
```

```
7180 CLS : PRINT : PRINT
7190 PRINT "POTENTIAL ENERGY IN JOULES"
7200 PRINT "--------------------------": PRINT
7210 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
7220 PRINT "-----  ---------  ---------  ---------  ---------"
7230 FOR J = 1 TO TNF
7240         PRINT USING "#####"; J;
7250     FOR I = 1 TO 4
7260         PRINT USING "######.####"; PE(I, J);
7270     NEXT I
7280     PRINT
7290 NEXT J
7300 PRINT : PRINT :
7310 PRINT "HORIZONTAL KINETIC ENERGY IN JOULES"
7320 PRINT "-----------------------------------": PRINT
7330 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
7340 PRINT "-----  ---------  ---------  ---------  ---------"
7350 FOR J = 1 TO TNF
7360         PRINT USING "#####"; J;
7370     FOR I = 1 TO 4
7380         PRINT USING "######.####"; HKE(I, J);
7390    NEXT I
7400    PRINT
7410 NEXT J
7420 PRINT : PRINT :
7430 PRINT "VERTICAL KINETIC ENERGY IN JOULES"
7440 PRINT "---------------------------------": PRINT
7450 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
7460 PRINT "-----  ---------  ---------  ---------  ---------"
7470 FOR J = 1 TO TNF
7480         PRINT USING "#####"; J;
7490     FOR I = 1 TO 4
7500        PRINT USING "######.####"; VKE(I, J);
7510    NEXT I
7520     PRINT
7530 NEXT J
7540 PRINT : PRINT :
7550 PRINT "TOTAL KINETIC ENERGY IN JOULES"
7560 PRINT "------------------------------": PRINT
```

```
7570 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
7580 PRINT "-----  ---------  ---------  ---------  ---------"
7590 FOR J = 1 TO TNF
7600         PRINT USING "#####"; J;
7610     FOR I = 1 TO 4
7620         PRINT USING "######.####"; TKE(I, J);
7630     NEXT I
7640     PRINT
7650 NEXT J
7660 PRINT : PRINT :
7670 PRINT "ROTATIONAL ENERGY IN JOULES"
7680 PRINT "---------------------------": PRINT
7690 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
7700 PRINT "-----  ---------  ---------  ---------  ---------"
7710 FOR J = 1 TO TNF
7720         PRINT USING "#####"; J;
7730     FOR I = 1 TO 4
7740         PRINT USING "######.####"; RE(I, J);
7750     NEXT I
7760     PRINT
7770 NEXT J
7780 PRINT : PRINT
7790 PRINT "TOTAL ENERGY PER SEGMENT IN JOULES"
7800 PRINT "----------------------------------": PRINT
7810 PRINT "FRAME    FOOT       SHANK      THIGH      H.A.T.
BODY"
7820 PRINT "-----  ---------  ---------  ---------  ---------  -------
--"
7830 FOR J = 1 TO TNF
7840         PRINT USING "#####"; J;
7850     FOR I = 1 TO 4
7860         PRINT USING "######.####"; TE(I, J);
7870     NEXT I
7875       PRINT USING "######.####"; TBE(J);
7880     PRINT
7890 NEXT J
7990 PRINT : PRINT
8000 INPUT "HIT RETURN TO CONTINUE", L$
8005 IF Z=1 GOTO 190
```

```
8010 GOTO 7070
8020 REM ***** PRINT TO FILE *************
8030 PRINT : INPUT "NAME OF FILE TO OUTPUT TO"; FILE$
8040 OPEN FILE$ FOR OUTPUT AS #1
8050 PRINT #1, "POTENTIAL ENERGY IN JOULES"
8060 PRINT #1, "--------------------------": PRINT #1, A$
8070 PRINT #1, "FRAME    FOOT      SHANK      THIGH      H.A.T."
8080 PRINT #1, "-----  ---------  ---------  ---------  ---------"
8090 FOR J = 1 TO TNF
8100         PRINT #1, USING "#####"; J;
8110     FOR I = 1 TO 4
8120         PRINT #1, USING "######.####"; PE(I, J);
8130     NEXT I
8140     PRINT #1, A$
8150 NEXT J
8160 PRINT #1, A$: PRINT #1, A$
8170 PRINT #1, "HORIZONTAL KINETIC ENERGY IN JOULES"
8180 PRINT #1, "-----------------------------------": PRINT #1, A$
8190 PRINT #1, "FRAME    FOOT      SHANK      THIGH      H.A.T."
8200 PRINT #1, "-----  ---------  ---------  ---------  ---------"
8210 FOR J = 1 TO TNF
8220         PRINT #1, USING "#####"; J;
8230     FOR I = 1 TO 4
8240         PRINT #1, USING "######.####"; HKE(I, J);
8250    NEXT I
8260    PRINT #1, A$
8270 NEXT J
8280 PRINT #1, A$: PRINT #1, A$
8290 PRINT #1, "VERTICAL KINETIC ENERGY IN JOULES"
8300 PRINT #1, "---------------------------------": PRINT #1, A$
8310 PRINT #1, "FRAME    FOOT      SHANK      THIGH      H.A.T."
8320 PRINT #1, "-----  ---------  ---------  ---------  ---------"
8330 FOR J = 1 TO TNF
8340         PRINT #1, USING "#####"; J;
8350     FOR I = 1 TO 4
8360        PRINT #1, USING "######.####"; VKE(I, J);
8370    NEXT I
8380     PRINT #1, A$
8390 NEXT J
```

```
8400 PRINT #1, A$: PRINT #1, A$
8410 PRINT #1, "TOTAL KINETIC ENERGY IN JOULES"
8420 PRINT #1, "------------------------------": PRINT #1, A$
8430 PRINT #1, "FRAME    FOOT       SHANK      THIGH      H.A.T."
8440 PRINT #1, "-----  ---------  ---------  ---------  ---------"
8450 FOR J = 1 TO TNF
8460         PRINT #1, USING "#####"; J;
8470     FOR I = 1 TO 4
8480         PRINT #1, USING "######.####"; TKE(I, J);
8490     NEXT I
8500     PRINT #1, A$
8510 NEXT J
8520 PRINT #1, A$: PRINT #1, A$
8530 PRINT #1, "ROTATIONAL ENERGY IN JOULES"
8540 PRINT #1, "---------------------------": PRINT #1, A$
8550 PRINT #1, "FRAME    FOOT       SHANK      THIGH      H.A.T."
8560 PRINT #1, "-----  ---------  ---------  ---------  ---------"
8570 FOR J = 1 TO TNF
8580         PRINT #1, USING "#####"; J;
8590     FOR I = 1 TO 4
8600         PRINT #1, USING "######.####"; RE(I, J);
8610     NEXT I
8620     PRINT #1, A$
8630 NEXT J
8640 PRINT #1, A$: PRINT #1, A$
8650 PRINT #1, "TOTAL ENERGY PER SEGMENT IN JOULES"
8660 PRINT #1, "----------------------------------": PRINT #1, A$
8670 PRINT #1, "FRAME    FOOT       SHANK      THIGH      H.A.T.
BODY"
8680 PRINT #1, "-----  ---------  ---------  ---------  ---------  ---
------"
8690 FOR J = 1 TO TNF
8700         PRINT #1, USING "#####"; J;
8710     FOR I = 1 TO 4
8720         PRINT #1, USING "######.####"; TE(I, J);
8730     NEXT I
8735       PRINT #1, USING "######.####"; TBE(J);
8740     PRINT #1, A$
8750 NEXT J
```

```
8850 CLOSE 1
8855 IF Z = 3 GOTO 190
8860 GOTO 7070
8870 IF Z = 2 THEN LPRINT CHR$(12)
8875 REM ***** PRINT TO LPRINTER *****
8880 LPRINT : LPRINT
8890 LPRINT "POTENTIAL ENERGY IN JOULES"
8900 LPRINT "--------------------------": LPRINT
8910 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
8920 LPRINT "-----  ---------  ---------  ---------  ---------"
8930  FOR J = 1 TO TNF
8940          LPRINT USING "#####"; J;
8950     FOR I = 1 TO 4
8960          LPRINT USING "######.####"; PE(I, J);
8970      NEXT I
8980      LPRINT
8990  NEXT J
9000  LPRINT : LPRINT :
9010  LPRINT "HORIZONTAL KINETIC ENERGY IN JOULES"
9020  LPRINT "-----------------------------------": LPRINT
9040 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
9050 LPRINT "-----  ---------  ---------  ---------  ---------"
9060  FOR J = 1 TO TNF
9070          LPRINT USING "#####"; J;
9080     FOR I = 1 TO 4
9090          LPRINT USING "######.####"; HKE(I, J);
9100     NEXT I
9110     LPRINT
9120  NEXT J
9130  LPRINT : LPRINT :
9135 LPRINT CHR$(12)
9140  LPRINT "VERTICAL KINETIC ENERGY IN JOULES"
9150  LPRINT "---------------------------------": LPRINT
9160 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
9170 LPRINT "-----  ---------  ---------  ---------  ---------"
9180  FOR J = 1 TO TNF
9190          LPRINT USING "#####"; J;
9200     FOR I = 1 TO 4
9210          LPRINT USING "######.####"; VKE(I, J);
```

```
9220        NEXT I
9230        LPRINT
9240    NEXT J
9250    LPRINT : LPRINT :
9260    LPRINT "TOTAL KINETIC ENERGY IN JOULES"
9270    LPRINT "------------------------------": LPRINT
9280 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
9290 LPRINT "-----  ---------  ---------  ---------  ---------"
9300    FOR J = 1 TO TNF
9310            LPRINT USING "#####"; J;
9320       FOR I = 1 TO 4
9330            LPRINT USING "######.####"; TKE(I, J);
9340        NEXT I
9350        LPRINT
9360    NEXT J
9370    LPRINT : LPRINT :
9375 LPRINT CHR$(12)
9380    LPRINT "ROTATIONAL ENERGY IN JOULES"
9390    LPRINT "---------------------------": LPRINT
9400 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T."
9410 LPRINT "-----  ---------  ---------  ---------  ---------"
9420    FOR J = 1 TO TNF
9430            LPRINT USING "#####"; J;
9440       FOR I = 1 TO 4
9450            LPRINT USING "######.####"; RE(I, J);
9460        NEXT I
9470        LPRINT
9480    NEXT J
9490 LPRINT : LPRINT
9500 LPRINT "TOTAL ENERGY PER SEGMENT IN JOULES"
9510 LPRINT "----------------------------------": LPRINT
9520 LPRINT "FRAME    FOOT       SHANK      THIGH      H.A.T.
BODY"
9530 LPRINT "-----  ---------  ---------  ---------  ---------  ------
---"
9540 FOR J = 1 TO TNF
9550           LPRINT USING "#####"; J;
9560       FOR I = 1 TO 4
9570           LPRINT USING "######.####"; TE(I, J);
```

```
9580     NEXT I
9585        LPRINT USING "######.####"; TBE(J);
9590     LPRINT
9600 NEXT J
9610 LPRINT CHR$(12)
9695 IF Z=2 GOTO 190
9700 GOTO 7070
```

14 APPENDIX E: ELASTICITY OF CALF MUSCLE

This BASIC program creates files for the angle of the ankle to be used in calculating the elasticity of the calf muscle.

```
10 REM ****************************************
20 REM *                                      *
30 REM *    THIS PROGRAM MAKES FILES FOR      *
40 REM *    THE ANGLE OF THE ANKLE TO BE      *
50 REM *    USED IN ELASTICITY PROGRAM        *
60 REM *                                      *
70 REM ****************************************
80 CLS
90 DIM PHI(25)
100 INPUT "ENTER SUBJECT NUMBER ";S$
110 CM$ = "B:CMG"+S$+".PRN"
120 INPUT "ENTER NUMBER OF FRAMES ";TNF
130 FOR N=1 TO TNF
140 PRINT "FRAME ";N
150 INPUT "ENTER VALUE FOR ANGLE OF ANKLE ";PHI(N)
160 NEXT N
170 CLS:PRINT "Writing to disk":PRINT"":PRINT"":PRINT CM$
180 OPEN "O", #1, CM$
190 FOR N=1 TO TNF
200 WRITE #1,PHI(N)
210 NEXT N
220 CLOSE #1
230 END
```

The following BASIC program calculates the different components of the calf muscles elasticity. The inputs to the program are the raw EMGs from the gastrocnemius and soleus muscle, combined with the angle of the ankle.

```
10 REM  *************************************************
20 REM  *                                               *
30 REM  *    THIS PROGRAM WILL CALCULATE THE            *
40 REM  *    ELASTICITY OF THE CALF MUSCLE              *
50 REM  *                                               *
60 REM  *************************************************
70 DIM X(2100),Y(2100),B(850),C(850),S(850),U(850)
80 INPUT "ENTER FILENUMBER ";S$
90 SS$ = "A:FILE"+S$+".PRN"
100 CLS:PRINT "Reading EMG data from disk": PRINT"":PRINT"":PRINT SS$
110 OPEN "I", #1, SS$
120 Y=0
130 FOR N=1 TO 10
140 INPUT #1,A
150 NEXT N
160 FOR N=1 TO 2000
170 INPUT #1,A,B,C,D
180 X(A)=B/2048
190 Y(A)=C/2048
200 NEXT N
210 CLOSE #1
220 REM start of calculation
230 INPUT "ENTER STARTING POINT ";LN
240 PRINT""
250 INPUT "ENTER RUNNING CYCLE TIME [MSEC] ";EP
260 PRINT""
270 INPUT "ENTER AMPLIFICATION FOR GASTROCNEMIUS (GG) ";GG
280 PRINT""
290 INPUT "ENTER AMPLIFICATION FOR SOLEUS (GS) ";GS$
300 PRINT""
310 FOR N=LN TO EP+LN
320 A=N-LN+1
330 B(A)=X(N)
340 C(A)=Y(N)
350 NEXT N
```

```
360 GOSUB 1380
370 FOR N=1 TO EP+1
380 REM amplifying
390 X(N)=B(N)*GG*5000
400 Y(N)=C(N)*GS*5000
410 REM rectifying
420 X(N)=SQR(X(N)^2)
430 Y(N)=SQR(X(N)^2)
440 REM summation and convertion to Nm
450 S(N)=(X(N)+Y(N))*.1
460 NEXT N
470 GOSUB 1510
480 REM smoothing by filter
490 T=.02
500 DT=.01
510 Y=0
520 AL=EXP(-DT/T)
530 FOR N=1 TO EP+1
540 Y=Y*AL + (1-AL)*S(N)
550 U(N)=Y
560 NEXT N
570 REM active state convertion
580 DIM MO(850),W(850),MV(850)
590 T=1
600 DT=0
610 IF U(T+1)<U(T) GOTO 670
620 MO(T)=U(T)
630 T=T+1
640 IF T=EP GOTO 660
650 GOTO 610
660 GOTO 790
670 W=U(T)
680 IF DT<30 GOTO 700
690 GOTO 750
700 MO(T)=W
710 T=T+1
720 DT=DT+1
730 IF T=EP GOTO 660
740 GOTO 680
```

```
750 MO(T)=W*EXP(-(DT-30)/60)
760 IF U(T)<MO(T) GOTO 710
770 DT=0
780 GOTO 620
790 REM creating file with only TNF data points
800 L=0
810 FOR N=1 TO EP+1 STEP 40
820 L=L+1
830 MV(L)=MO(N)
840 NEXT N
850 TNF=L
860 GOSUB 1640
870 REM calculation of elasticity
880 INPUT "WEIGHT OF SUBJECT (Kg) ";M
890 PRINT""
900 INPUT "HORIZONTAL DISTANCE BETWEEN TOE AND ANKLE (M) ";D
910 PRINT""
920 DIM
F(30),MC(30),MP(30),M(30),QZ(30),Q(30),QE(30),QC(30),DQ(30),DQC(30)
930 G=9.810001
940 PI=3.141592654#
950 F=3.62
960 Q1=130: Q2=90: BE=20: BN=1.2: NU=.12: MS=1: MPO=3.33: QP=8: CN=.05
970 MR=M*G*D
980 K=(1/((2*PI*F)^2*M*(D^2)) - 1/(BE*MR))^-1
990 FQC=0
1000 DQC(1)=0
1010 QZ=Q2
1020 CM$= "B:CMG"+S$+".PRN"
1030 CLS:PRINT "Reading CMG data from disk": PRINT"":PRINT"":PRINT CM$
1040 OPEN "I",#1,CM$
1050 FOR N=1 TO TNF
1060 INPUT #1,A
1070 Q(N)=A
1080 NEXT N
1090 CLOSE #1
1100 FOR N=1 TO TNF
1110 GOSUB 1300
1120 IF QC(N)>=Q1 THEN FQC=0:GOTO 1200
```

```
1130 IF QC(N)<=Q2 THEN FQC=1:GOSUB 1300:GOTO 1150
1140 IF QC(N)>Q2 AND QC<Q1 THEN FQC=(Q1-QZ)/(Q1-Q2):GOSUB 1300:GOTO
1170
1150 IF QC(N)>Q2 AND QC<Q1 THEN FQC=(Q1-QC)/(Q1-Q2):GOSUB 1300:GOTO
1200
1160 GOTO 1200
1170 IF QC(N)>QZ*.9999 AND QC(N)<1.001*QZ GOTO 1200
1180 IF FQC<0 GOTO 1200
1190 QZ=QZ+.01
1200 GOTO 1210
1210 IF N=1 THEN GOTO 1270
1220 DQ(N)=((Q(N)-Q(N-1))*PI/180)/.04
1230 DQC(N)=((Q(N)-Q(N-1))*PI/180)/.04
1240 GOSUB 1300
1250 MP(N)=MPO*EXP(-(Q(N)-90)/QP)
1260 M(N)=MC(N)+MP(N)
1270 NEXT N
1280 GOSUB 1820
1290 END
1300 REM SUBROUTINE
1310 MC(N)=MO(N)*(FQC-NU*DQC(N)/BN)/(1+DQC(N)/BN)
1320 IF MC(N)>(1+CN)*MO(N)*FQC THEN LET MC(N)=(1+CN)*MO(N)*FQC
1330 IF MC(N)<0 THEN LET MC(N)=0
1340 IF DQC(N) > (BN/NU)*FQC THEN LET MC(N)=0
1350 QE(N)=((1/BE)*LOG((MC(N)+MS)/MS)+MC(N)/K)*180/PI
1360 QC(N)=Q(N)+QE(N)
1370 RETURN
1380 KEY OFF
1390 SCREEN 2
1400 CLS
1410 FOR N=1 TO 600
1420 PSET(N,65)
1430 PSET(N,65-B(N)*50)
1440 PSET(N,135)
1450 PSET(N,135-C(N)*50)
1460 NEXT N
1470 INPUT "HIT RETURN";D$
1480 IF D$="" GOTO 1500
1490 GOTO 1470
```

```
1500 RETURN
1510 KEY OFF
1520 SCREEN 2
1530 CLS
1540 FOR N=1 TO 600
1550 PSET(N,65)
1560 PSET(N,65-X(N)/50)
1570 PSET(N,135)
1580 PSET(N,135-Y(N)/50)
1590 NEXT N
1600 INPUT "HIT RETURN";D$
1610 IF D$="" GOTO 1630
1620 GOTO 1470
1630 RETURN
1640 KEY OFF
1650 SCREEN 2
1660 CLS
1670 FOR N=1 TO 600
1680 PSET(N,45)
1690 PSET(N,45-U(N)/10)
1700 PSET(N,105)
1710 PSET(N,105-MO(N)/10)
1720 PSET(N,165)
1730 NEXT N
1740 FOR N=1 TO 600 STEP 40
1750 PSET(N,165-MO(N)/10)
1760 NEXT N
1770 INPUT "HIT RETURN";D$
1780 IF D$="" GOTO 1800
1790 GOTO 1470
1800 SCREEN 0
1810 RETURN
1820 REM creating a file for LOTUS 1-2-3
1830 EL$ = "B:HILL"+S$+".PRN"
1840 CLS:PRINT "writing to disk": PRINT"":PRINT"":PRINT EL$
1850 OPEN "O", #1, EL$
1860 FOR N=1 TO  TNF
1870 WRITE #1,N,Q(N),QE(N),QC(N),MP(N),MC(N),M(N)
1880 NEXT N
```

```
1890 CLOSE #1
1900 RETURN
```

15 APPENDIX F: FFT-ANALYSIS

This BASIC program reads a data file and creates files with 1024 data points for FFT-analysis on the PDP-11 computer. The program listing is as follows:

```
10 REM *****************************************************
20 REM *                                                   *
30 REM * THIS PROGRAM CREATES FILES WITH 1024 DATA POINTS  *
40 REM * FOR FFT-ANALYSIS ON THE PDP-11 COMPUTER           *
50 REM *                                                   *
60 REM *****************************************************
70 DIM X(2100),Y(2100)
80 INPUT "ENTER FILENUMBER ";S$
90 SS$ = "A:FILE"+S$+".PRN"
100 CLS:PRINT "Reading from disk": PRINT"":PRINT"":PRINT SS$
110 OPEN "I", #1, SS$
120 FOR N=1 TO 10
130 INPUT #1,A
140 NEXT N
150 FOR N=1 TO 2000
160 INPUT #1,A,B,C,D
170 GOSUB 270
180 GOSUB 310
190 NEXT N
200 CLOSE #1
210 CLS:INPUT "SAVE AS TEXTFILE";B$
220 IF B$="Y" GOTO 250
230 IF B$="N" GOTO 260
240 GOTO 210
250 GOSUB 350
260 END
```

```
270 REM convertion to voltage
280 B=B/2048
290 C=C/2048
300 RETURN
310 REM storage
320 X(A)=B
330 Y(A)=C
340 RETURN
350 REM creation of file for FFT-analysis
360 INPUT "ENTER STARTING POINT ";SP
370 INPUT "ENTER RUNNING CYCLE TIME [MSEC.] ";EP
380 FF$= "A:GAST"+S$+".PRN"
390 CLS:PRINT "writing to disk":PRINT"":PRINT"":PRINT FF$
400 OPEN "o", #2, FF$
410 FOR N=SP TO EP+SP
420 B=X(N)
430 WRITE #2,B
440 NEXT N
450 FOR N=EP+1+SP TO 1023+SP
460 B=0
470 WRITE #2,B
480 NEXT N
490 CLOSE #2
500 BB$= "A:SOLE"+S$+".PRN"
510 PRINT"":PRINT"":PRINT BB$
520 OPEN "o", #2, BB$
530 FOR N=SP TO EP+SP
540 B=Y(N)
550 WRITE #2,B
560 NEXT N
570 FOR N=EP+1+SP TO 1023+SP
580 B=0
590 WRITE #2,B
600 NEXT N
610 CLOSE #2
620 RETURN
```

This FORTRAN program does FFT-analysis on the PDP-11 computer. The program reads a data file and calls the subroutines FFT and COSQT for the actual computation.

```
      PROGRAM DATA


      INTEGER N,LNX
      REAL DR(1024),DI(1024),XMAG(1024)
      DIMENSION TABLE(1024)

      TYPE *,' HOW MANY SAMPLE POINTS WOULD YOU LIKE TO
      PROCESS?'
      TYPE *,' (POWER OF 2)'
      READ(5,*) N
      LNX = INT((ALOG(FLOAT(N))) / (ALOG(2.0)))

      OPEN(NAME = 'EMGDAT.D1',TYPE='OLD',UNIT=1)

      DO 5 I = 1 , N
         READ(1,*) DR(I)
            DR(I) = DR(I) * (-1) ** I
         DI(I) = 0.0
5     CONTINUE

      CLOSE(UNIT=1)

      CALL COSQT(LNX,TABLE)
      CALL FFT(DR,DI,TABLE,LNX,LNX,-1)

      OPEN(NAME='EMGREL.DAT',TYPE='NEW',UNIT=2)
      OPEN(NAME='EMGMAG.DAT',TYPE='NEW',UNIT=3)

      DO 6 I = 1 , N

            J = I - (N/2) - 1

         XMAG(I) = SQRT(DR(I)*DR(I) + DI(I)*DI(I))

         XMAG(I) = XMAG(I) / FLOAT(N)
```

```
         DR(I)    = DR(I) / FLOAT(N)

c        DR(I)    = DR(I) * (-1) ** I / FLOAT(N)

         WRITE(2,*) J,DR(I)
         WRITE(3,*) J,XMAG(I)

6     CONTINUE

      CLOSE(UNIT=2)
      CLOSE(UNIT=3)

      END
```

The program listing of the subroutine FFT is as follows:

```
      SUBROUTINE FFT(X,Y,TABLE,M,LL,ISN)
C
C
C     FFT is IN-PLACE DFT computation using SANDE ALGORITHM
C     and MARKEL PRUNING modification.
C
C     X is an array of length 2**M used to hold REAL part of
C          COMPLEX input.
C     Y is an array of length 2**M used to hold IMAGINARY
C          part of COMPLEX input.
C     TABLE is an array of length (N/4)+1, where N=2**M.
C          TABLE contains QUARTER-LENGTH cosine table.
C     M = integer. Size of FFT to be performed is given by
C          N=2**M.
C
C     (Note that the bit reverse table is set for a maximum
C     of N=2**12=4096)
C
C     LL = integer. There are 2**LL actual data points.
C     ISN is either -1 or 1. Set ISN to -1 for FORWARD DFT
C     and set ISN to 1 for INVERSE DFT.
C
```

```
C
      DIMENSION X(1096),Y(1096),TABLE(1025),L(12)
      EQUIVALENCE (L12,L(1)),(L11,L(2)),(L10,L(3)),
      $               (L9,L(4)),(L8,L(5)),(L7,L(6)),
      $               (L6,L(7)),(L5,L(8)),(L4,L(9)),
      $               (L3,L(10)),(L2,L(11)),(L1,L(12))


      N=2**M
      ND4=N/4
      ND4P1=N/4 + 1
      ND4P2=ND4P1 + 1
      ND2P2=ND4 + ND4P2
      LLL=2**LL

      DO 8 LO=1,M
         LMX=2**(M-LO)
         LMM=LMX
         LIX=2*LMX
         ISCL=N/LIX

C     Test for PRUNING

         IF(LO-M+LL) 1,2,2
1        LMM=LLL
2     DO 8 LM=1,LMM
         IARG=(LM-1)*ISCL+1
         IF(IARG.LE.ND4P1) GOTO 4
         K1=ND2P2-IARG
         C=-TABLE(K1)
         K3=IARG-ND4
         S=ISN*TABLE(K3)
         GOTO 6
4        C=TABLE(IARG)
         K2=ND4P2-IARG
         S=ISN*TABLE(K2)
6        CONTINUE
      DO 8 LI=LIX,N,LIX
         J1=LI-LIX+LM
```

```
         J2=J1+LMX
         T1=X(J1)-X(J2)
         T2=Y(J1)-Y(J2)
         X(J1)=X(J1)+X(J2)
         Y(J1)=Y(J1)+Y(J2)
         X(J2)=C*T1-S*T2
         Y(J2)=C*T2+S*T1
8     CONTINUE

C     Perform BIT REVERSAL

      DO 40 J=1,12
         L(J)=1
         IF(J-M) 31,31,40
31       L(J)=2**(M+1-J)
40    CONTINUE

      JI=1

      DO 60 J1=1,L1
      DO 60 J2=J1,L2,L1
      DO 60 J3=J2,L3,L2
      DO 60 J4=J3,L4,L3
      DO 60 J5=J4,L5,L4
      DO 60 J6=J5,L6,L5
      DO 60 J7=J6,L7,L6
      DO 60 J8=J7,L8,L7
      DO 60 J9=J8,L9,L8
      DO 60 J10=J9,L10,L9
      DO 60 J11=J10,L11,L10
      DO 60 JR=J11,L12,L11
         IF(JI-JR) 51,51,54
51       R=X(JI)
         X(JI)=X(JR)
         X(JR)=R
         FI=Y(JI)
         Y(JI)=Y(JR)
         Y(JR)=FI
54       IF(ISN) 53,53,52
```

```
52        X(JR)=X(JR)/FLOAT(N)
          Y(JR)=Y(JR)/FLOAT(N)
53        JI=JI+1
60    CONTINUE

      RETURN
      END
```

The program listing of the subroutine COSQT is as follows:

```
      SUBROUTINE COSQT(M,TABLE)

C     This subroutine generates QUARTER-LENGTH cosine table.

      DIMENSION TABLE(2)

      N=2**M
      ND4P1=N/4 + 1
      SCL=6.283185307/FLOAT(N)

      DO 10 I=1,ND4P1
         ARG=FLOAT(I-1)*SCL
10    TABLE(I)=COS(ARG)

      RETURN
      END
```

16 APPENDIX G: FIGURES AND TABLES

The following are the figures and tables that were not presented in the Chapter: Results and Discussion.

16.1 Biomechanics

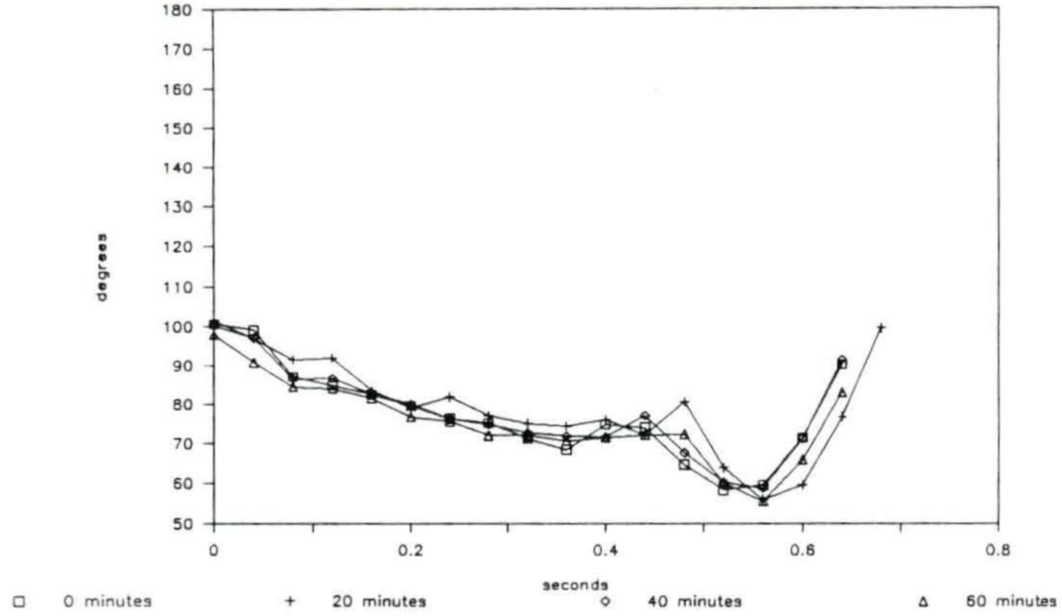

Figure 16.1: Angle of the ankle (subject 2)

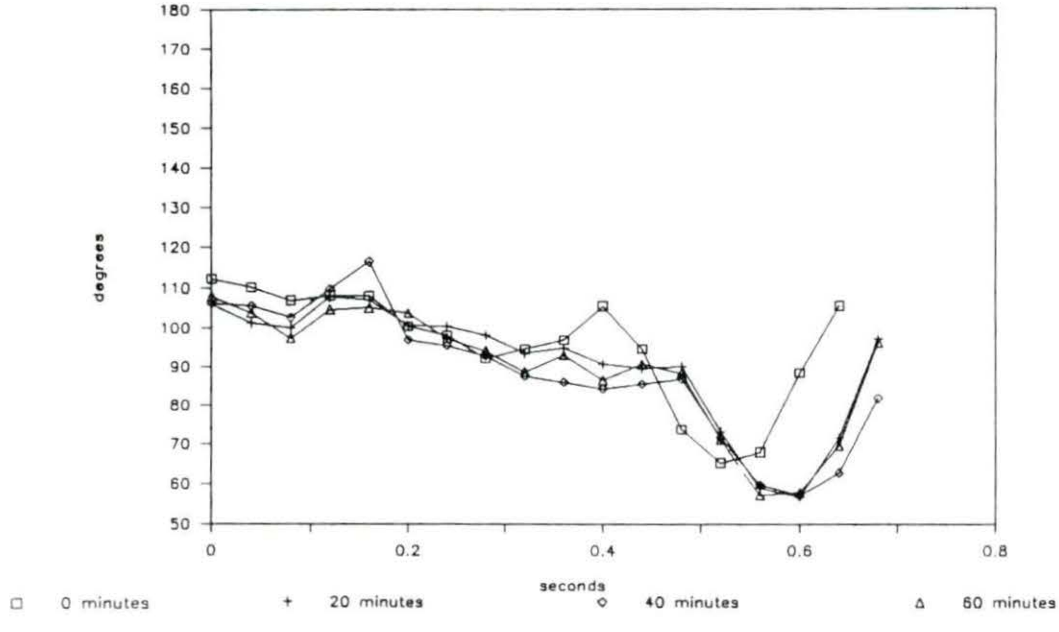

Figure 16.2: Angle of the ankle (subject 3)

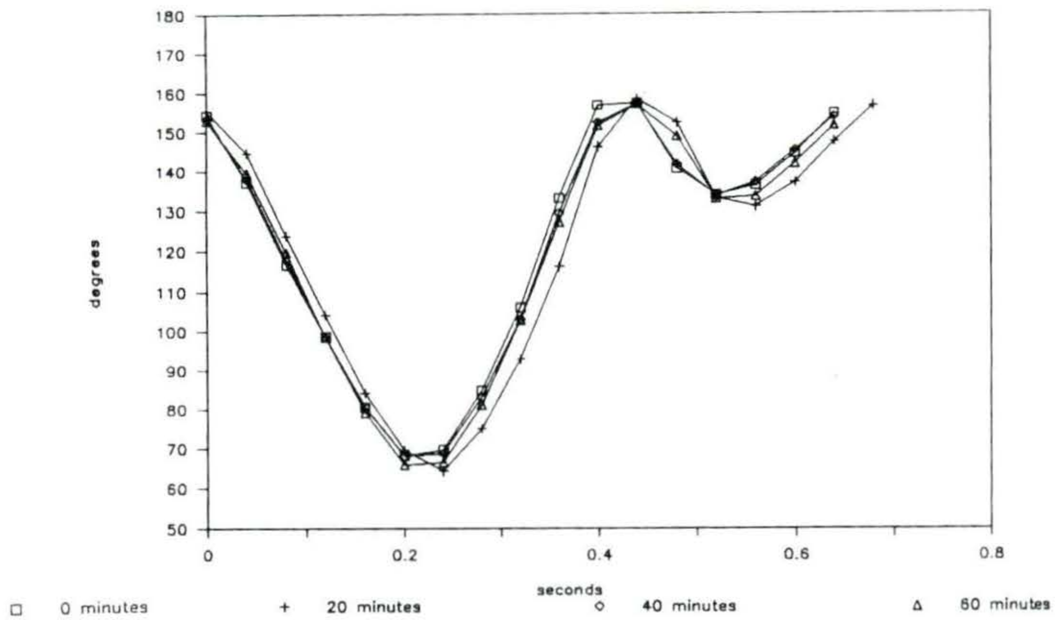

Figure 16.3: Angle of the knee (subject 2)

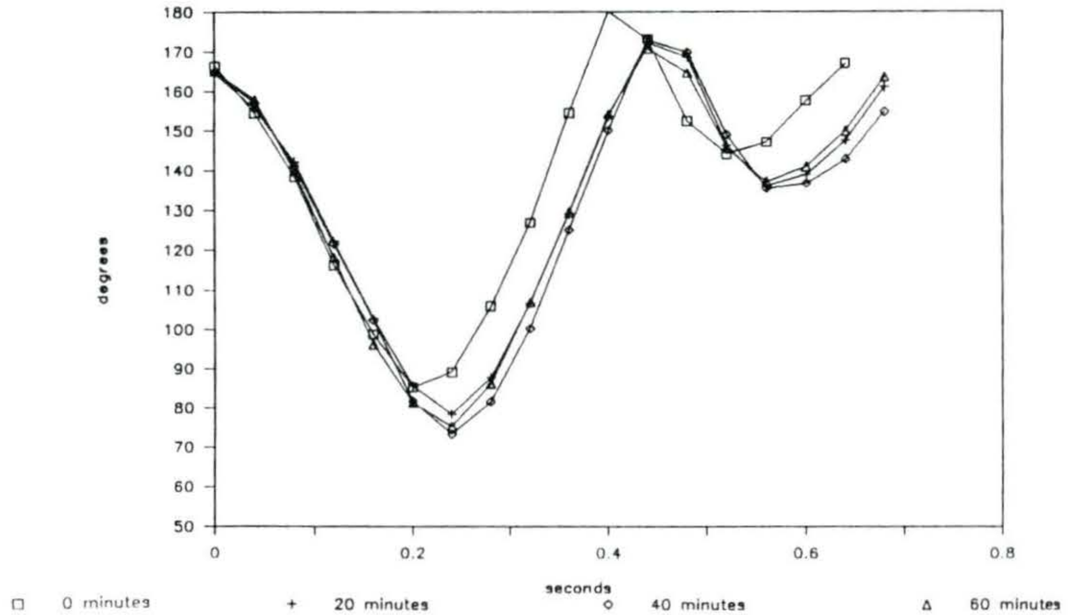

Figure 16.4: Angle of the knee (subject 3)

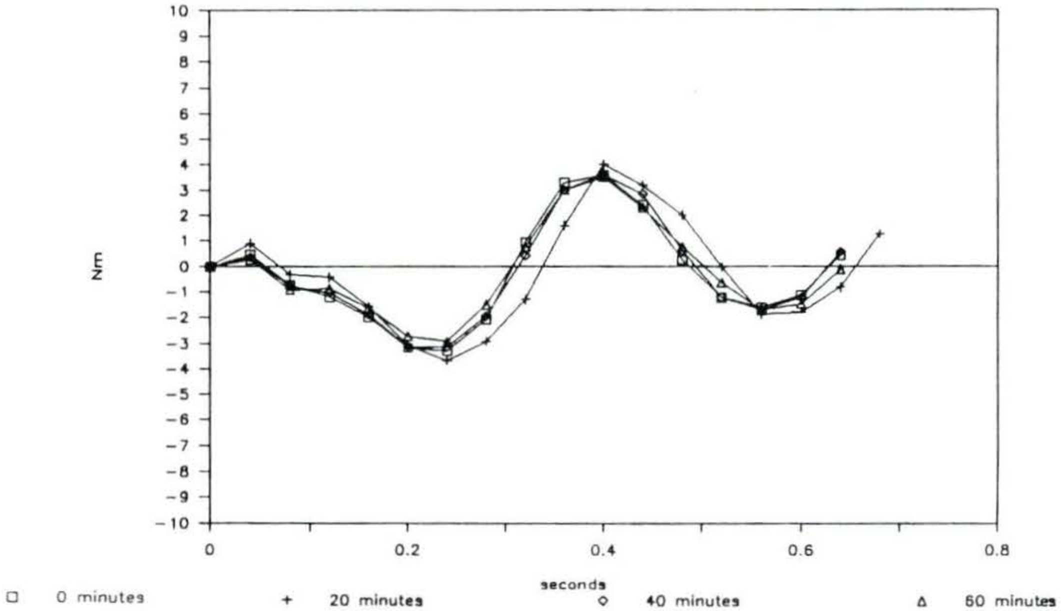

Figure 16.5: Dynamic moment around ankle (subject 2)

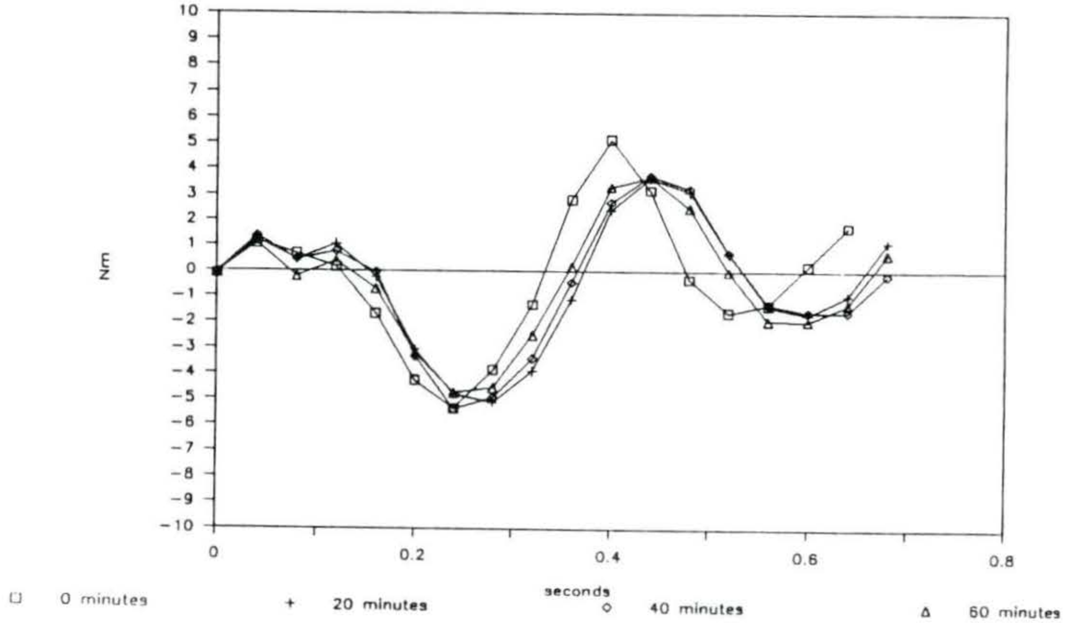

Figure 16.6: Dynamic moment around ankle (subject 3)

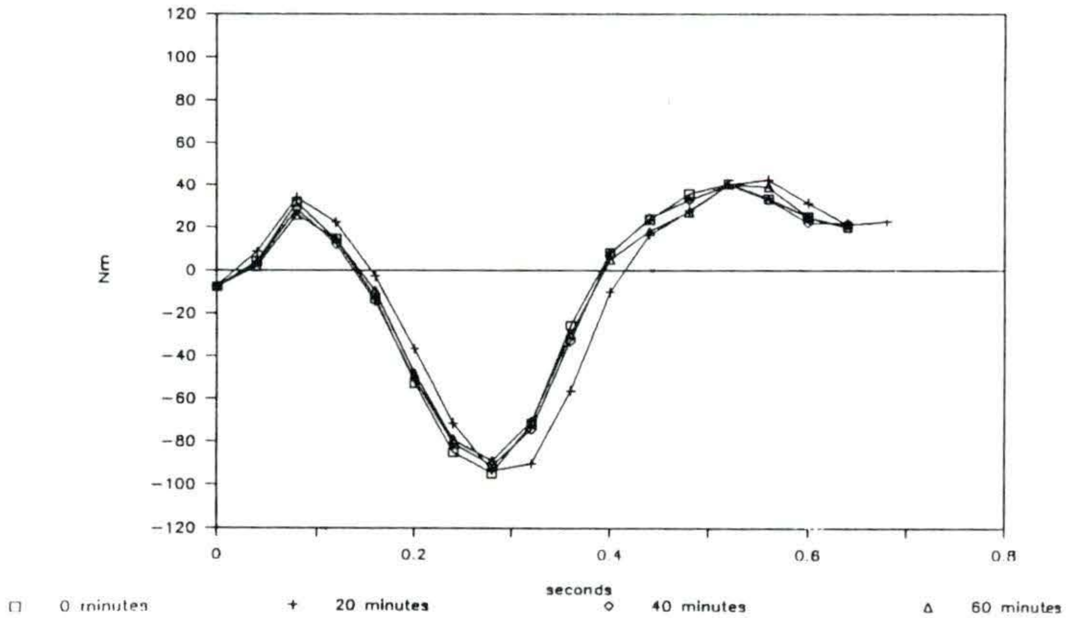

Figure 16.7: Dynamic moment around knee (subject 2)

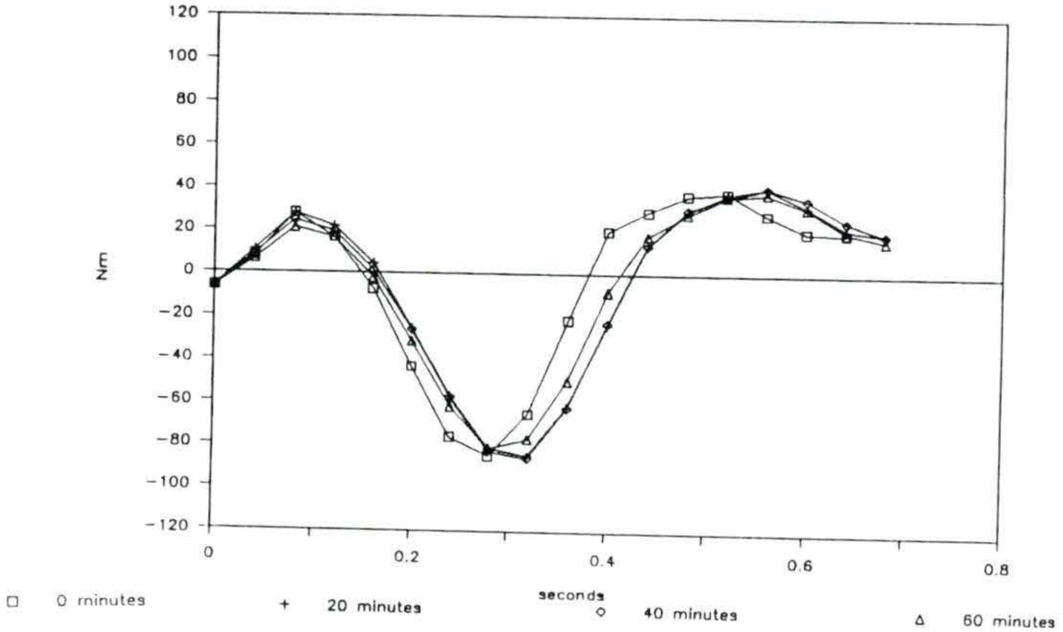

Figure 16.8: Dynamic moment around knee (subject 3)

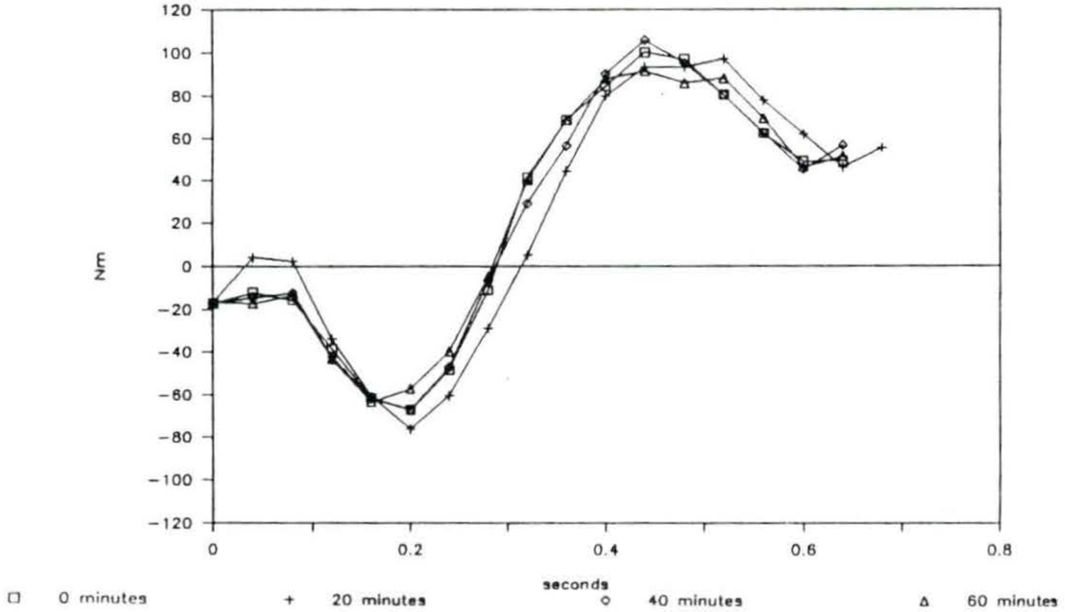

Figure 16.9: Dynamic moment around hip (subject 2)

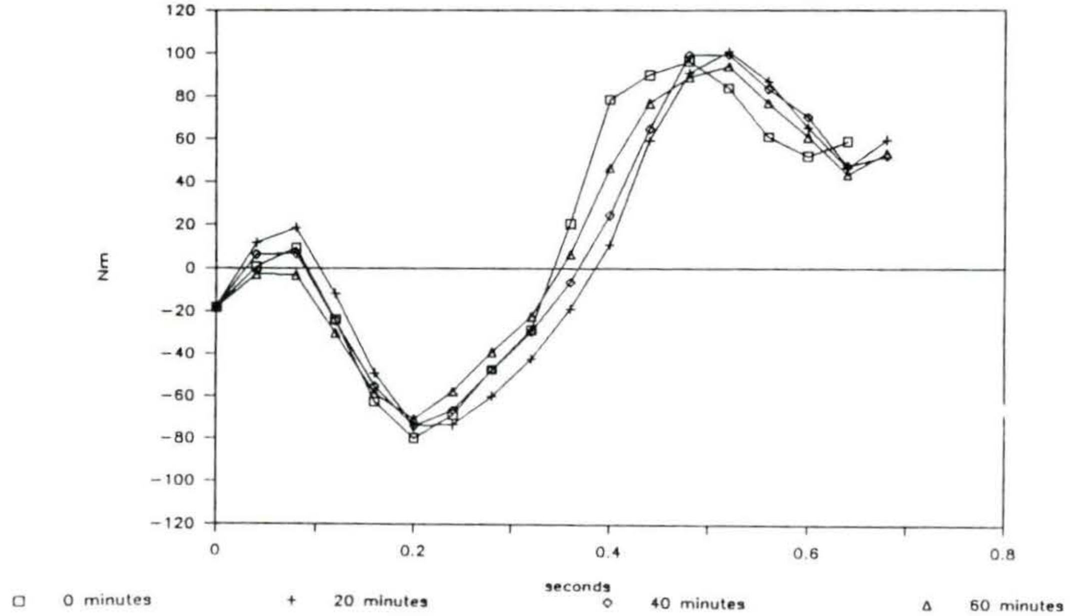

Figure 16.10: Dynamic moment around hip (subject 3)

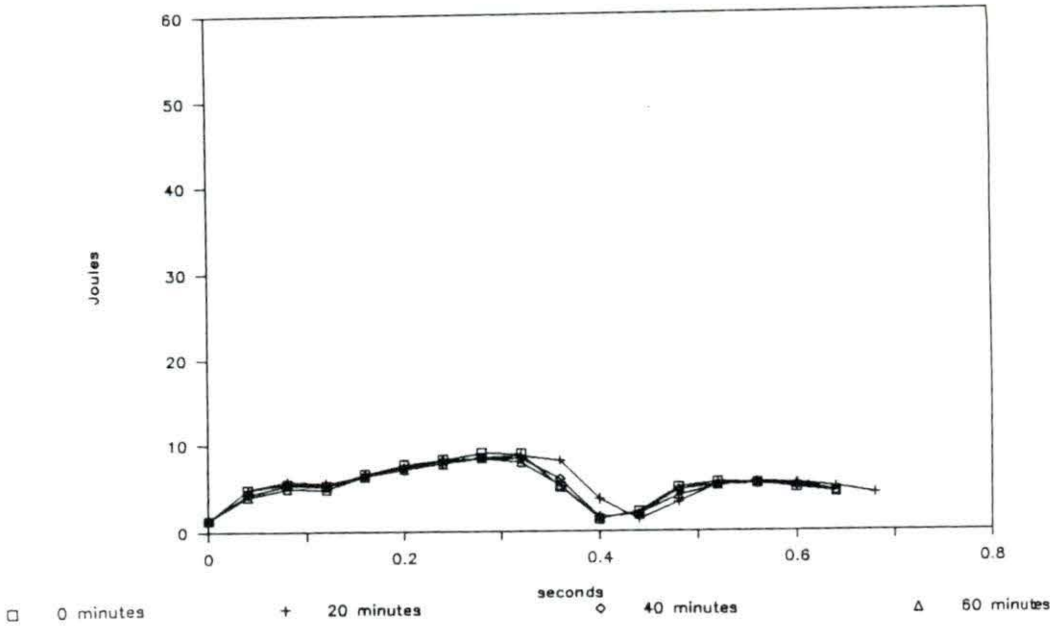

Figure 16.11: Total energy for foot (subject 2)

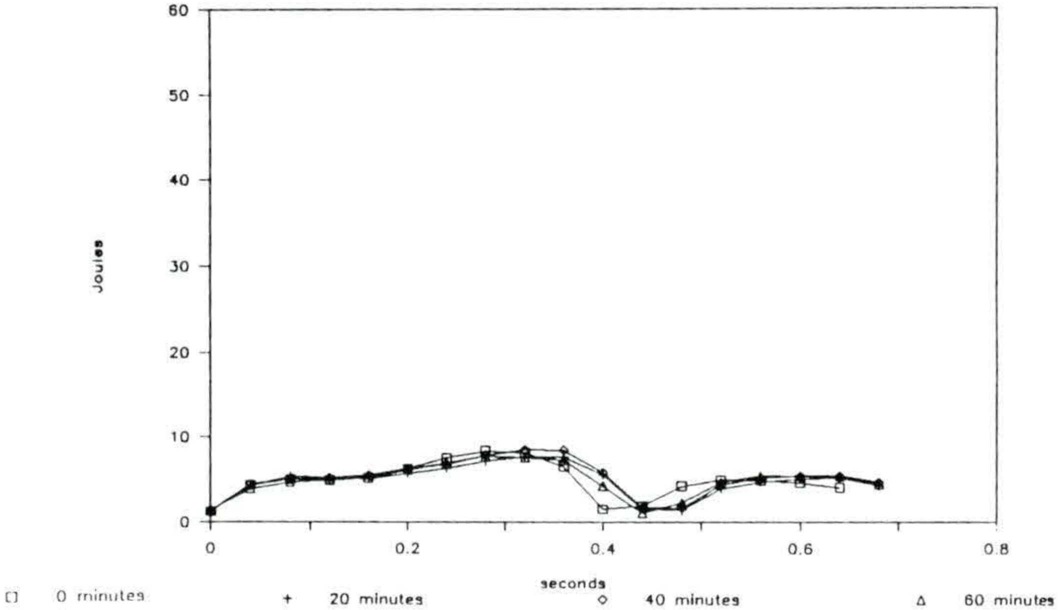

Figure 16.12: Total energy for foot (subject 3)

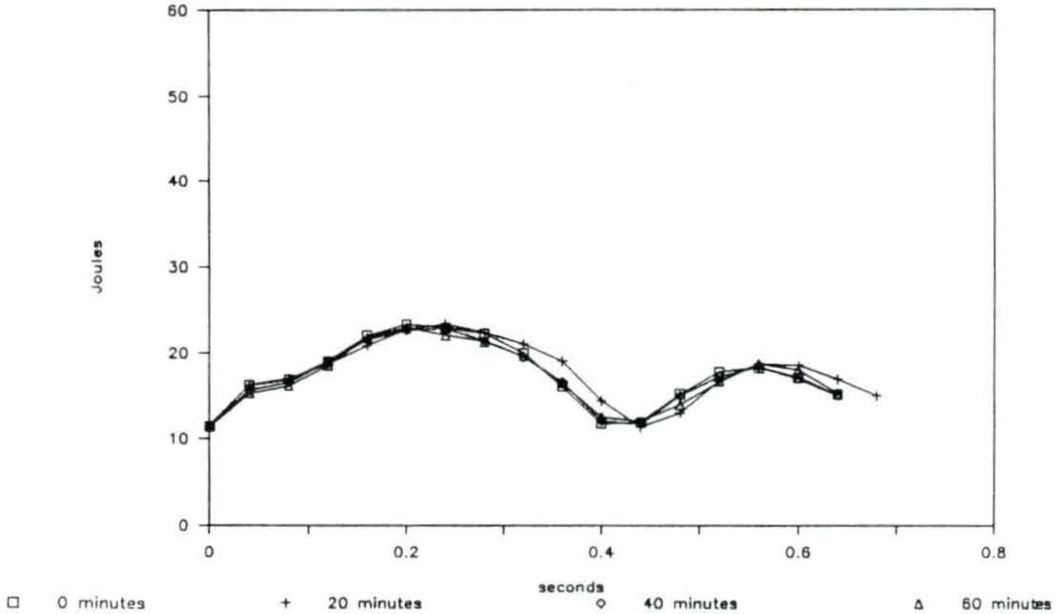

Figure 16.13: Total energy for shank (subject 2)

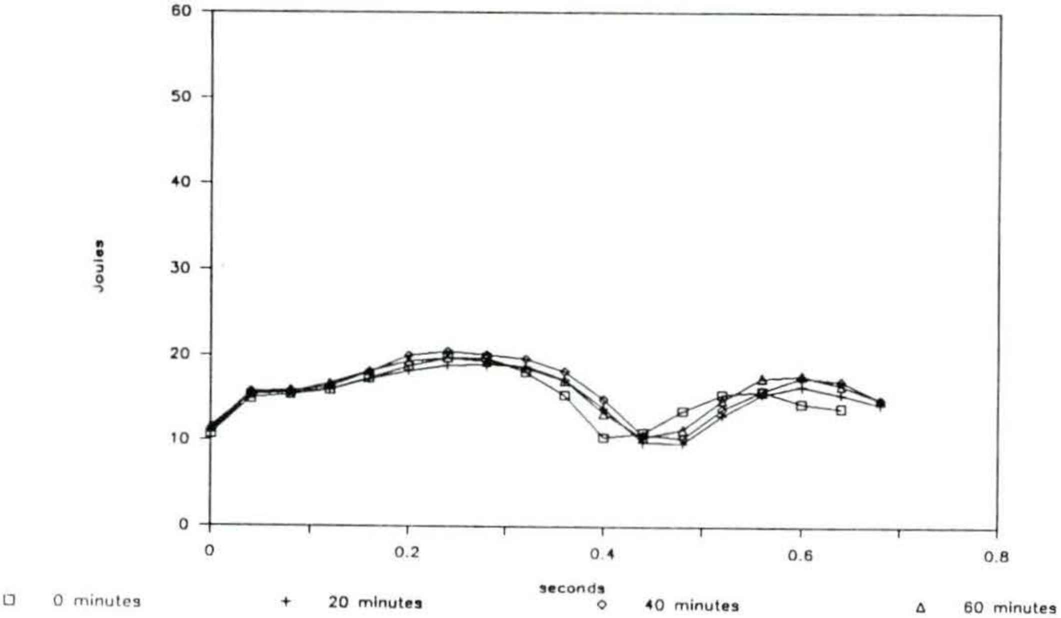

Figure 16.14: Total energy for shank (subject 3)

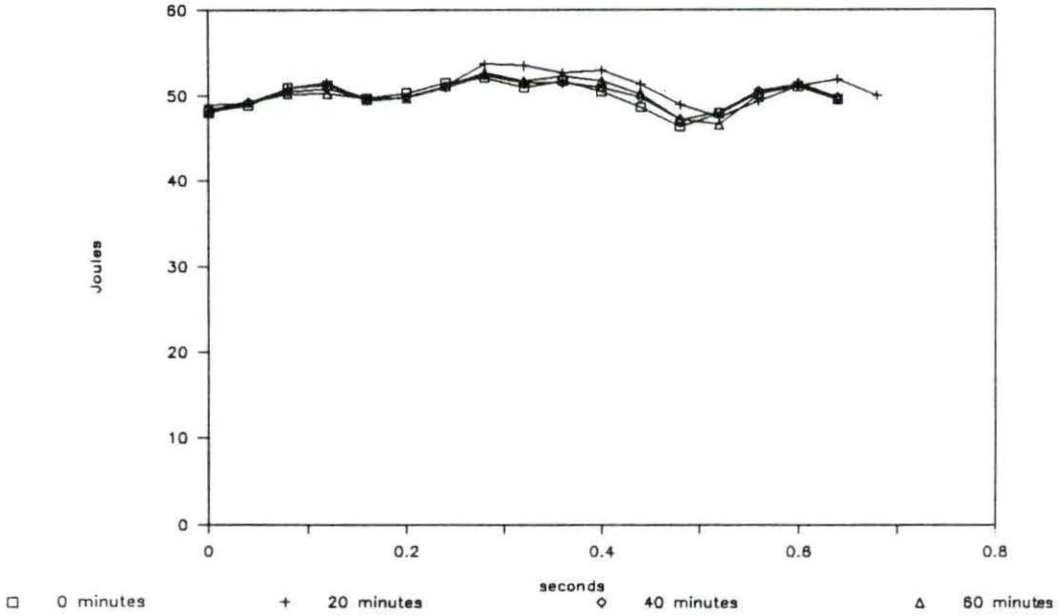

Figure 16.15: Total energy for thigh (subject 2)

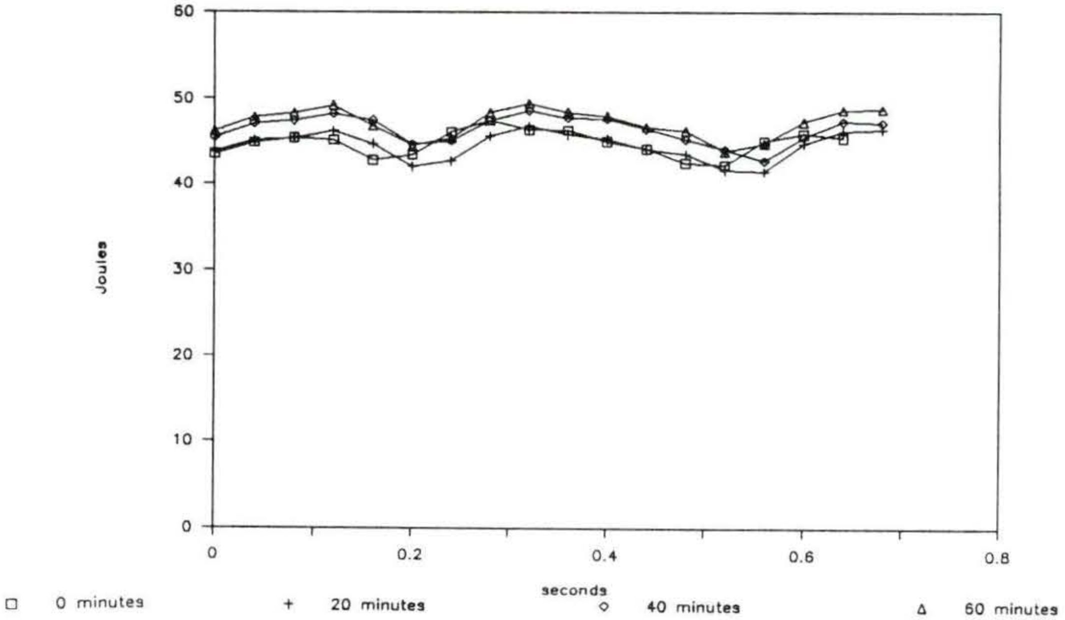

Figure 16.16: Total energy for thigh (subject 3)

16.2 EMG Recording

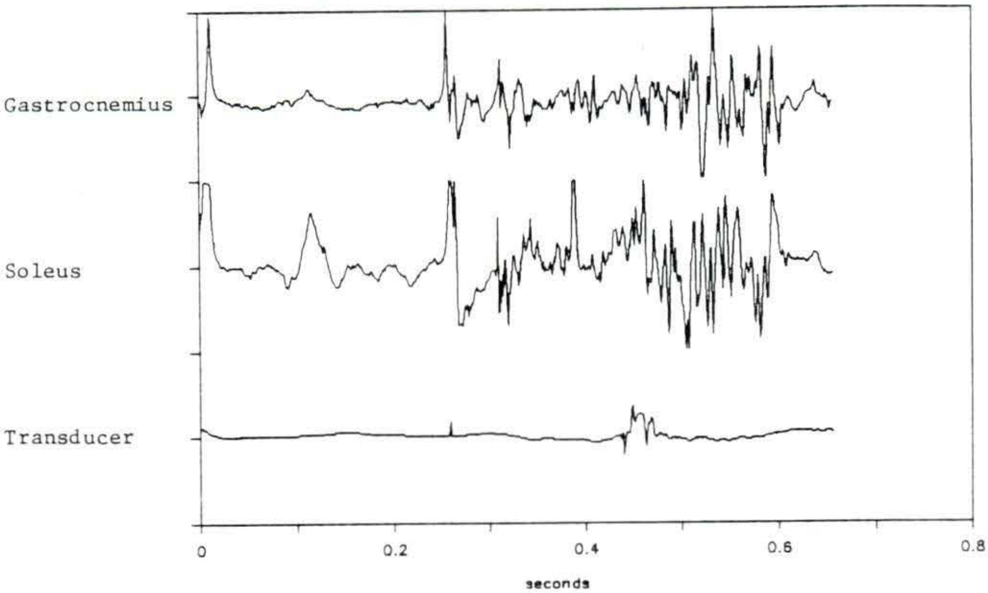

Figure 16.17: EMG recording after 0 minutes (subject 2)

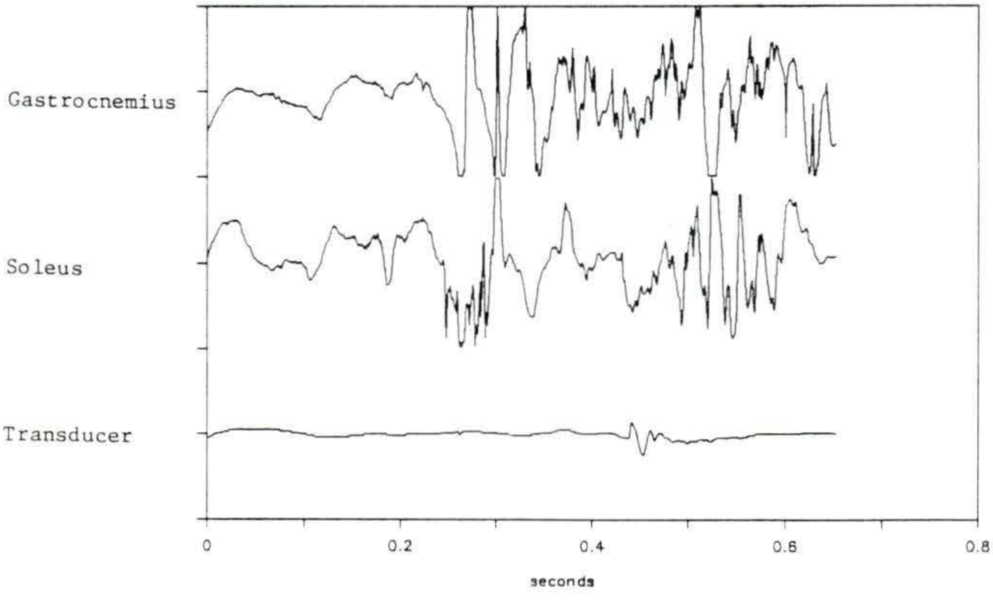

Figure 16.18: EMG recording after 0 minutes (subject 3)

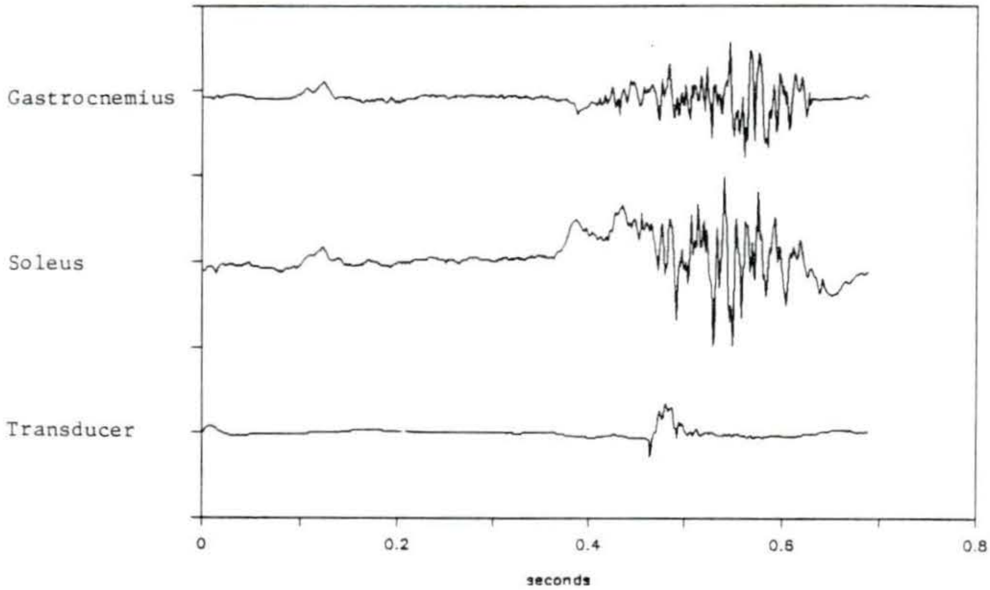

Figure 16.19: EMG recording after 20 minutes (subject 2)

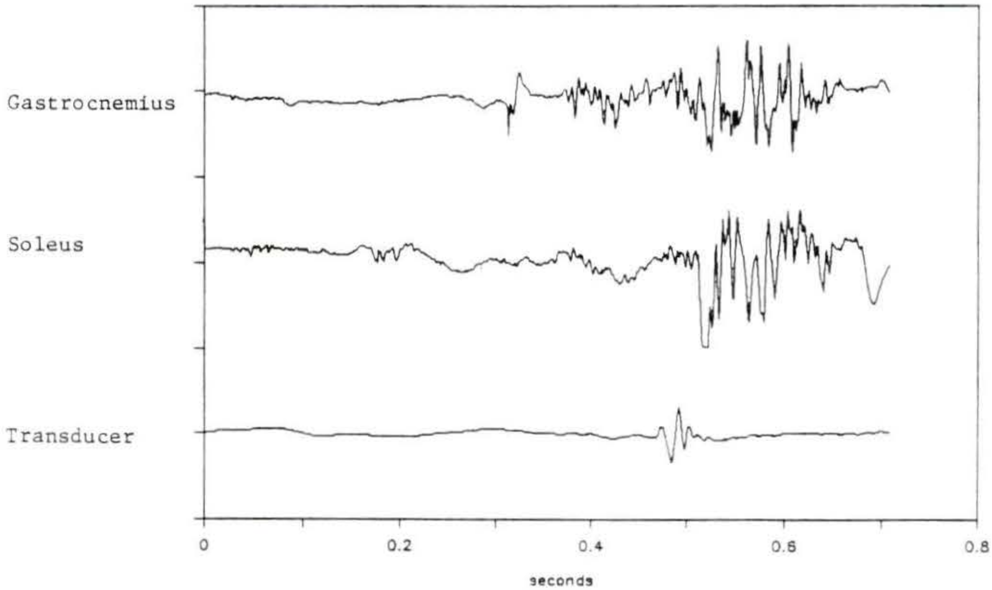

Figure 16.20: EMG recording after 20 minutes (subject 3)

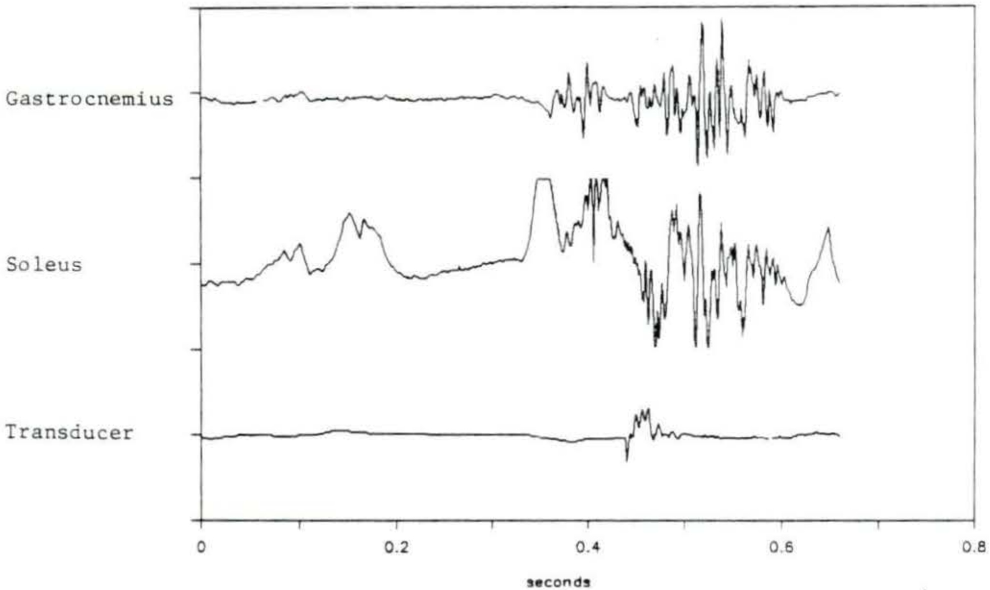

Figure 16.21: EMG recording after 40 minutes (subject 2)

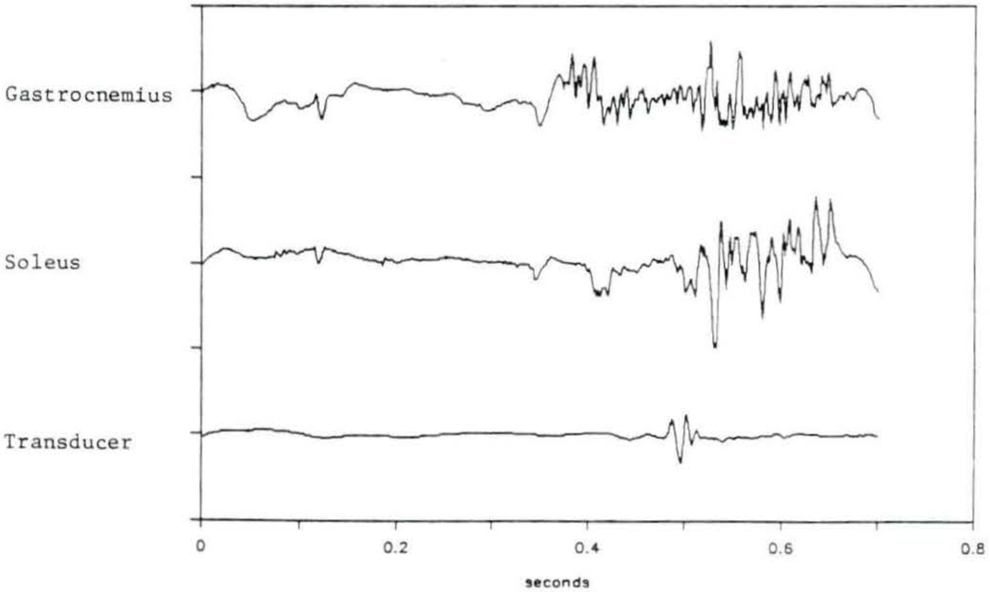

Figure 16.22: EMG recording after 40 minutes (subject 3)

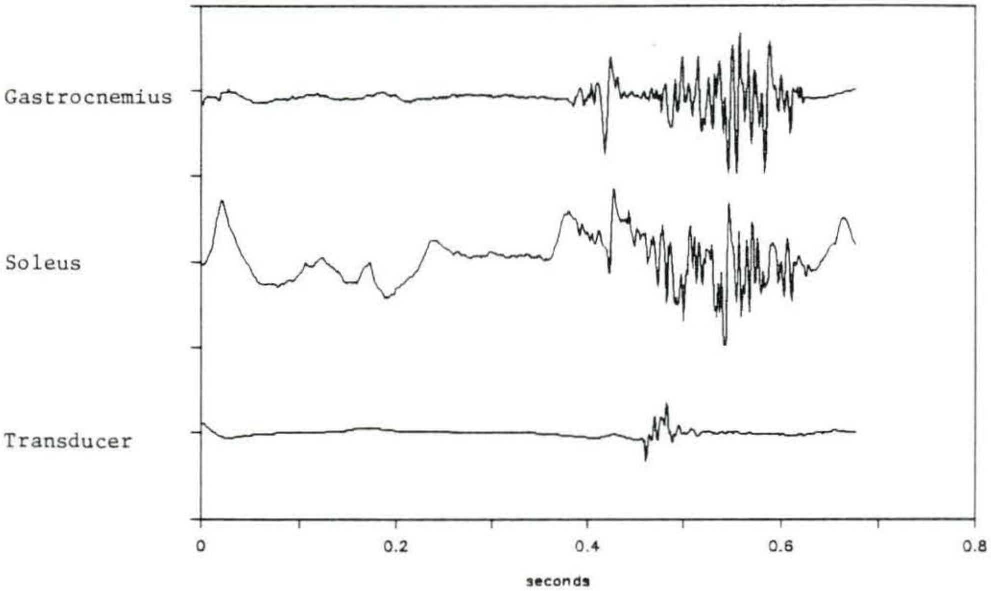

Figure 16.23: EMG recording after 60 minutes (subject 2)

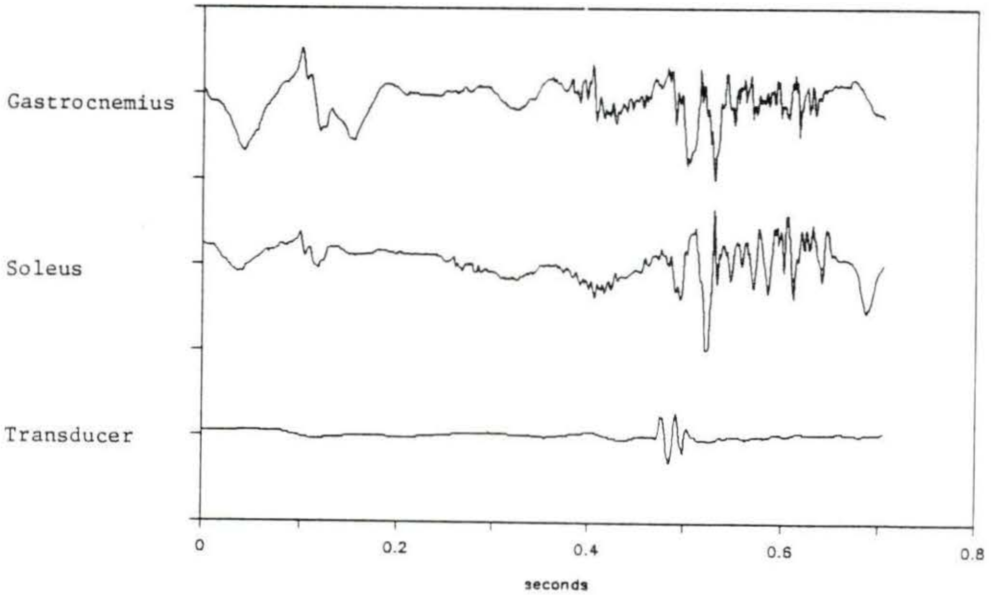

Figure 16.24: EMG recording after 60 minutes (subject 3)

16.3 Elasticity

Table 16.1: The factors for the elasticity parameters in running for subject 1 after 0 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	104.9095	36.05507	140.9646	0	266.8214	0
2	104.4025	0	104.4025	.5502736	0	.5502736
3	96.6766	0	96.6766	1.445417	0	1.445417
4	93.15	0	93.15	2.24616	0	2.24616
5	94.9143	43.86649	138.7808	1.801618	359.4919	361.2935
6	90.96321	0	90.96321	2.95226	0	2.95226
7	83.8243	0	83.8243	7.206147	0	7.206147
8	81.9046	0	81.9046	9.160466	0	9.160466
9	79.5207	259.7902	339.3109	12.34048	3151.682	3164.023
10	77.00141	0	77.00141	16.90815	0	16.90815
11	76.45201	259.7902	336.2423	18.11012	3151.682	3169.792
12	79.6286	0	79.6286	12.17515	0	12.17515
13	75.9463	0	75.9463	19.2919	0	19.2919
14	83.1014	0	83.1014	7.88764	0	7.88764
15	71.6766	0	71.6766	32.89753	0	32.89753
16	62.3293	0	62.3293	105.8274	0	105.8274
17	62.8976	207.7863	270.6839	98.57052	2468.593	2567.163
18	75.6053	0	75.6053	20.13198	0	20.13198
19	97.1774	6.052248	103.2296	1.357707	6.055907	7.413614

Subject 1, 0 minutes

Table 16.2: The factors for the elasticity parameters in running for subject 2 after 0 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	100.5974	16.86385	117.4613	0	60.51897	0
2	99.085	19.75332	118.8383	1.069667	83.99084	85.06051
3	87.07	0	87.07	4.802912	0	4.802912
4	84.76541	32.23853	117.0039	6.40639	203.215	209.6213
5	82.5011	34.14127	116.6424	8.502284	222.8204	231.3227
6	79.5816	0	79.5816	12.2469	0	12.2469
7	76.3325	0	76.3325	18.3827	0	18.3827
8	75.2858	35.27042	110.5562	20.95228	234.5663	255.5186
9	71.2556	0	71.2556	34.67511	0	34.67511
10	68.5112	35.25916	103.7704	48.86553	234.4488	283.3144
11	74.919	15.19979	90.11879	21.93531	48.24681	70.18211
12	74.1103	35.2479	109.3582	24.26864	234.3313	258.6
13	64.7606	0	64.7606	78.09279	0	78.09279
14	58.307	0	58.307	174.967	0	174.967
15	59.6337	26.06515	85.69884	148.2292	141.6957	289.9249
16	71.4917	10.43333	81.92503	33.66672	20.17441	53.84114
17	90.2396	5.604232	95.84383	3.231745	5.094975	8.32672
Subject 2, 0 minutes						

Table 16.3: The factors for the elasticity parameters in running for subject 3 after 0 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	112.2442	32.8835	145.1277	0	258.4832	0
2	110.1977	0	110.1977	.2666708	0	.2666708
3	106.8971	0	106.8971	.4028603	0	.4028603
4	108.1398	0	108.1398	.3448993	0	.3448993
5	108.0354	53.05297	161.0884	.3494297	534.2816	534.631
6	100.3642	0	100.3642	.9116015	0	.9116015
7	98.0774	53.2541	151.3315	1.213244	537.1165	538.3298
8	92.1633	0	92.1633	2.541006	0	2.541006
9	94.4877	32.15644	126.6441	1.900296	249.0232	250.9235
10	96.9015	0	96.9015	1.405348	0	1.405348
11	105.3992	17.69637	123.0956	.4858148	78.60221	79.08802
12	94.5861	0	94.5861	1.877066	0	1.877066
13	73.80371	0	73.80371	25.21675	0	25.21675
14	65.3668	0	65.3668	72.39392	0	72.39392
15	68.0525	72.42951	140.482	51.74925	811.3953	863.1446
16	88.3765	0	88.3765	4.079235	0	4.079235
17	105.4926	9.580439	115.073	.480176	17.83537	18.31554
Subject 3, 0 minutes						

Table 16.4: The factors for the elasticity parameters in running for subject 1 after 20 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	104.9095	36.05507	140.9646	0	266.8214	0
2	104.4025	0	104.4025	.5502736	0	.5502736
3	96.6766	0	96.6766	1.445417	0	1.445417
4	93.15	0	93.15	2.24616	0	2.24616
5	94.9143	43.86649	138.7808	1.801618	359.4919	361.2935
6	90.96321	0	90.96321	2.95226	0	2.95226
7	83.8243	0	83.8243	7.206147	0	7.206147
8	81.9046	0	81.9046	9.160466	0	9.160466
9	79.5207	259.7902	339.3109	12.34048	3151.682	3164.023
10	77.00141	0	77.00141	16.90815	0	16.90815
11	76.45201	259.7902	336.2423	18.11012	3151.682	3169.792
12	79.6286	0	79.6286	12.17515	0	12.17515
13	75.9463	0	75.9463	19.2919	0	19.2919
14	83.1014	0	83.1014	7.88764	0	7.88764
15	71.6766	0	71.6766	32.89753	0	32.89753
16	62.3293	0	62.3293	105.8274	0	105.8274
17	62.8976	207.7863	270.6839	98.57052	2468.593	2567.163
18	75.6053	0	75.6053	20.13198	0	20.13198
19	97.1774	6.052248	103.2296	1.357707	6.055907	7.413614
Subject 1, 20 minutes						

Table 16.5: The factors for the elasticity parameters in running for subject 2 after 20 minutes

Frame	θ	θ_e	θ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	101.3078	14.44344	115.7512	0	43.03571	0
2	96.9139	0	96.9139	1.403171	0	1.403171
3	91.433	0	91.433	2.783885	0	2.783885
4	91.82141	19.44818	111.2696	2.651952	81.40245	84.05441
5	83.5588	0	83.5588	7.449316	0	7.449316
6	79.0446	0	79.0446	13.09718	0	13.09718
7	81.875	14.89786	96.77286	9.194424	46.13703	55.33146
8	77.017	0	77.017	16.87524	0	16.87524
9	75.1392	23.14621	98.28541	21.33977	114.1488	135.4886
10	74.3828	23.19353	97.57632	23.45591	114.585	138.0409
11	76.00891	17.92511	93.93402	19.14149	68.85376	87.99526
12	72.2326	0	72.2326	30.68879	0	30.68879
13	80.70571	10.27632	90.98203	10.64147	19.46486	30.10633
14	63.9424	0	63.9424	86.50238	0	86.50238
15	55.9913	0	55.9913	233.705	0	233.705
16	59.576	14.93236	74.50836	149.3021	46.37615	195.6783
17	76.7705	5.139951	81.91046	17.4033	4.304169	21.70747
18	99.5777	.0536656	99.63136	1.005777	.0183632	1.02414

Subject 2, 20 minutes

Table 16.6: The factors for the elasticity parameters in running for subject 3 after 20 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	106.0377	11.16324	117.2009	0	26.0904	0
2	101.1904	0	101.1904	.822154	0	.822154
3	100.0312	15.03036	115.0616	.9503478	54.06175	55.0121
4	107.9226	7.086805	115.0094	.3543916	8.718964	9.073356
5	106.9711	15.02717	121.9983	.3991512	54.0347	54.43385
6	100.6473	0	100.6473	.8799059	0	.8799059
7	100.3731	15.02399	115.3971	.9105876	54.00765	54.91824
8	98.03119	15.0224	113.0536	1.220272	53.99413	55.2144
9	93.43049	0	93.43049	2.168772	0	2.168772
10	94.7613	12.2104	106.9717	1.836405	32.62086	34.45727
11	90.5857	0	90.5857	3.094913	0	3.094913
12	89.5692	15.01603	104.5852	3.514237	53.94002	57.45426
13	90.0539	13.6277	103.6816	3.307639	42.73702	46.04466
14	73.211	0	73.211	27.15598	0	27.15598
15	59.1627	0	59.1627	157.2182	0	157.2182
16	56.6931	15.03354	71.72664	214.0767	54.0888	268.1655
17	71.6993	3.970677	75.66998	32.80429	2.754461	35.55875
18	96.9364	0	96.9364	1.39923	0	1.39923

Subject 3, 20 minutes

Table 16.7: The factors for the elasticity parameters in running for subject 1 after 40 minutes

Frame	φ	φ_e	φ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	97.7867	12.84786	110.6346	0	34.69754	0
2	115.103	0	115.103	.1444384	0	.1444384
3	104.9973	0	104.9973	.5108446	0	.5108446
4	96.9518	0	96.9518	1.39654	0	1.39654
5	98.0106	16.48034	114.4909	1.223417	61.62338	62.8468
6	95.4107	20.97945	116.3902	1.693225	102.3993	104.0926
7	93.9222	20.97682	114.899	2.039484	102.3737	104.4132
8	87.9142	0	87.9142	4.32191	0	4.32191
9	83.7536	0	83.7536	7.270115	0	7.270115
10	81.4852	20.96891	102.4541	9.653518	102.2968	111.9503
11	79.70201	20.96627	100.6683	12.06394	102.2712	114.3351
12	80.2507	18.51271	98.76341	11.26426	79.23202	90.49628
13	78.8598	20.961	99.8208	13.40325	102.2199	115.6232
14	78.036	20.95837	98.99437	14.85701	102.1943	117.0513
15	81.5047	13.12387	94.62857	9.630016	36.4968	46.12682
16	77.8767	0	77.8767	15.15582	0	15.15582
17	67.5489	0	67.5489	55.1116	0	55.1116
18	57.9162	0	57.9162	183.7263	0	183.7263
19	73.6316	5.230629	78.86223	25.76514	4.514963	30.2801
20	91.2092	4.216411	95.42561	2.862864	3.024904	5.887768

Subject 1, 40 minutes

Table 16.8: The factors for the elasticity parameters in running for subject 2 after 40 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	100.2801	13.10036	113.3805	0	34.42857	0
2	97.0861	0	97.0861	1.373291	0	1.373291
3	86.5346	0	86.5346	5.135347	0	5.135347
4	86.6962	18.17923	104.8754	5.032655	70.90183	75.93449
5	82.6213	0	82.6213	8.375492	0	8.375492
6	79.9507	20.127	100.0777	11.69469	87.19167	98.88635
7	76.2486	0	76.2486	18.57651	0	18.57651
8	74.8675	21.48112	96.34862	22.07696	99.05606	121.133
9	72.7196	22.16168	94.88127	28.87634	105.1626	134.0389
10	71.9112	22.56843	94.47963	31.9468	108.8542	140.801
11	71.6411	23.78802	95.42911	33.04383	120.0962	153.1401
12	77.1029	12.48769	89.59059	16.69501	30.80251	47.49752
13	67.71041	0	67.71041	54.01008	0	54.01008
14	60.2411	0	60.2411	137.3915	0	137.3915
15	58.8377	24.98992	83.82762	163.7367	131.4058	295.1425
16	71.3819	7.74488	79.12678	34.13199	10.11335	44.24535
17	91.44069	3.133186	94.57388	2.78121	1.829929	4.611139
Subject 2, 40 minutes						

Table 16.9: The factors for the elasticity parameters in running for subject 3 after 40 minutes

Frame	ϕ	θ_e	θ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	106.1344	9.007517	115.1419	0	15.33147	0
2	105.5824	9.188283	114.7707	.4748162	16.09402	16.56883
3	102.5906	0	102.5906	.6901458	0	.6901458
4	109.7395	4.111188	113.8507	.2823902	2.927595	3.209985
5	116.5418	4.245166	120.787	.1206631	3.099471	3.220134
6	96.8416	0	96.8416	1.41591	0	1.41591
7	95.48739	9.183586	104.671	1.677071	16.07389	17.75096
8	92.7848	9.182647	101.9674	2.351075	16.06986	18.42094
9	87.4484	0	87.4484	4.581022	0	4.581022
10	85.9353	9.180768	95.11608	5.534823	16.06181	21.59664
11	84.2721	9.179827	93.45192	6.813864	16.05779	22.87165
12	85.4536	7.571596	93.02519	5.87833	10.14192	16.02025
13	86.7623	7.447884	94.21018	4.991243	9.763815	14.75506
14	71.6349	0	71.6349	33.06943	0	33.06943
15	59.7988	0	59.7988	145.2014	0	145.2014
16	57.0885	9.189221	66.27773	203.7532	16.09804	219.8513
17	62.8228	4.693825	67.51663	99.49649	3.726178	103.2227
18	81.8573	.8201641	82.67747	9.214791	.3217065	9.536497

Subject 3, 40 minutes

Table 16.10: The factors for the elasticity parameters in running for subject 1 after 60 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	109.9774	11.41101	121.3884	0	26.0904	0
2	102.6207	0	102.6207	.6875541	0	.6875541
3	95.4867	0	95.4867	1.677215	0	1.677215
4	97.1764	12.56	109.7364	1.357877	32.86971	34.22759
5	97.1437	16.48045	113.6242	1.363439	61.62433	62.98776
6	93.5729	0	93.5729	2.130507	0	2.130507
7	90.1321	0	90.1321	3.275464	0	3.275464
8	84.2014	0	84.2014	6.874351	0	6.874351
9	82.6976	17.32004	100.0176	8.295988	68.71283	77.00882
10	80.2252	17.3533	97.57849	11.30023	68.99926	80.29948
11	79.1604	17.37265	96.53305	12.90897	69.1661	82.07506
12	78.5	17.38358	95.88358	14.01982	69.26041	83.28023
13	81.3962	11.76285	93.15905	9.76151	28.07642	37.83793
14	80.0703	17.39215	97.46245	11.52116	69.33441	80.85557
15	77.6282	17.39302	95.02122	15.63399	69.34191	84.9759
16	65.8629	0	65.8629	68.04096	0	68.04096
17	63.5019	17.42404	80.92593	91.39901	69.60985	161.0089
18	69.2336	9.347694	78.5813	44.64636	16.12111	60.76747
19	86.3859	3.565344	89.95125	5.231691	2.270715	7.502405
20	108.4114	.6752143	109.0866	.3333866	.2572782	.5906648

Subject 1, 60 minutes

Table 16.11: The factors for the elasticity parameters in running for subject 2 after 60 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	97.9349	19.01074	116.9456	0	77.73325	0
2	90.74389	0	90.74389	3.034316	0	3.034316
3	84.3768	0	84.3768	6.725271	0	6.725271
4	83.9959	29.86034	113.8563	7.053221	179.0917	186.1449
5	81.5668	29.85589	111.4227	9.555548	179.0469	188.6025
6	76.7555	0	76.7555	17.43596	0	17.43596
7	75.5641	29.84696	105.4111	20.23592	178.9573	199.1932
8	72.0372	0	72.0372	31.44758	0	31.44758
9	72.0908	28.6197	100.7105	31.2376	166.7022	197.9398
10	70.7777	29.83357	100.6113	36.80963	178.8228	215.6325
11	71.51641	24.82882	96.34523	33.56289	129.8776	163.4405
12	72.1333	25.39692	97.53022	31.07208	135.2827	166.3548
13	72.4222	27.13251	99.55471	29.97	152.0547	182.0247
14	60.181	0	60.181	138.4276	0	138.4276
15	55.5303	0	55.5303	247.5678	0	247.5678
16	66.0049	10.20734	76.21224	66.8439	19.15784	86.00174
17	83.0931	6.045242	89.13834	7.895829	5.936703	13.83253
Subject 2, 60 minutes						

Table 16.12: The factors for the elasticity parameters in running for subject 3 after 60 minutes

Frame	ϕ	ϕ_e	ϕ_c	M_p	M_c	M
	degrees	degrees	degrees	Nm	Nm	Nm
1	107.9448	9.383366	117.3282	0	16.94531	0
2	103.7447	0	103.7447	.597432	0	.597432
3	97.3613	0	97.3613	1.326853	0	1.326853
4	104.6409	5.50857	110.1495	.5341171	5.088043	5.62216
5	105.0408	10.67402	115.7148	.5080742	23.32872	23.83679
6	103.675	11.57334	115.2484	.6026594	28.54858	29.15124
7	97.30269	0	97.30269	1.33661	0	1.33661
8	94.0225	0	94.0225	2.014075	0	2.014075
9	88.6175	0	88.6175	3.958182	0	3.958182
10	92.9238	7.040983	99.96478	2.310578	8.592488	10.90307
11	86.3936	0	86.3936	5.226659	0	5.226659
12	90.5505	7.13148	97.68198	3.108561	8.84358	11.95214
13	88.1827	11.56521	99.74791	4.179262	28.49855	32.67781
14	71.1508	0	71.1508	35.13234	0	35.13234
15	57.1276	0	57.1276	202.7598	0	202.7598
16	58.0097	9.997376	68.00708	181.5915	19.81871	201.4102
17	69.6804	3.795039	73.47543	42.22121	2.547934	44.76914
18	96.1724	0	96.1724	1.539445	0	1.539445
Subject 3, 60 minutes						

16.4 FFT-Analysis

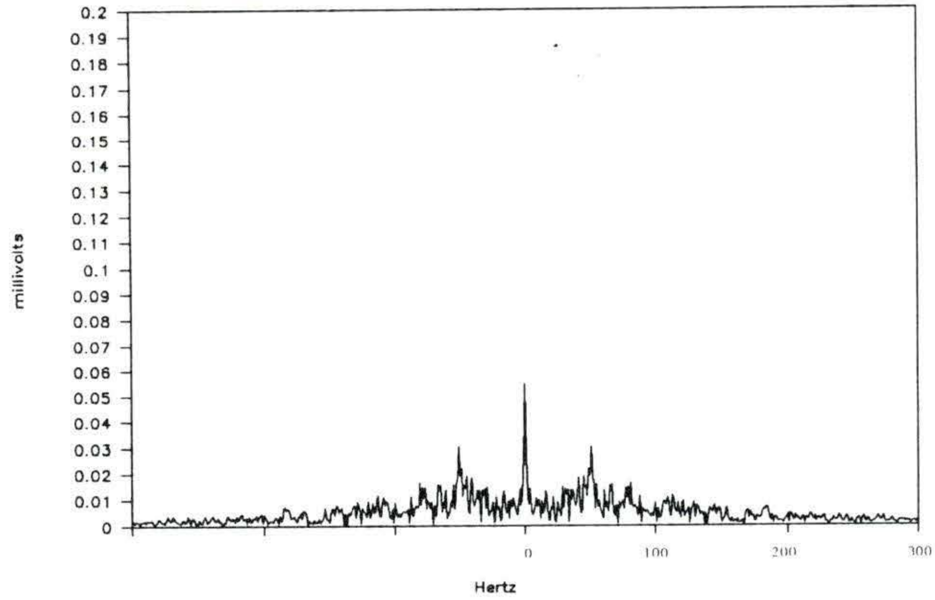

Figure 16.25: FFT-analysis for gastrocnemius muscle after 0 minutes (subject 2)

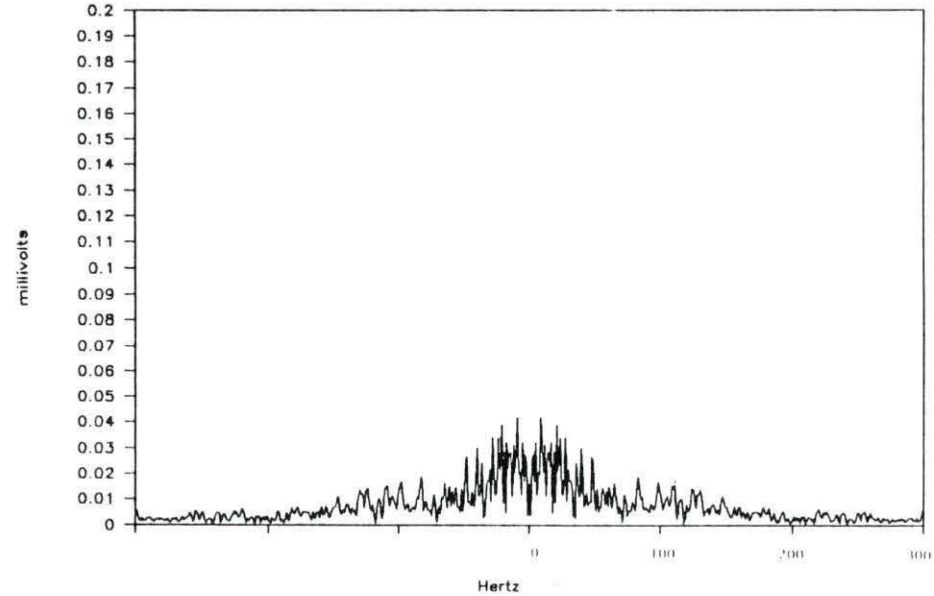

Figure 16.26: FFT-analysis for soleus muscle after 0 minutes (subject 2)

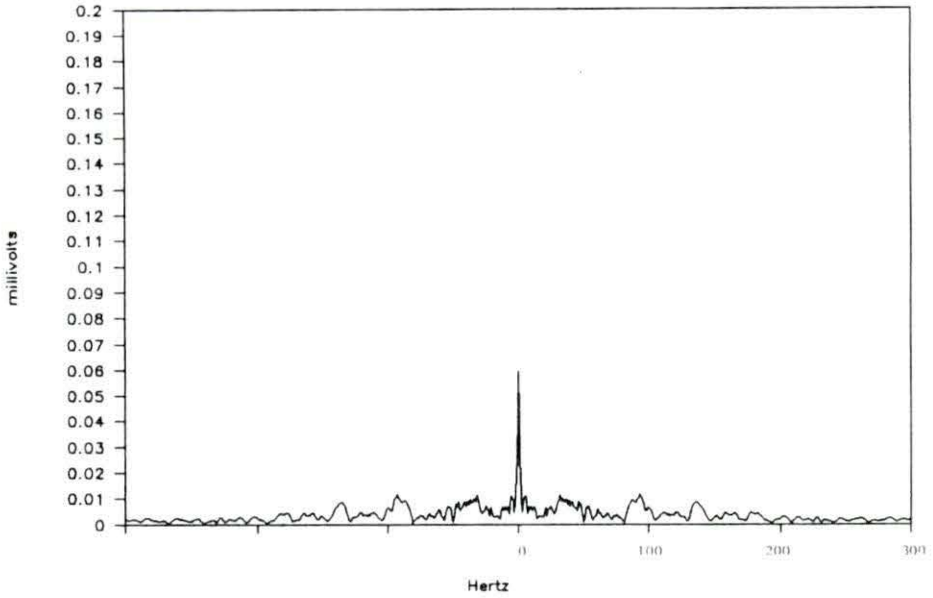

Figure 16.27: FFT-analysis for gastrocnemius muscle after 20 minutes (subject 2)

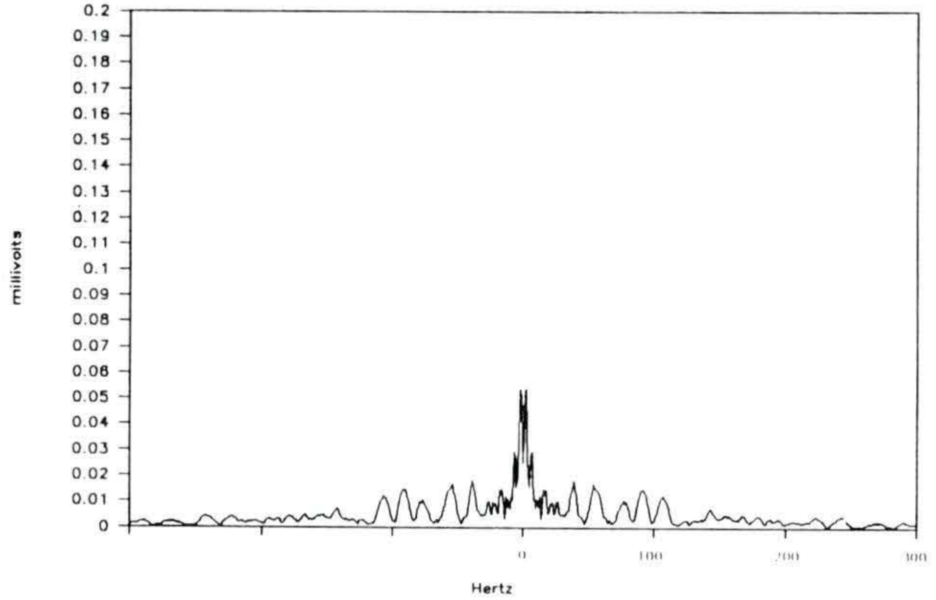

Figure 16.28: FFT-analysis for soleus muscle after 20 minutes (subject 2)

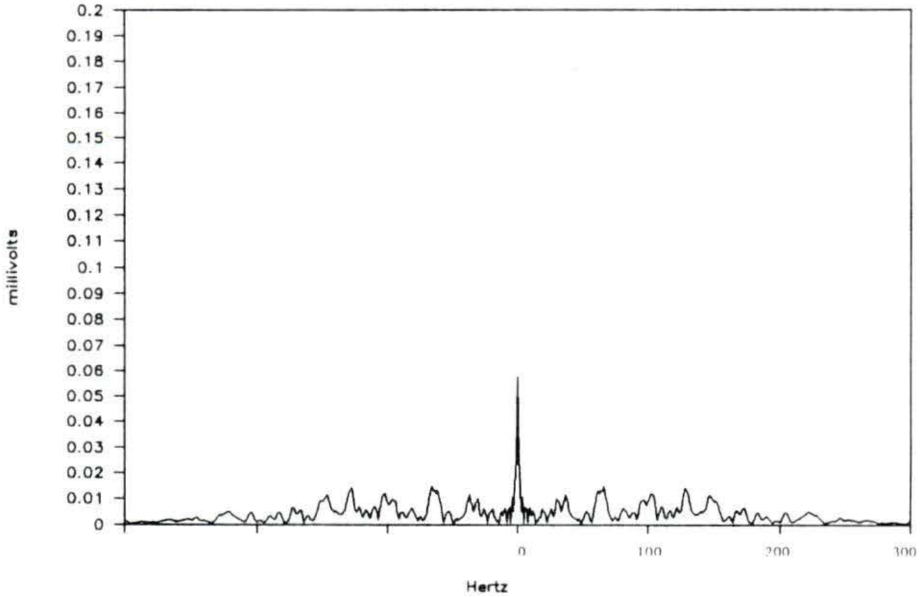

Figure 16.29: FFT-analysis for gastrocnemius muscle after 40 minutes (subject 2)

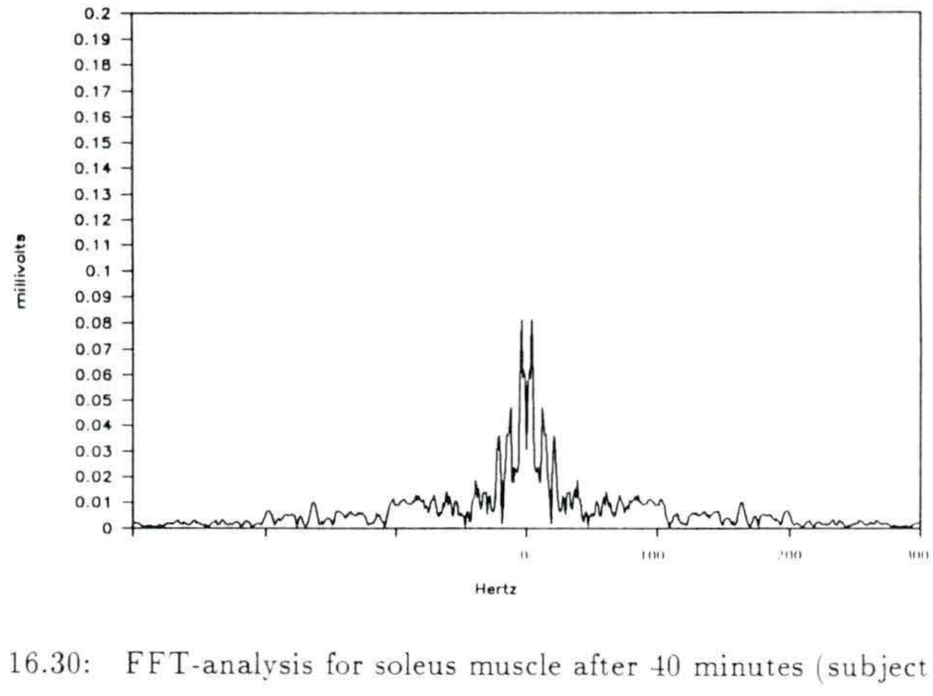

Figure 16.30: FFT-analysis for soleus muscle after 40 minutes (subject 2)

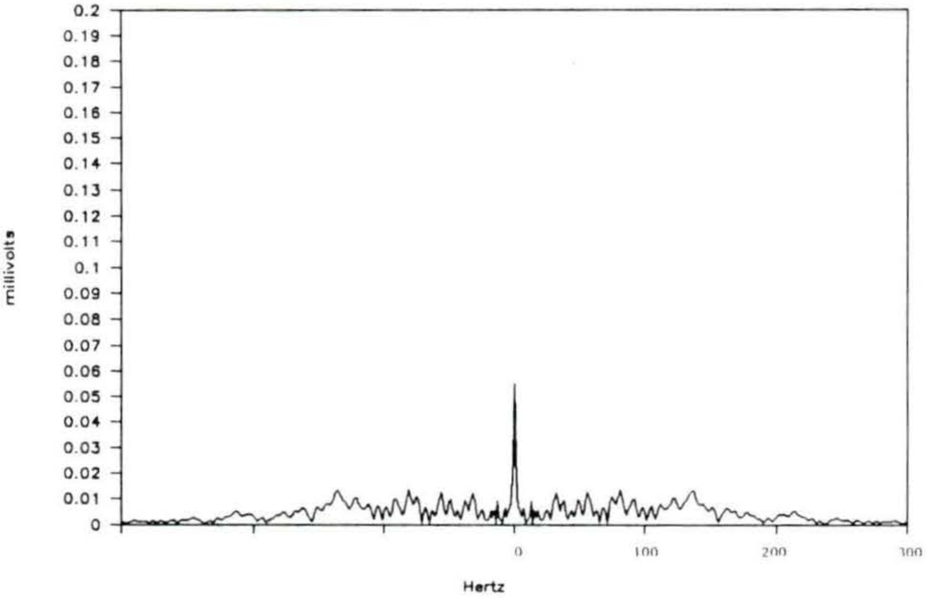

Figure 16.31: FFT-analysis for gastrocnemius muscle after 60 minutes (subject 2)

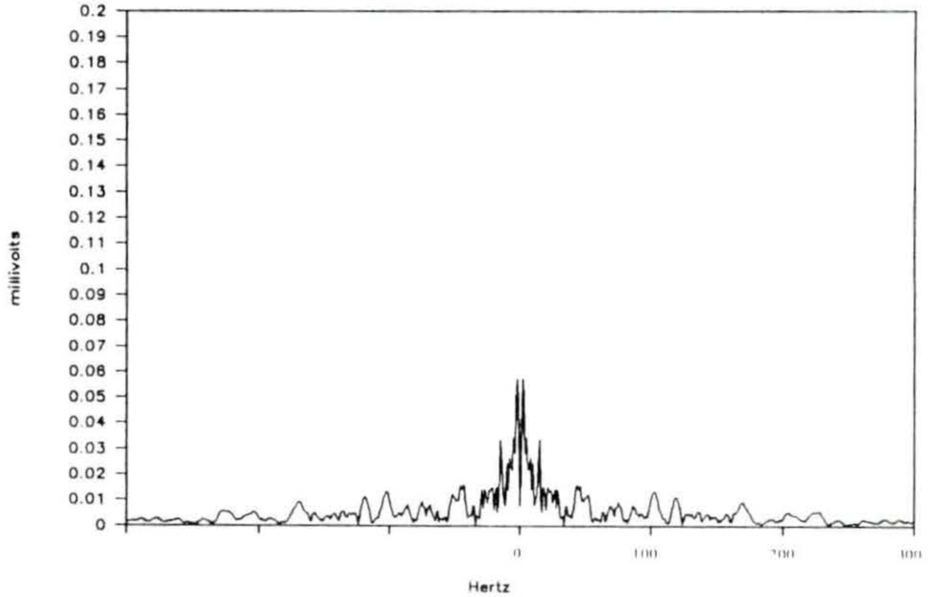

Figure 16.32: FFT-analysis for soleus muscle after 60 minutes (subject 2)

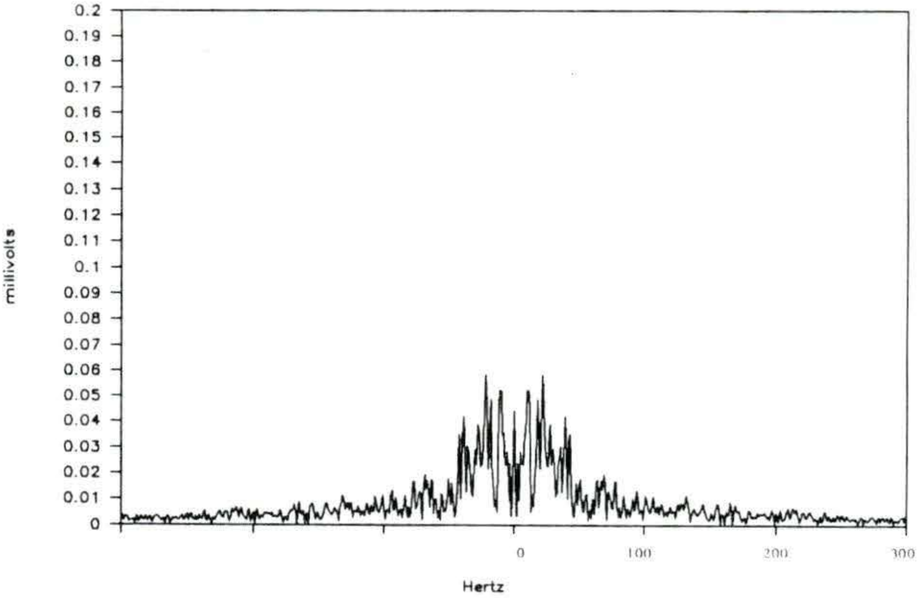

Figure 16.33: FFT-analysis for gastrocnemius muscle after 0 minutes (subject 3)

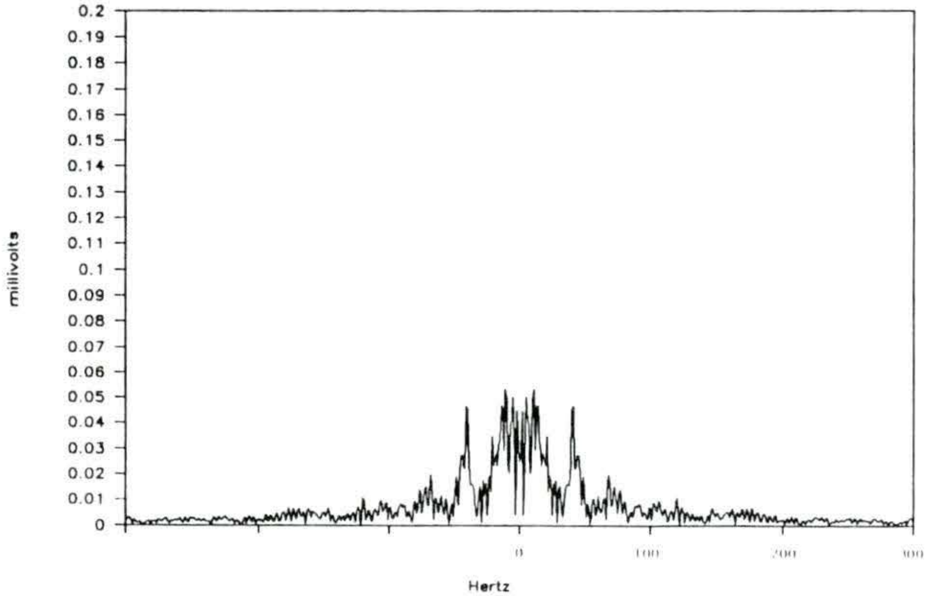

Figure 16.34: FFT-analysis for soleus muscle after 0 minutes (subject 3)

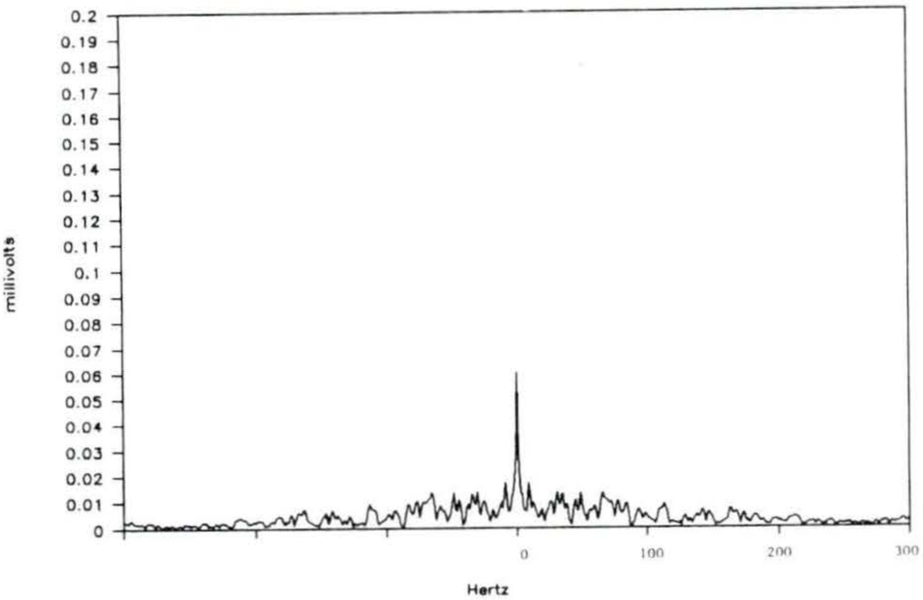

Figure 16.35: FFT-analysis for gastrocnemius muscle after 20 minutes (subject 3)

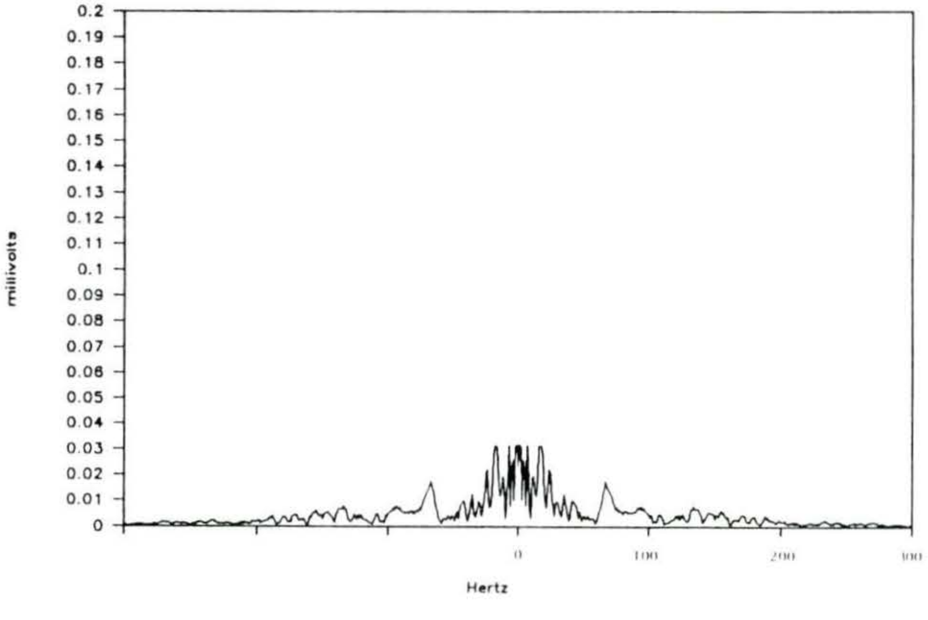

Figure 16.36: FFT-analysis for soleus muscle after 20 minutes (subject 3)

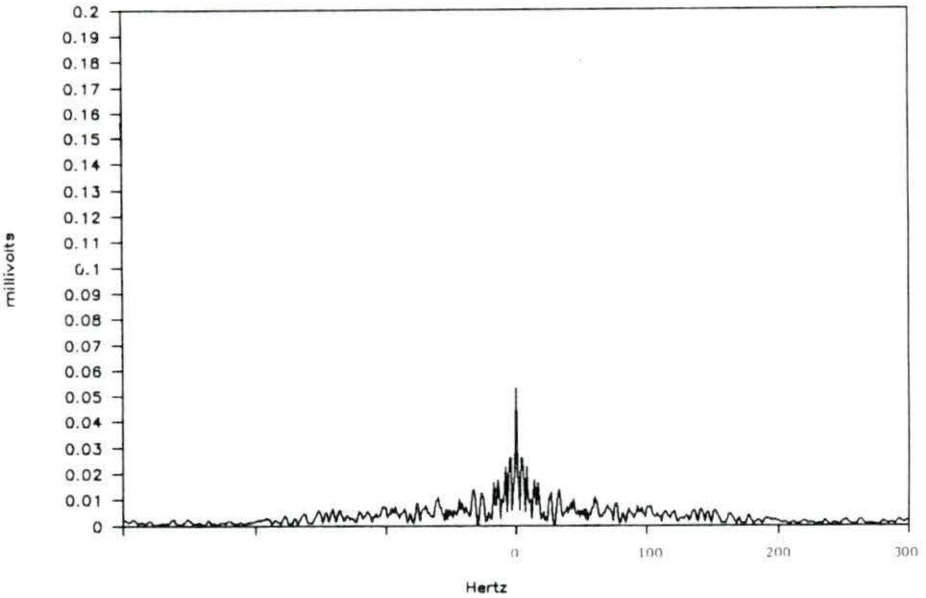

Figure 16.37: FFT-analysis for gastrocnemius muscle after 40 minutes (subject 3)

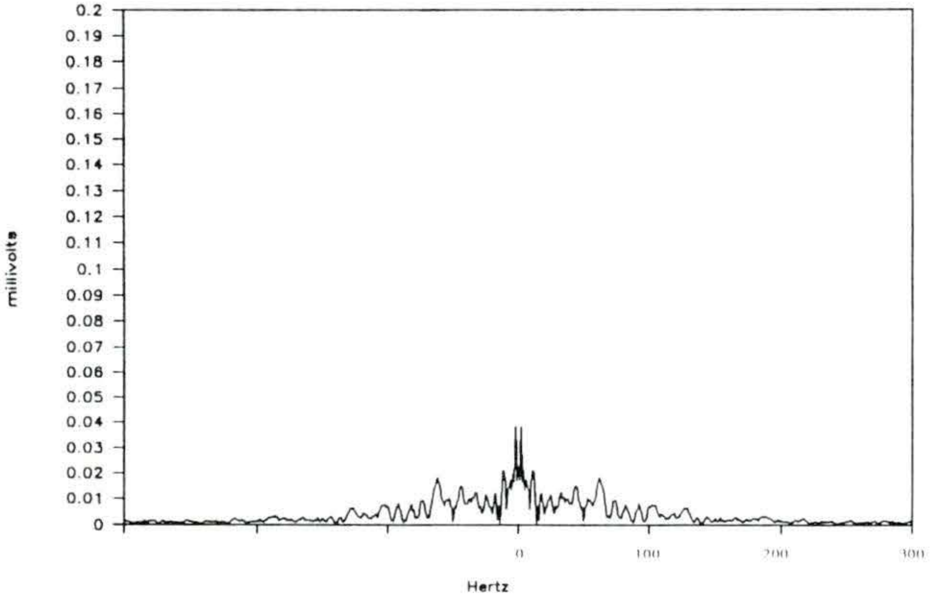

Figure 16.38: FFT-analysis for soleus muscle after 40 minutes (subject 3)

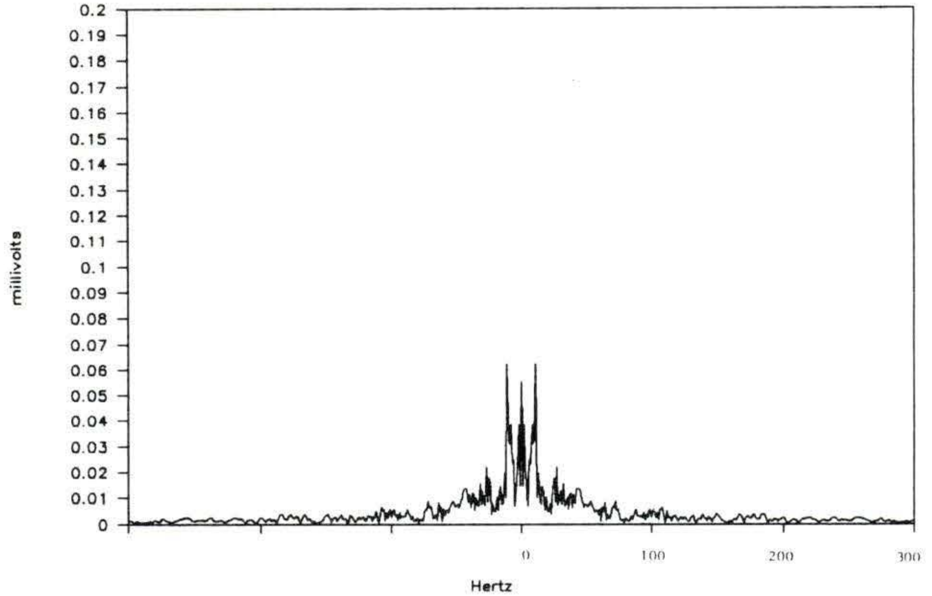

Figure 16.39: FFT-analysis for gastrocnemius muscle after 60 minutes (subject 3)

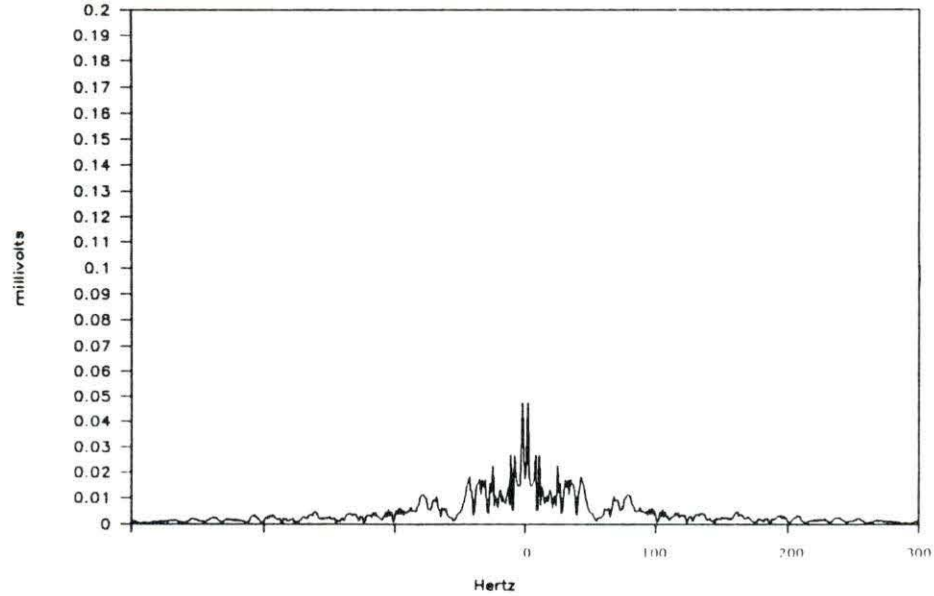

Figure 16.40: FFT-analysis for soleus muscle after 60 minutes (subject 3)