Effects of Mental Stress on ECG

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Abstract

This Undergraduate Fellows program focused on establishing a link between mental stress and changes in the heart's electrical activity. Electrocardiograms were taken before and after a stressful event (a lab quiz). Examining those ECG records by FFT analysis revealed trends that can be used to quantify test anxieties. A major energy increase in the 1st harmonic was evident in students who had completed the lab quiz. In addition, subjects who excelled on the quiz experienced an upward shift of the 2nd and 3rd frequency peaks. Subjects who did well experienced no frequency shifts. Those who performed not as well experienced a downward shift in their 2nd and 3rd frequency peaks. Since a large part of how much the subject 'unwound' after the quiz was determined by how well he did on the quiz, the various frequency shifts represented the different levels of anxiety change the subject experienced.

Effects of Mental Stress on ECG

Psychological stress is often measured in subjective terms. Traditional methods of anxiety measurements involve questioning and observing the subject by qualified psychologists. Being subjective in nature, it is difficult to either quantify or categorize the level of stress. Even the most competent psychologists may disagree over exactly how stressed the subject may be.

The main purpose of this Undergraduate Fellows study was to find a reliable physical indicator of mental anxiety through the analysis of electrocardiogram records. A weekly lab quiz was used to create the stressful environment. Volunteer students in the lab section were randomly selected over the course of the semester until everyone had participated in the experiment. Lead I ECG recordings lasting 10 seconds each were digitized and recorded immediately before and after the quiz. Background information was supplied by a questionnaire which the subjects filled out before each ECG recording session. It was hoped that by correlating the questionnaires with the ECG recordings, a relationship between the heart's electrical activity and mental stress could be found.

Background

This study was designed to determine whether a relationship existed between mental stress and the heart's electrical activity. Of the various ways to mentally stress a person, the most convenient method was to use a written test. In order to create high stress levels however, the consequences of the test must have some bearing on the subjects. "A transaction is appraised as stressful only if the situation engages a significant motive, that is, the person judges that something is at stake." (Lazarus, 1966). Any type of test outside of the subjects' class curriculum would not normally produce any great levels of anxiety.

In the human heart, the S-A node is where the normal self-excitatory impulse that causes the heart to beat rhythmically is generated. This signal generated by the S-A node spreads through the atria, causing the cardiac muscles there to depolarize and contract. Since the atria are effectively isolated from the ventricles by a layer of nonconducting tissue, the ventricles are not immediately affected by the electrical activity of the atria. Instead, the generated impulse is propagated through the A-V node after a slight delay. This delay allows the atria to empty its contents into the ventricles before the ventricles contract. The Purkinje fibers, which originate in the A-V node, carry the electrical impulse to the cardiac muscles in the ventricle, causing them to contract. As the impulse passes through the heart, electrical currents spread into the surrounding tissues, and a small proportion of these spreads all the way to the surface of the body. If electrodes are placed on the skin on opposite sides of the heart, electrical potentials generated by the heart can be recorded. This recording is known as an electrocardiogram or ECG (Guyton, p.176). The normal electrocardiogram is composed of a P wave, a QRS complex, and a T wave. The P wave is caused by electrical currents generated as the atria depolarize prior to contraction. The QRS complex is caused by currents generated when the ventricles depolarize prior to contraction. The T wave is caused by currents generated as the ventricles recover from the state of depolarization (Guyton, p.176).

For this experiment, only lead I ECG recordings were used. In the lead I set up, the negative terminal of the electrocardiograph was connected to the right arm and the positive terminal to the left arm. The resultant differential signal became the lead I ECG. Other standard leads could have been used, but since they are all similar to each other, it would not have made much difference (Guyton, p.180).

By comparing the ECG recordings of individuals in a stressed and unstressed state, I hoped to find changes in the heart's electrical activity caused solely by mental anxiety.

Method

Subjects

With the cooperation of Dr. Jon F. Hunter and the students in his VTPP 334 class, the problem of producing a suitable test was bypassed. Every week during the Fall semester of '86, Dr. Hunter gave his physiology class a lab quiz. Due to the challenging nature of these quizes, the students in his class were usually very anxious about it. The high anxiety levels caused by the weekly quizes made it a suitable vehicle for use in this experiment. Since the students were more likely to be worried before the exam than after (Folkman, p.155), the pretest ECG would be considered stressed, while the posttest ECG unstressed. The late afternoon 3 hour lab provided ample time to conduct the ECG recordings without interfering with the subjects' normal schedules. The afternoon class meant that the students were usually under no pressure to be elsewhere at the end of the period. Hence, no additional stress was created by keeping the students a while longer after class.

Materials

The ECG waveforms were recorded using standard ECG plates and paste. Shielded leads connected the electrodes to a precision isolation amplifier (1) . A DASH-8 analog to digital converter (2) provided the necessary interface between the amplifier and microcomputer. A TI personal computer with 256K RAM, color graphics, and disk drive was used to buffer and store the digitized ECG data. The data were stored on floppy disks for a permanent record.

An IBM AT with a 80287 math co-processor chip was used in the frequency analysis of the ECG records. The FFT routines provided by the 87FFT (3) software package were used to find the energy and frequency spectrum of the ECGs. A Microsoft Basic Compiler (4) was used both to speed up program execution and to provide the proper format for use with the

87FFT routines. All other collecting and analyzing programs were specifically designed and written for the study.

Design and Procedure

Efforts were made to minimize variations in procedures and conditions experienced by the subjects during the ECG collection phase. To lessen the probability of interfering with the student's normal study habits, subject's chosen for the experiments were not informed until immediately before the quizes. Order of appearance for the experiment was determined randomly by a random order program. If the subject was absent the day of the experiment, he was moved to a latter time slot. A section consisted of 5 individuals whose ECGs were recorded before and after the lab quiz. Set methods of operations were followed for every section. A brief outline of the experiment and the apparatus to be used was provided before the start of the experiment, and any questions the section had were answered. The subjects then filled out the first part of a two part questionnaire. A sample questionnaire can be found in Appendix A. The subjects detailed their physical condition, emotional state, and overall grade in the class by circling the appropriate answers. Because the questionnaire was self made, there is no basis of validity to any psychological interpretation. It only provided general background information. Individual ECGs were then recorded from every member of the section.

During the actual ECG recordings, any article of jewelry that interfered with the placement of lead I electrodes was removed. Electrode plates with adequate amounts of ECG paste were attached by means of elastic bands to the inside wrist of the right and left arm. A pair of wire leads attached to the ECG plates connected them to a differential amplifier. The subject sat in an upright position with their hands not touching, and in their laps. Care was taken that no part of the subject touched metal in case the metallic object acted as an antenna to pick up unwanted electrical interference. The subject was also encouraged not to move or talk during the data collecting phase.

A precision isolation amplifier with an input impedence of 4 Megohms amplified the ECG signal by a factor of 2000. The analog signal was converted to digital form by a DASH 8 ADC in conjunction with a TI personal computer. A ten second ECG record of 500 samples per second was achieved by setting the appropriate parameters in the sampling program (Appendix B). After the sampling interval, the signal was plotted by the computer on a display screen for verification. Depending on whether the record was satisfactory or not, the data were either saved or another ECG taken. Data were stored in a sequential file format on a floppy disk for later analysis. The entire recording procedure took less than two minutes per person to complete.

After collecting the stress ECGs, the subjects returned to class to take their quizes. Upon completion of the quiz, they returned to the data collecting area for the after-test

ECG. They filled out the second portion of the questionnaire and followed the same procedure as the first ECG for a second recording. In part two of the questionnaire, the subject's emotional state was asked along with what grade he thought he made on the quiz. It was felt that perceived performance levels were more important than actual performance. Their actual grade on the quiz did not affect the subjects at the time of the recording since it was unknown.

Determining the amplitudes of the various ECG wavetypes was an important objective. However, due to the wide variability of the ECG from individual to individual, and the sometimes spurious noise of electrical interference, a computer program which automatically scans the records to pick out the individual wave peaks seemed unfeasible to produce. It was far easier to develop a program which used programmer assisted graphical methods to designate the wave peaks. The program listed in appendix C plotted the ECG wave and allowed the user to determine the position and magnitude of the various wavetypes. At a peak, the user decided what type of wave it is and the computer stored the wave type and position in memory. After completing the record, the position and magnitude of the different waves are stored in a file. The program also allowed definition of a ECG heartbeat cycle to be analyzed later by fast Fourier transform. An example of a ECG segment as defined by the program is shown in appendix D.

The program in appendix E retrieved the wave peak data, provided averages of the various parameters, and compared the before test ECG with the after test ECG. The percentage increase in the various wave form amplitudes, heart rate, as well as the different ratios and intervals are calculated and printed out. It was hoped that statistical averaging of these readily calculated variables would provide the key to successful stress identification.

Another analysis method was the fast Fourier transform. The FFT, as it is normally called, provided frequency and energy breakdown of a waveform. Added together, the frequency spectra would reproduce the original signal. Using a developed program called 87FFT, and a IBM AT with a 80287 math co-processor, the FFTs of the different ECGs were calculated. The 87FFT program is a software package containing optimized routines for use with the math co-processor. These FFT routines greatly speeded up calculations and provided results in a fraction of the time it would have taken for older, more traditional programs. A program utilizing these routines was developed (appendix F) to calculate the magnitudes of the energy associated with the various frequencies. A single ECG cycle, as defined and set aside by the program in appendix C, is recalled into a 1042 point array. Unused portions of the array were padded with zeroes. After using a Hamming window on the array to smooth out the data, a real fast Fourier transform is performed followed by transformation to polar coordinates. The FFT of the ECG was then saved to an ASCII sequential file. The procedure was performed on both the pretest and posttest ECG segments. A graphical presentation of a sample FFT can be found in appendix G.

Of major interest were the energy and frequency locations of the various wavetypes. Any spurious noise in the ECG record would show up as dispersed high frequency peaks. All the major wave types are relatively slow changing and would show up in the low frequency spectrum. Energies above the 100th harmonic represented only electrical interference and were ignored. The program in appendix H scanned the FFT file, determined the four highest peaks, and printed them out in descending orders of magnitude. Almost all the major energy spikes occurred within the first 20 harmonic frequencies. Since the T wave changed the slowest, it was associated with the fundamental frequency. These peaks presented only the alternating nature of the ECG, the DC offset was ignored.

Results

An attempt was made to assign a stress level to each subject based on their answers given in the stress and relaxation questions. A number from 1 to 9 was assigned to the stress answer; 9 being the most stressed, 1 not at all. A number was also assigned to the relaxation answer; 1 being the most relaxed, 9 very tense. The difference between the two values would give the stress level. However, the results were unsatisfactory. Many students 'achieved' a negative and

0 stress level as shown in appendix I. Taken at face value, it would imply that those students were just as, or even more stressed after the test than before. Since that would not normally be the case, and the fact that the stress options in the questions did not conform to any empirical data but were arbitrarily formed, the stress levels calculated by the above method were not used in the group correlations. Instead, another approach involving class grades and perceived quiz grades were used in the correlations.

In general, when a person feels that he has performed a task well, he is more at ease and less stressed than if he thought he did poorly. The process of reward and punishment may have much to do with developing this type of mentality. From youth, we are trained by a series of affirmative, and sometimes negative reinforcements to do well academically. An 'A' on a test brings with it a smile, a pet on the head, and maybe even a 'treat'. Failing a test on the other hand, brings about disapproval, admonishment, and sometimes, more severe forms of punishment. By the time we get to college, this conditioning is not solely supplemented by the urge to please others, but to do well to please ourselves as well. Good grades probably mean a better paying job after graduation whereas bad grades may mean no job at all. Making a good grade becomes a source of satisfaction while failing causes frustration and anxiety. "The grade a student receives should have a strong influence at the outcome of the examination. The higher the grade, the better the person should feel about the exam and, conversely, the lower the grade, the worse he or she should feel." (Folkman, p.162). Thus it is not unreasonable to assume that subjects who performed well on the lab quiz would be more relaxed and less stressed than if they did poorly.

An attempt was made to categorize students based on amplitude, ratio, and interval differences between the pretest ECG and posttest ECG. Most of the students fell into 3 major groups. Group 1 subjects displayed an increase T wave peak, decreased P-R interval, decreased Q-T interval, and an increased T-P interval. Group 2 subjects showed increased T wave peaks, increased P-R interval, increased Q-T interval, and a decreased T-P interval. Group 3 subjects had no change in T wave amplitude, T/R ratio, or interval changes. These 3 major groups were further subdivided according to other parameters. However, analysis of the individuals within a group failed to provide a common link. Each group had a cross section of quiz grades, class grades, and varied perceived stress levels. No significant correlation was found that linked any group to either an increase or decrease in stress. The different heart rates and % changes in the amplitudes of the different wave types are listed in appendix I.

Categories formed by grouping individuals with similar changes in frequency and energy levels proved more interesting. The resultant major frequency peaks from the FFT analysis are listed in appendix J. Subjects were separated according to energy level changes and frequency shifts. A total of 10 distinct categories were formed. A description of each category can be found in appendix K. Even though there were 10 different categories, most of the students fitted into 4 major groups. Group A students' experienced an upward shift in their 2nd and 3rd frequency peaks. Group B students' 2nd and 3rd peaks shifted down. Only the 3rd frequency peak shifted down in group C, while group F had no significant frequency shifts. For a frequency peak to have been considered shifted, it must have moved at least two fundamental frequency locations either up or down. For the amplitude to be considered changed, there must have been at least a 5% increase or decrease. A common factor in the above 4 major groups was that all the students displayed great percentage increases in their 1st harmonic vector. In fact 92.1% of all subjects who took the quiz experienced significant energy increases in the first harmonic. The different individuals within each group, their grades, and 1st harmonic magnitude increases are listed in appendix L. In practical terms, the energy exhibited by the T wave is reflected in the magnitude of the 1st harmonic. In instances where the students were expecting a quiz, but did not receive one, only 1 person experienced an increase in the 1st harmonic. The other 4 subjects either did not experience any change in the harmonic, or the 1st harmonic actually decreased in magnitude. It was interesting to note that the sole student whose 1st harmonic increased when there was no quiz was failing the class at that time; the other 4 students were passing the course with a 'C' or better.

Within each major group, the class averages followed a normal grades distribution. In each case, there were a few 'A's, mostly 'B's, a few 'C's, a couple of 'D's, an the occasional 'F'. All the major groups held a proper ratio of grades represented (Appendix M). It can therefore be shown that the subject's overall grade does not affect what category he fits into. This is supported by a study which concluded that the GPA of a subject was unimportant in explaining the emotions experienced during preparation for an exam. Present, immediate concerns were more important than past performance (Folkman, pp. 165-166).

Correlating how the subjects thought they did on the quiz however, revealed some interesting trends. The table in Appendix N shows the tendency of the individuals within a group to cluster their performance ratings in a narrow range. Group A tended to make mostly 'A's, group B in the 'B'-'C' range, group C in the 'B' range, and group F in the 'A'-'B' range.

In instances where the 1st harmonic energy levels did not change, the subjects either did not take the quiz, or had physically exerted themselves (like running up the stairs) prior to the second recording.

Excluding subjects who did not take a quiz, and the individual who made it known he ran up the stairs, 35 out of 39 students showed an increase of 15% or more in the 1st harmonic amplitude. The majority of these 35 students showed much higher than a 15% increase; the most extreme case being a 163% increase.

Discussion

The tendency for grades within a group to cluster supported the theory that varied perceived levels of performance will affect the subject differently. If levels of stress reduction is directly related to how well the subject thinks he does on the quiz, then the various groups can be ranked in terms of stress by quiz grades.

In the few cases where a subject took the quiz but did not show an energy increase in the first harmonic, physical activity (rushing to the recording area) probably helped lower the 1st harmonic, which cancelled out the expected rise in energy level from the completion of the quiz. In cases where no quiz was given, a possible theory is that the subjects were unable to 'work off' their built up mental stress, nor did they have time for the stress to ebb away before the second recording was taken. Thus, there was no change.

In the few instances where the 1st harmonic energy levels actually went down, no quiz was given. If stress-relaxation is tied to the 1st harmonic, then this decrease would signify an increase in mental stress. This explanation fits the data and can be easily rationalized. If the students felt angry that they had wasted their time and efforts, their mental stress levels would be higher during the second ECG recording. Even so, the average percentage decrease in the 1st harmonic is considerably less than the average percentage increase in cases where a test was given.

In a separate study, it was found that T-wave amplitude became attenuated during difficult mental tasks (Scher, p.326). Since the 1st harmonic reflected the T-wave energy level, which in almost all cases were higher in the posttest ECG, it can be concluded that the subjects were more mentally 'involved' during the pretest than the posttest periods. Higher 1st harmonic energies indicated less mental effort. Conversely, lower 1st harmonic energies indicated greater mental effort. Since mental effort implies mental stress, 1st harmonic levels could thus be used to determine the levels of stress once a baseline, relaxation state is known.

The major assumptions were that the students generally felt less stressed after taking the quiz than before, and that students were more relaxed if they had done well on the quiz than if they had not. Derived from these basic assumptions, the four major groups ranked from the most stress-relaxation to the least were, 1) group A 2) group F 3) group C 4) group B. If these groups actually represented scaled levels in mental stress, then it can be expected that the frequency components would likewise follow a gradual change. In fact, the frequency shifts of the ranked groups changed gradually with no discontinuities. The group that experienced the least stress-relaxation, group B, had both frequency peaks 2 and 3 shifted down. Group C, which experienced a little more stress level reductions, had only its 3rd frequency peak shifted down. Group F, which experienced more stress reduction than either of the above groups, did not show any frequency changes. Group A, which experienced the highest level of stress reduction, had frequency peaks 2 and 3 shifted up. It may therefore be concluded that in addition to increased energy levels in the 1st harmonic, frequency shifts of the 2nd and 3rd peaks occur after completing of the quiz. Performance levels on the quiz dictate how the frequency peaks shift. The better the perceived quiz grade, the more the peaks shifted up. On the other hand, the worse the perceived performance, the more the peaks shifted down.

Perhaps the same changes in the ECG occur when going from an unstressed to a stressed state. However, the experimental data are insufficient to support such a claim. What the experiment does show is that definite changes in the ECG occur after a test, which can be correlated to how well the subjects did. The psychological states of the individuals in each case are at best still ambiguous. It is beyond the scope of this experiment to exactly determine the psychological changes that the subjects experienced. Perhaps a different experiment which concentrated on the psychological aspects of test taking would provide a more precise link between the different mental stresses and the changes in the ECGs.

References

Folkman, S., and Lazarus, R.S. (1985). If it Changes it Must be a Process: Study of Emotion and Coping During Three Stages of a College Examination. _Journal of Personality and Social Psychology_, _48_, 150-170.

Guyton, A. (1981). _Textbook of Medical Physiology_. 6th Ed. Philadelphia: W.B. Saunders Company.

Lazarus, R.S. (1966). _Psychological Stress and the Coping Process_. New York: McGraw-Hill.

Scher, H., Furedy, J., and Heslegrave, R. (1984). Phasic T-Wave Amplitude and Heart Rate Changes as Indices of Mental Effort and Task Incentive. _Psychophysiology_, _21_, 326-333.

Footnotes

(1) Precision Isolation Amplifier. Input impedence 4 MegaOlms. Gain Error 0.5% max. Gain 2000X.

(2) Dash8 Analog to Digital Converter. 8-channel, 12-bit, successive approximation A/D converter with full scale input of +/- 5 volts and resolution of .00244 volts.

(3) 87FFT version 2.03 Fast Fourier Transform Utility Package. Copyright 1985. Microway, P.O. Box 79. Kingston, Mass. 02364 USA.

(4) Microsoft QuickBasic Compiler, version 1.02. Copyright 1985. Microsoft Corporation, 10700 Northup Way. Box 97200, Bellevue, Wa 98009. Needs 256K memory and Dos 2.0 or higher.

Appendix A

(4)

ECG STRESS TEST QUESTIONNAIRE

PRE-TEST (circle your answer)

1) Did you have a good night's rest? (Yes / No)

2) How prepared are you for this test?

very / adequately / moderately / barely / not at all

3) What is your present grade in this course? (A / B / C / D / F)

4) Have you been ill in the past week? (Yes / No)

5) How stressed do you feel now?

total nervous wreck / extremely anxious / very stressed
moderately stressed / slightly nervous / sort of tense
barely worried / not at all worried / cool as ice

POST-TEST (circle your answer)

1) Estimate your performance on today's quiz (A / B / C / D / F)

2) Did you have enough time to finish the test? (Yes / No)

3) How relaxed are you now?

limp as a noddle / extremely calm / very relaxed
pretty settled / almost relaxed / a little jumpy
moderately upset / very angry / screaming mad

Analysis of

	da4		db4		
Heart Rate =	82.1168 bpm		73.7595 bpm		
average P wave ampl =	79.46154		83.25		4 % diff
average Q wave ampl =	454.9231		442.0834		-3 % diff
average T wave ampl =	207.0769		212.5833		2 % diff
avg T/R ratio =	45 %		48 %		3 % diff
avg P-Q interval =	54	(14 %)	55	(13 %)	
avg Q-T interval =	107	(29 %)	110	(27 %)	
avg T-P interval =	203	(55 %)	240	(59 %)	

stress factor (1-2) = 0

D

Appendix B

ECG Recording Program

```
1 CLS:KEY OFF
2 DASH8=0:DIM Z%(5010)
3 GOTO  10000
5 DEF SEG = &H2000
8 BLOAD "TIDASH.BIN",0
10 MD%=0:BASADR%=&H300:FLAG%=X
20 CALL DASH8 (MD%,BASADR%,FLAG%)
30 MD%=1:LT%(0)=1:LT%(1)=1
40 CALL DASH8 (MD%,LT%(0),FLAG%)
50 MD%=2:CH%=1
60 CALL DASH8(MD%,CH%,FLAG%)
70 MD%=10:DIO%(0)=2:DIO%(1)=3
80 CALL DASH8(MD%,DIO%(0),FLAG%)
81 IF DIO%(0)=2 THEN DIO%(0)=1 :GOTO 80
85 SAM=INT(2386400!/1000+.5):REM SAMPLING RATE OF 500/SEC
90 MD%=11:DIO%(0)=2:DIO%(1)=SAM
100 CALL DASH8(MD%,DIO%(0),FLAG%)
101 IF DIO%(0)=2 THEN DIO%(0)=1 :DIO%(1)=2:GOTO 100
200 CLS:INPUT "NAME OF FILE ";N$
210 PRINT:PRINT"PRESS ANY KEY TO BEGIN SAMPLING
    DATA":A$=INPUT$(1)
300 CLS
1110 REM STARTS COLLECTING DATA FROM ADC
1120 MD%=5:TRAN%(0)=VARPTR(Z%(0)):TRAN%(1)=5000
1130 CALL DASH8(MD%,TRAN%(0),FLAG%)
2000 REM GRAPHICS WOW BIG DEAL
2005 CLS
2007 PSET (0,150-Z%(1)/4)
2010 FOR X=1 TO 710 STEP 2
2020 Y =Z%(X*2)/7   :REM 4    IS SCALING FACTOR FOR GRAPH IN
     Y DIR 2030 LINE -(X,150-Y),4
2040 NEXT X
2500 IF NG=1 THEN LOCATE 22,1:PRINT "PRESS KEY TO CONTINUE":
     C$=INPUT$(1):GOTO 10000
3000 LOCATE 22,1:PRINT "IF GRAPH OK (Y/N)? ";:Y$=INPUT$(1):IF
     Y$="N" THEN GOTO 210
3050 LOCATE 22,1:PRINT "WANT TO SAVE IT?
     (Y/N)":Y$=INPUT$(1):IF Y$="N" THEN GOTO 5000
3100 LOCATE 22,1:PRINT "SAVE IT AS  ";N$;" (Y/N)
     ":Y$=INPUT$(1):IF Y$="Y" THEN GOTO 4000
3200 LOCATE 23,1:INPUT "NAME OF FILE = ",N$
4000 OPEN "O",#1,N$
4100 FOR X=1 TO 5000:PRINT #1,Z%(X):NEXT X:CLOSE
5000 GOTO 10100
7000 REM RETRIEVES GRAPH AND DRAWS IT
7003 INPUT "NAME OF FILE TO RETRIEVE ",N$
7100 OPEN "I",#1,N$
7200 FOR X=1 TO 5000:INPUT #1,Z%(X):NEXT X:CLOSE
7300 NG=1:GOTO 2000
8000 REM TRANSFER FILES FROM HARD TO FLOPPY
10000 REM MAIN MENU
10100 CLS:COLOR 5
```

```
10200 LOCATE 3,18:PRINT "ELECTROCARDIAGRAM DATA COLLECTOR "
10300 COLOR 6:LOCATE 7,1:PRINT "1) BEGIN TO SAMPLE ECG "
10400 LOCATE 9,1:PRINT"2) RETRIEVE ECG FROM DISK"
10500 LOCATE 20,1:INPUT "WHAT WILL IT BE? ",W$
10600 IF W$="1" THEN GOTO 5
10700 IF W$="2" THEN GOTO 7000
10800 GOTO 10500
```

Appendix C

Wave Type and Segment Program

```
1 CLS:KEY OFF:DEFINT B
2 DIM Z%(5010), B(532),CX(40),Q(30),P(30),T(30),QM(30),
  PM(30),TM(30) 3 LINE (0,50)-(700,50),2
5 GET (0,50)-(700,51),B
7 LINE (0,5)-(10,5),2:LINE (5,0)-(5,10),2:GET (0,0)-
  (10,10),CX
100 GOTO 7000
1000 REM
2005 CLS
2007 PSET (5,150-Z%(A )/7),4
2010 FOR X=   1 TO   705 STEP 1
2015 IF X*2+A>5000 THEN GOTO 2040
2020 Y =Z%(X*2+ A)/7   :REM 4    IS SCALING FACTOR FOR GRAPH
     IN Y DIR 2030 LINE -(X+5,150-Y),4
2040 NEXT X
3000 LOCATE 4,64:COLOR 4:PRINT N$:LINE (500,40)-(550,40),4
3030 LINE (0,265)-(710,265),4: FOR X=0 TO 710 STEP 250:LINE
     (X,260)-(X,268):NEXT X 3100 IF S$="S" OR S$="s" THEN
     GOTO 3700
3200 GOSUB 35000
3700 PUT (0,0),CX,XOR:X=0:Y=145
4000 RETURN
7000 REM RETRIEVES TWO GRAPHS
7001 CLS:PRINT:COLOR 5:PRINT "      This Program allows
     designation of P,QRS,T waves"
7002 COLOR 6
7003 PRINT:PRINT:INPUT "Name of file to retrieve ",N$
7005 COLOR 5:PRINT:PRINT"Desinate peaks(P) OR FFT segment(S)?
     ";: S$=INPUT$(1)
7008 IF S$="S" OR S$="s" THEN PRINT:PRINT:PRINT "J to
     move left, K to move right": PRINT:PRINT"space bar sets
     boundary, E erases boundaries":PRINT:PRINT "When
     boundaries are set, the signal segment can be saved to
     disk":GOTO 7100
7010 COLOR 5:PRINT:PRINT"Pressing 'j' or 'k' will move
     the pointer right or left on the graph"
7020 PRINT:PRINT"At the peak of each wave, press either
     'p','q', or 't' for the various"
7030 PRINT:PRINT"wave types. Moving the pointer past the
     right edge of the screen "
7040 PRINT:PRINT"   will advance to the next portion of the
     graph."
7050 PRINT:PRINT"When all the wave points have been entered,
     press 'Z' to escape and"
7060 PRINT:PRINT"   to save the information on to the disk."
7100 OPEN "I",#1,N$ 7200 FOR X=1 TO 2000:INPUT #1,Z%(X):NEXT
     X:CLOSE
8500 GOSUB 1000
10000 D$=INPUT$(1)
10005 OX=X  :OY=145-Y
10010 IF D$="j" THEN X=X-1  :IF X<0 THEN X=0
10015 IF D$="J" THEN X=X-10  :IF X<0 THEN X=0
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10017 IF X*2+A>4989 THEN GOTO 10045
10020 IF D$="k" THEN X=X+1  :IF X>705 THEN A=A+705*2:GOSUB
      1000:OX=0:OY=0
10030 IF D$="K" THEN X=X+10: IF X>705 THEN
      A=A+705*2:GOSUB 1000:OX=0:OY=0
10032 IF (S$="s" OR S$="S") AND D$="E" THEN
      BON1=0:BOUN=0:LOCATE 4,32,0:PRINT" "
10035 IF (S$="s" OR S$="S") AND D$=" " THEN
      BOUN=BOUN+1:LINE (X+5,50)-(X+5,298),2:IF BOUN=1 THEN
      BON1=X*2+A
10037 IF (S$="s" OR S$="S") AND BOUN=1 THEN LOCATE
      4,32,0:PRINT "seg length = ";ABS(X*2+A-BON1);" "
10040 IF (S$="s" OR S$="S") AND BOUN=2 THEN GOTO 40000
10045 Y=Z%(X*2+A)/7
10047 PUT (OX,OY),CX,XOR
10050 PUT (X  ,145-Y),CX,XOR
10060 LOCATE 1,1:COLOR 3:PRINT"XPOS":LOCATE 1,50:PRINT"MAG"
10070 LOCATE 2,1:COLOR 5:PRINT X*2+A:LOCATE 2,50,0:PRINT
      Z%(X*2+A) 10075 IF S$="s" OR S$="S" THEN GOTO 10200
10080 IF D$="P" OR D$="p" THEN PN=PN+1:P(PN)=X*2+A:
      PM(PN)=Z%(P(PN))-BL: CIRCLE (X+5,150-Y),3,2
10090 IF D$="Q" OR D$="q" THEN QN=QN+1:Q(QN)=X*2+A:
      QM(QN)=Z%(Q(QN))-BL:CIRCLE (X+5,150-Y),3,2
10100 IF D$="T" OR D$="t" THEN TN=TN+1:T(TN)=X*2+A:TM(TN)=
      Z%(T(TN))-BL: CIRCLE (X+5,150-Y),3,2
10150 IF D$="Z" THEN GOTO 20000
10200 GOTO 10000
20000 CLS
20005 PRINT
20010 PRINT"p at ";:FOR X=1 TO PN:PRINT P(X);"(";
      Z%(P(X));")",: NEXT X
20015 PRINT
20020 PRINT"q at ";:FOR X=1 TO QN:PRINT Q(X);"(";
      Z%(Q(X));")",:NEXT X
20025 PRINT
20030 PRINT"t at ";:FOR X=1 TO TN:PRINT T(X);"(";
      Z%(T(X));")",:NEXT X
30000 N1$="D"+N$
30010 COLOR 5:PRINT:PRINT "SAVE IT AS ";:COLOR 6:PRINT
      N1$;:COLOR 5:PRINT"? (Y/N)";
32000 A$=INPUT$(1):IF A$ ="Y" OR A$ ="y" THEN GOTO 33000
32100 PRINT:PRINT:PRINT"name of file : ";:INPUT N1$
33000 PRINT:OPEN "O",#1,N1$
33500 PRINT #1,PN
34000 FOR X=1 TO PN:PRINT #1,P(X):PRINT #1,PM(X)   :NEXT X
34005 PRINT #1,QN
34010 FOR X=1 TO QN:PRINT #1,Q(X):PRINT #1,QM(X)   :NEXT X
34015 PRINT #1,TN
34020 FOR X=1 TO TN:PRINT #1,T(X):PRINT #1,TM(X)   :NEXT X
34021 CLOSE
34022 PRINT:PRINT:PRINT"do FFT Segment or Quit (S/Q)";
      :S$=INPUT$(1):IF S$="Q" OR S$="q" THEN END
34025 A=0:BOUN=0:GOTO 8500
34040 END
```
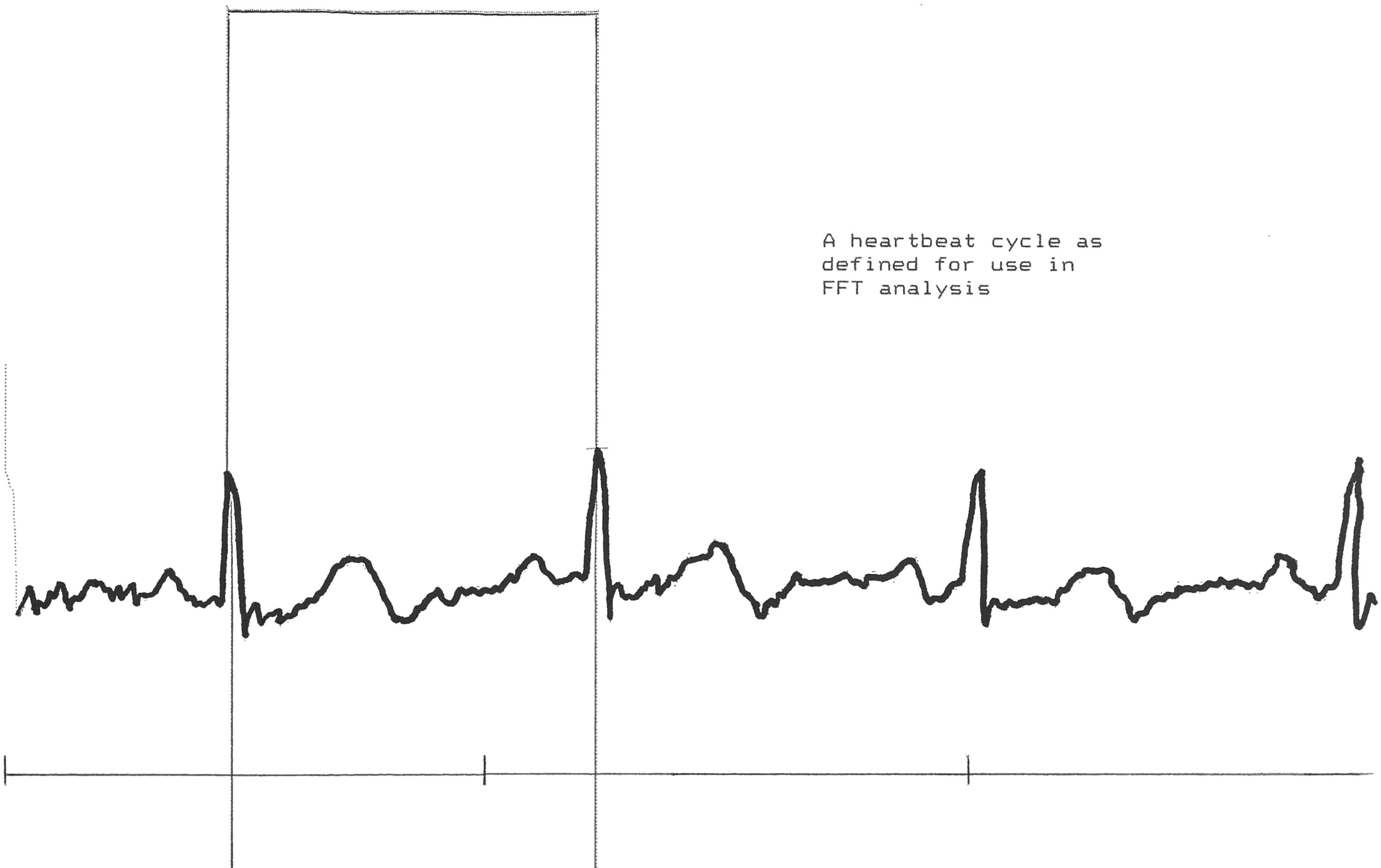

```
35000 COLOR 4
35010 PUT (0,150),B,XOR:OY=150:Y=150
35100 LOCATE 3,1,0:PRINT "Set base line (I-up, M-down, Z-
      finish) 35120 A$=INPUT$(1)
35125 PUT (0,OY),B,XOR
35130 IF A$="I" THEN Y=Y-5:IF Y<0 THEN Y=0
35140 IF A$="i" THEN Y=Y-1:IF Y<0 THEN Y=0
35150 IF A$="M" THEN Y=Y+5:IF Y>280 THEN Y=280
35160 IF A$="m" THEN Y=Y+1:IF Y>280 THEN Y=280
35165 PUT (0,Y),B,XOR:OY=Y
35170 IF A$="Z" THEN BL=(150-Y)*7:LOCATE 3,1,0:PRINT "
      ":RETURN
35200 GOTO 35120
40000 BXN1=(BON1/2)-A+5
40050 LINE (X+5,50)-(BXN1,50),2:LINE(X+5,298)-(BXN1,298),2
40100 CLS 2
40200 PRINT:PRINT"Is segment ok (Y/N)? ";:W$=INPUT$(1):IF
      W$="N" OR W$="n" THEN D$="E":LINE(X+5,50)-
      (BXN1,50),8:LINE -(BXN1,298),8:LINE -(X+5,298),8:LINE -
      (X+5,50),8: GOTO 10032
40300 IF BON1>X*2+A THEN BON2=BON1:BON1=X*2+A:ELSE BON2=X*2+A
40400 BLEN=BON2-BON1
40500 N2$="F"+N$
40510 PRINT:PRINT "save it as ";N2$;" (Y/N)?
      ";:W$=INPUT$(1):IF W$<>"y" AND W$<>"Y" THEN
      PRINT:PRINT"name of file? ";:INPUT N2$
40530 OPEN N2$ FOR OUTPUT AS #1
40550 FOR X=BON1 TO BON2
40560 PRINT #1, Z%(X)
40570 NEXT X
40572 FOR X= BON2 TO 513:PRINT #1,0:NEXT X
40580 CLOSE
40600 CLS:PRINT"designate Points,Quit,Do another (P/Q/D)
      ";:S$=INPUT$(1):IF S$="Q" OR S$="q" THEN END
40650 IF S$<>"d" AND S$<>"D" AND S$<>"P" AND S$<>"p" THEN
      GOTO 40600
40660 IF S$="d" OR S$="D" THEN CLEAR:GOTO 1
40700 BOUN=0:GOTO 8500
```

Appendix D

B7



A heartbeat cycle as defined for use in FFT analysis

Appendix E

Averaging and Heart Rate Program

```
2 KEY OFF
5 COLOR 5
10 CLS:PRINT"    Program analyzes data established by ZSTAT
   prog."
15 '------------ Load file -------------------
20 GOSUB 32100
30 COLOR 5
35 ' ----------- Calculate averages ------------
40 SUM=0:FOR X=1 TO PN:SUM=SUM+PM(X):NEXT X
50 AVGP=SUM/PN
55 SUM=0:FOR X=1 TO PN2:SUM=SUM+PM2(X):NEXT X
57 AVGP2=SUM/PN2
60 SUM=0:FOR X=1 TO QN:SUM=SUM+QM(X):NEXT X
70 AVGQ=SUM/QN
75 SUM=0:FOR X=1 TO QN2:SUM=SUM+QM2(X):NEXT X
77 AVGQ2=SUM/QN2
80 SUM=0:FOR X=1 TO TN:SUM=SUM+TM(X):NEXT X
90 AVGT=SUM/TN
95 SUM=0:FOR X=1 TO TN2:SUM=SUM+TM2(X):NEXT X
97 AVGT2=SUM/TN2
98 ' --------- Calculate increases ---------------
100 DIF=0:FOR X=1 TO QN:DIF=DIF+(Q(X)-P(X)):NEXT X
110 AVGPQ=DIF/QN
115 DIF=0:FOR X=1 TO QN2:DIF=DIF+(Q2(X)-P2(X)):NEXT X
117 AVGPQ2=DIF/QN2
120 DIF=0:FOR X=1 TO TN:DIF=DIF+(T(X)-Q(X)):NEXT X
130 AVGQT=DIF/TN
135 DIF=0:FOR X=1 TO TN2:DIF=DIF+(T2(X)-Q2(X)):NEXT X
137 AVGQT2=DIF/TN2
140 DIF=0:FOR X=1 TO PN-1:DIF=DIF+(P(X+1)-T(X)):NEXT X
150 AVGTP=DIF/(PN-1)
155 DIF=0:FOR X=1 TO PN2-1:DIF=DIF+(P2(X+1)-T2(X)):NEXT X
157 AVGTP2=DIF/(PN2-1)
158 ' ---------- Calculate Heart Rate ---------------
160 HR=(QN-1)*500/(Q(QN)-Q(1))*60
163 HR2=(QN2-1)*500/(Q2(QN2)-Q2(1))*60
164 ' ---------- Print Out Results ------------------
165 CLS:COLOR 7:PRINT TAB(30) "Analysis of " :COLOR 5:PRINT
    TAB(24) N$;:COLOR 6:PRINT TAB(42) N2$
167 PRINT
170 COLOR 4:PRINT TAB(10) "Heart Rate = ";:COLOR 5:PRINT HR;"
    bpm";:COLOR 6:PRINT TAB(40) HR2;" bpm"
180 COLOR 4:PRINT:PRINT"average P wave ampl = ";:COLOR
    5:PRINT AVGP;:COLOR 6:PRINT TAB(40) AVGP2;:COLOR 4:PRINT
    TAB(60) INT((AVGP2-AVGP)/AVGP*100) TAB(64) "% diff"
190 COLOR 4:PRINT"average Q wave ampl = ";:COLOR 5:PRINT
    AVGQ;:COLOR 6:PRINT TAB(40) AVGQ2;:COLOR 4:PRINT TAB(60)
    INT((AVGQ2-AVGQ)/AVGQ*100) TAB(64) "% diff"
200 COLOR 4:PRINT"average T wave ampl = ";:COLOR 5:PRINT
    AVGT;:COLOR 6:PRINT TAB(40) AVGT2;:COLOR 4:PRINT TAB(60)
    INT((AVGT2-AVGT)/AVGT*100) TAB(64) "% diff"
205 TINT=AVGPQ+AVGQT+AVGTP:TINT2=AVGPQ2+AVGQT2+AVGTP2
```

```
210 COLOR 4:PRINT:PRINT TAB(4) "avg P-Q interval = ";:COLOR
    5:PRINT INT(AVGPQ) TAB(28) "(";INT(AVGPQ/TINT*100);"%)";
    :COLOR 6:PRINT TAB(40) INT(AVGPQ2) TAB(45) "(";
    INT(AVGPQ2/TINT2*100);"%)" 220 COLOR 4:PRINT TAB(4) "avg
    Q-T interval = ";:COLOR 5:PRINT INT(AVGQT) TAB(28) "
    (";INT(AVGQT/TINT*100);"%)";:COLOR 6:PRINT TAB(40)
    INT(AVGQT2) TAB(45) " (";INT(AVGQT2/TINT2*100);"%)"
230 COLOR 4:PRINT TAB(4) "avg T-P interval = ";:COLOR 5:PRINT
    INT(AVGTP) TAB(28) " (";INT(AVGTP/TINT*100);"%)";:COLOR
    6:PRINT TAB(40) INT(AVGTP2) TAB(45) "
    (";INT(AVGTP2/TINT2*100);"%)"
235 PRINT:PRINT " ";
240 IF HR>HR2 THEN COLOR 5:PRINT "A  ";:ELSE COLOR 6:PRINT "B
    ";
242 IF AVGP>AVGP2 THEN COLOR 5:PRINT "A  ";:ELSE COLOR
    6:PRINT "B  ";
244 IF AVGQ>AVGQ2 THEN COLOR 5:PRINT "A ";:ELSE COLOR 6:PRINT
    "B  ";
246 IF AVGT>AVGT2 THEN COLOR 5:PRINT "A  ";:ELSE COLOR
    6:PRINT "B  ";
248 IF AVGPQ/TINT>AVGPQ2/TINT2 THEN COLOR 5:PRINT "A  ";:ELSE
    COLOR 6:PRINT "B  ";
250 IF AVGQT/TINT>AVGQT2/TINT2 THEN COLOR 5:PRINT "A  ";:ELSE
    COLOR 6:PRINT "B  ";
252 IF AVGTP/TINT>AVGTP2/TINT2 THEN COLOR 5:PRINT "A  ";:ELSE
    COLOR 6:PRINT "B  "
298 LINE (0,155)-(185,166),4,B
300 '------- plot wave forms--------------------------------
310 IF AVGQ<AVGQ2 THEN FAC=150/AVGQ2:ELSE FAC=150/AVGQ
320 LINE (400,300)-(420,300-AVGP*FAC),5,B :PAINT(410,298),5,5
330 LINE (500,300)-(520,300-AVGQ*FAC),5,B :PAINT(510,298),5,5
340 LINE (600,300)-(620,300-AVGT*FAC),5,B :PAINT(610,298),5,5
350 LINE (410,300)-(430,300-AVGP2*FAC),6,B:PAINT(420,298),6,6
360 LINE (510,300)-(530,300-AVGQ2*FAC),6,B:PAINT(520,298),6,6
370 LINE (610,300)-(630,300-AVGT2*FAC),6,B:PAINT(620,298),6,6
500 LOCATE 2,1,0:A$=INPUT$(1)
10000 END
32100 '---------- Retrieve files -------------------
32110 PRINT:PRINT:PRINT"name of file : ";:COLOR 6:INPUT N$
33000 PRINT:OPEN "I",#1,N$
33500 INPUT #1,PN
33510 DIM P(PN),PM(PN)
34000 FOR X=1 TO PN:INPUT #1,P(X),PM(X):NEXT X
34005 INPUT #1,QN
34008 DIM Q(QN),QM(QN)
34010 FOR X=1 TO QN:INPUT #1,Q(X),QM(X):NEXT X
34015 INPUT #1,TN
34018 DIM T(TN),TM(TN)
34020 FOR X=1 TO TN:INPUT #1,T(X),TM(X):NEXT X
34030 CLOSE
34500 PRINT:COLOR 5:PRINT "load another?
(Y/N)";:A$=INPUT$(1):IF A$="n" OR A$="N" THEN RETURN
34600 PRINT:PRINT "name of file 2 : ";:COLOR 6:INPUT N2$
34620 PRINT:OPEN "I",#1,N2$
```

```
34630 INPUT #1,PN2
34640 DIM P2(PN2),PM2(PN2)
34650 FOR X=1 TO PN2:INPUT #1,P2(X),PM2(X):NEXT X
34660 INPUT #1,QN2
34670 DIM Q2(QN2),QM2(QN2)
34680 FOR X=1 TO QN2:INPUT #1,Q2(X),QM2(X):NEXT X
34690 INPUT #1,TN2
34700 DIM T2(TN2),TM2(TN2)
34710 FOR X=1 TO TN2:INPUT #1,T2(X),TM2(X):NEXT X
34730 CLOSE
35000 RETURN
```

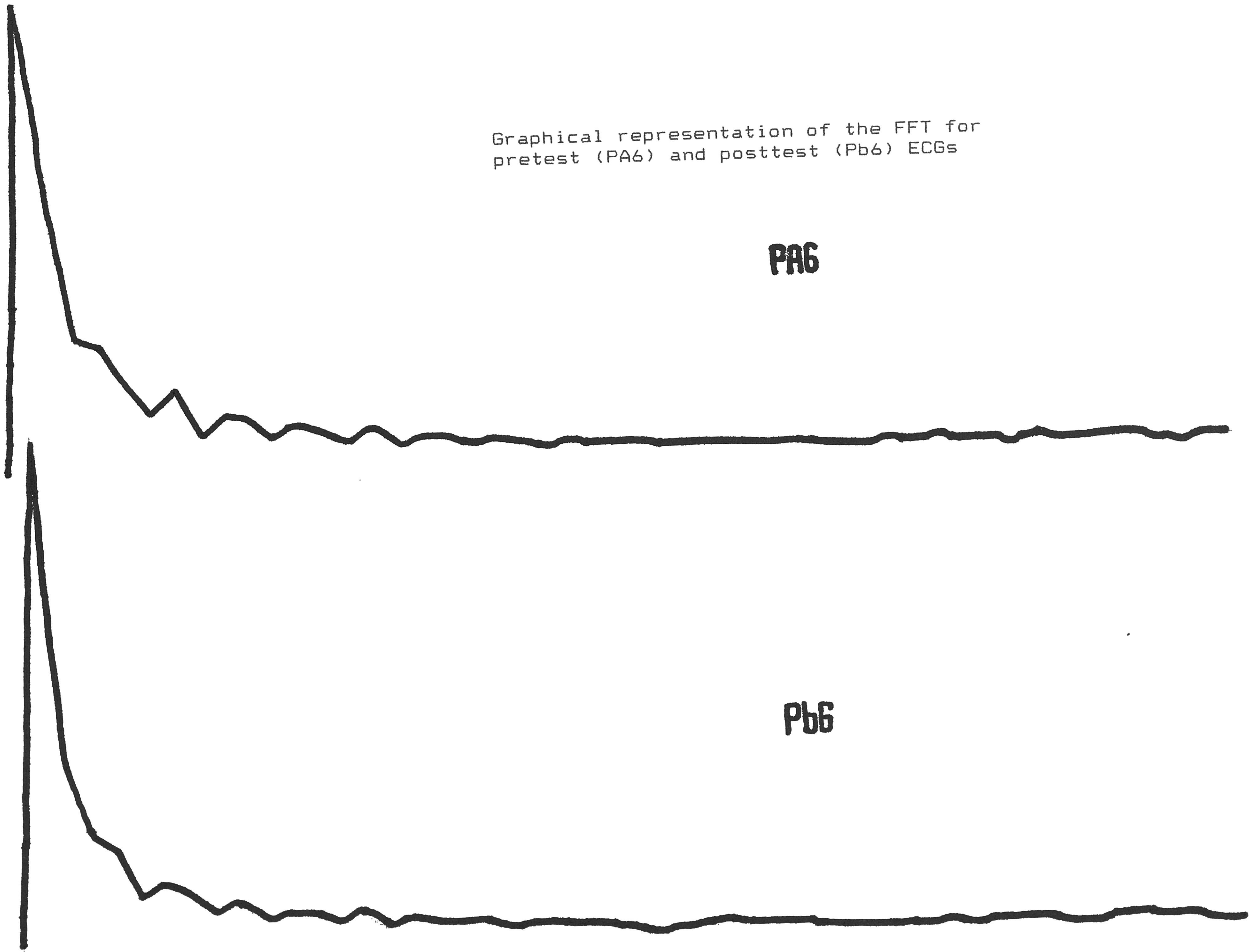
Appendix F

FFT Program

```
15 DEFINT M,N,I
20 DIM A(1050),B(1050),A1(1050),B1(1050)
30 CLS:INPUT "What is the Record # ",N$
32 ' ---------- Retrieves First ECG segment ---------
35 N1$="fa"+N$
40 OPEN N1$ FOR INPUT AS #1
60 INPUT #1, A(I)
65 I=I+1
70 IF EOF(1) THEN CLOSE:PRINT I:FOR Z=I TO 1050:A(Z)=0:NEXT
   Z:GOTO 200
80 GOTO 60
200 ' --------- Retrieves Second ECG segment --------
205 N2$="FB"+N$:I=0
210 OPEN N2$ FOR INPUT AS #1
220 INPUT #1,B(I)
230 I=I+1
240 IF EOF(1) THEN CLOSE:PRINT I:FOR Z=I TO 1050:B(Z)=0:NEXT
    Z:GOTO 300
250 GOTO 220
300 ' -------- Set Parameters for FFT routines -------
302  M   =10
304  MODE=2
306  SCALE=1
308    N=250
400 ' ------- Performing Hamming Window on data ------
401 CALL HAMM(A(0),A1(0),M)
410 CALL HAMM(B(0),B1(0),M)
417 FOR I=0 TO 10:PRINT B(I);" ";:NEXT I:PRINT
420 FOR I=0 TO 10:PRINT A1(I);" ";:NEXT I
425 ' ----------- Performing Real FFT on data -------
430 CALL RFFT(A1(0), M,MODE,SCALE):PRINT:PRINT M,MODE,SCALE
432 CALL RFFT(B1(0), M,MODE,SCALE)
450 PRINT:FOR I=0 TO 10:PRINT A1(I);" ";:NEXT I
451 ' -- Transforming from complex to Polar Coordinates ---
452 MODE=1
453 CALL POLAR(A1(0), A1(0), N, MODE ):PRINT:PRINT N,MODE
454 CALL POLAR(B1(0), B1(0), N, MODE )
455 ' ----- Saving FFT from 1st ECG segment ---------------
456 N3$="B:PA"+N$
457 OPEN N3$ FOR OUTPUT AS #1
460 FOR I=0 TO 500
470 PRINT #1,A1(I)
500 NEXT I
510 CLOSE
515 ' ----- Saving FFT from 2nd ECG segment --------------
520 N4$="B:PB"+N$
530 OPEN N4$ FOR OUTPUT AS #1
540 FOR I=0 TO 500
550 PRINT #1,B1(I)
560 NEXT I
570 CLOSE
580 CLEAR:GOTO 15
```

Appendix G

Graphical representation of the FFT for
pretest (PA6) and posttest (Pb6) ECGs



Appendix H

Frequency Peak and Location Program

```
10 ' find fft peak values
12 DIM B$(30)
15 DIM Z(202),P(50),BP(5)
20 INPUT "Number of files to process",NF
40 FOR Y=1 TO NF:INPUT "file # = ",B$(Y):NEXT Y
50 FOR XY=1 TO NF
60 ' load data part A
65 N$="pa"+B$(XY)
70 GOSUB 1000
80 ' -----------------------------find all peaks
90 GOSUB 2000
100 '----------------------------- find 4 highest peaks
110 GOSUB 3000
112 LPRINT TAB(10) "FFT peaks for subject ";B$(XY)
114 LPRINT:LPRINT TAB(12) "Before test ECG"
120 '----------------------------- print out results
130 GOSUB 4000
140 '----------------------------- repeat for data part B
145 N$="pb"+B$(XY)
150 GOSUB 1000
160 GOSUB 2000
170 GOSUB 3000
174 LPRINT:LPRINT TAB(12) "After  test ECG"
180 GOSUB 4000
185 LPRINT:LPRINT
187  IF ND=6 THEN ND=0:LPRINT CHR$(12);
190 NEXT XY
200 GOTO 20
1000 ' subroutine to load data ------------------------------
1010 OPEN N$ FOR INPUT AS #1
1020 FOR X=0 TO 200:INPUT #1,Z(X):NEXT X
1030 CLOSE
1040 RETURN
2000 ' subroutine to pick peaks -----------------------------
2010 Z(0)=0
2020 FOR X=2 TO 200 STEP 2
2030 IF Z(X)>Z(X-2) AND Z(X)>Z(X+2) THEN I=I+1:P(I)=X
2040 NEXT X
2050 RETURN
3000 ' subroutine to pick 4 highest peaks -------------------
3005 OLP=-200
3010 FOR Y=1 TO 4
3020 FOR X=1 TO I
3030 FOR Z=1 TO Y-1:IF P(X)=BP(Z) THEN NG=1
3035 NEXT Z
3040 IF NG=1 THEN GOTO 3070
3050 IF Z(P(X))>OLP THEN OLP=Z(P(X)):OLX=P(X)
3070 NG=0
3080 NEXT X
3090 BP(Y)=OLX
3100 OLP=-200
3110 NEXT Y
```

```
3120 RETURN
4000 ' subroutine to print peak location & values -----------
4030 LPRINT TAB(15) "location" TAB(50) "magnitude"
4031 LPRINT
4040 FOR X=1 TO 4:LPRINT TAB(17) BP(X)/2 TAB(50)
     Z(BP(X)):NEXT X
4045 FOR X=1 TO I:P(X)=0:NEXT X:FOR X=1 TO 4:BP(X)=0:NEXT
     X:I=0
4048 ND=ND+1
4050 RETURN
```

Appendix I

#	HR1(bpm)	HR2(bpm)	P %inc	QRS %inc	T %inc	stress
1	61	52	3	0	10	0
3	72	78	0	-5	14	0
4	82	74	4	-3	2	0
5	65	52	11	-4	21	-3
6	53	55	21	40	33	-1
7	77	80	2	-5	-5	-3
8	67	65	-20	-12	-15	1
9	64	70	-11	4	-7	5
10	86	76	12	1	16	1
11	58	57	-1	31	-9	-1
12	61	63	1	1	0	2
13	68	74	6	10	8	0
14	64	56	-2	-5	-9	-1
15	65	64	-1	2	0	-2
16	64	67	13	9	6	-1
17	89	114	14	-6	31	-7
18	67	64	3	6	9	-2
19	68	63	-31	-25	-25	-1
20	60	62	-26	-22	2	0
21	77	79	-13	-5	-6	-2
22	56	53	12	5	-4	0
23	79	76	-19	-18	-4	0
24	82	77	2	11	11	0
27	78	75	3	-2	-2	-1
28	66	60	-11	-2	-7	3
29	55	60	-6	-13	-2	2
30	59	56	-8	-1	-1	1
31	84	82	8	2	6	0
32	73	69	10	13	25	1
34	93	83	15	30	-1	-2
35	67	62	5	-4	51	-2
36	71	80	17	-17	19	-1
37	80	67	-12	-1	-17	1
39	73	81	9	-1	6	1
40	77	71	26	2	-7	1
41	44	42	5	28	19	0
42	64	66	2	11	55	-3
43	68	71	-3	-5	9	-2
44	81	76	25	2	7	-1
45	78	84	4	0	-8	0
46	64	63	-4	2	-13	0
47	60	78	6	6	17	0
48	71	71	24	43	0	0
49	66	70	-5	-11	4	-2
50	61	61	12	-1	-9	-2

Appendix J

FFT peaks for subject 1

Before test ECG

location	magnitude
1	23.70263
11	7.808779
5	7.597137
14	7.486438

After test ECG

location	magnitude
1	46.24395
4	11.87744
6	9.440404
9	9.179469

FFT peaks for subject 3

Before test ECG

location	magnitude
1	72.5344
8	10.55807
10	8.613231
14	7.386226

After test ECG

location	magnitude
1	71.82688
6	15.27176
10	10.25327
14	7.394955

FFT peaks for subject 4

Before test ECG

location	magnitude
1	46.37812
7	11.52038
11	8.205838
16	7.12635

After test ECG

location	magnitude
1	62.18339
7	14.30395
11	8.358042
16	6.99185

FFT peaks for subject 5

Before test ECG

location	magnitude
1	53.57616
5	12.41124
9	8.779946
13	4.93846

After test ECG

location	magnitude
1	84.94328
5	17.65229
8	13.33554
12	7.450265

FFT peaks for subject 6

Before test ECG

location	magnitude
1	162.0985
6	21.24943
9	14.2494
11	10.44347

After test ECG

location	magnitude
1	189.1337
7	25.9846
9	16.88679
12	13.10738

FFT peaks for subject 7

Before test ECG

location	magnitude
1	80.71072
7	16.71238
10	10.00982
13	9.483708

After test ECG

location	magnitude
1	112.5678
9	14.22474
15	9.84645
20	5.021517

FFT peaks for subject 8

Before test ECG

location	magnitude
1	85.04862
5	21.8366
8	19.18966
11	17.63394

After test ECG

location	magnitude
1	83.93276
5	20.0877
8	18.01578
12	13.57527

FFT peaks for subject 9

Before test ECG

location	magnitude
1	118.3722
7	16.37514
9	9.996716
12	9.688077

After test ECG

location	magnitude
1	138.0412
7	18.22732
10	12.49624
13	11.36009

FFT peaks for subject 10

Before test ECG

location	magnitude
1	32.34684
8	9.381247
14	6.99555
18	6.49421

After test ECG

location	magnitude
1	67.71605
6	13.99774
9	11.32685
13	8.588246

FFT peaks for subject 11

Before test ECG

location	magnitude
1	36.54922
5	9.110987
8	7.907718
14	7.295554

After test ECG

location	magnitude
1	92.52919
9	11.11202
11	9.028535
14	8.337561

FFT peaks for subject 12

Before test ECG

location	magnitude
1	73.52896
5	13.93781
8	11.29282
12	10.40653

After test ECG

location	magnitude
1	110.8393
7	15.01974
11	12.80204
14	11.46406

FFT peaks for subject 13

Before test ECG

location	magnitude
1	37.96594
6	8.821331
9	6.668745
16	6.286977

After test ECG

location	magnitude
1	36.6622
7	8.700688
12	5.601018
16	5.503924

FFT peaks for subject 14

Before test ECG

location	magnitude
1	19.29292
6	6.420562
17	5.688248
14	5.621229

After test ECG

location	magnitude
1	42.97696
4	11.35109
7	8.135641
10	5.908975

FFT peaks for subject 15

Before test ECG

location	magnitude
1	34.30423
14	17.76998
11	17.57335
17	17.16235

After test ECG

location	magnitude
1	88.42043
5	19.61453
7	16.05891
14	15.91468

FFT peaks for subject 16

Before test ECG

location	magnitude
1	93.71768
5	20.27926
8	15.80275
11	11.96777

After test ECG

location	magnitude
1	101.1796
6	22.05383
9	16.19233
13	12.91803

FFT peaks for subject 17

Before test ECG

location	magnitude
1	13.02305
17	5.895728
10	5.825562
20	5.053423

After test ECG

location	magnitude
1	22.67371
10	6.12291
18	4.62702
14	4.038006

FFT peaks for subject 18

Before test ECG

location	magnitude
1	93.7805
8	12.40459
13	8.699039
15	7.442109

After test ECG

location	magnitude
1	94.05349
6	17.97063
9	11.24427
11	10.21898

FFT peaks for subject 19

Before test ECG

location	magnitude
1	55.78771
6	14.0514
10	8.437977
14	6.522647

After test ECG

location	magnitude
1	104.0497
7	15.59078
11	10.70652
13	7.850957

FFT peaks for subject 20

Before test ECG

location	magnitude
1	77.67596
6	9.690583
10	9.286018
8	9.127682

After test ECG

location	magnitude
1	78.8852
5	16.64232
8	12.54214
12	8.273639

FFT peaks for subject 21

Before test ECG

location	magnitude
1	46.12171
7	10.88606
11	7.592794
16	6.020327

After test ECG

location	magnitude
1	57.58049
7	12.11579
10	8.230759
16	6.000804

FFT peaks for subject 22

Before test ECG

location	magnitude
1	36.40435
4	12.18478
15	12.09261
7	11.75696

After test ECG

location	magnitude
1	94.58158
4	20.53675
7	16.79359
13	14.27676

FFT peaks for subject 23

Before test ECG

location	magnitude
1	49.82822
7	13.32405
12	7.23186
15	6.034016

After test ECG

location	magnitude
1	66.31318
6	14.95187
10	8.555662
15	6.077769

FFT peaks for subject 24

Before test ECG

location	magnitude
1	11.41684
17	6.735976
14	6.248841
8	6.005817

After test ECG

location	magnitude
1	17.59628
13	7.732562
16	7.614873
8	7.412489

FFT peaks for subject 27

Before test ECG

location	magnitude
1	32.60656
6	8.214786
9	5.866576
14	4.938407

After test ECG

location	magnitude
1	49.6102
6	12.24461
10	9.193672
15	7.240126

FFT peaks for subject 28

Before test ECG

location	magnitude
1	55.27541
6	10.26075
11	7.739152
15	6.830648

After test ECG

location	magnitude
1	108.6329
9	9.903199
12	9.707426
14	8.653889

FFT peaks for subject 29

Before test ECG

location	magnitude
1	102.0141
6	12.51733
8	10.948
10	8.875444

After test ECG

location	magnitude
1	86.83958
7	13.2407
11	9.425393
14	6.975936

FFT peaks for subject 30

Before test ECG

location	magnitude
1	24.55728
8	7.38116
11	7.112026
14	7.058908

After test ECG

location	magnitude
1	49.64219
4	11.66775
6	9.105746
9	8.802939

FFT peaks for subject 31

Before test ECG

location	magnitude
1	32.27967
15	9.520859
18	8.682339
10	8.44293

After test ECG

location	magnitude
1	55.45085
7	10.45788
15	9.491551
10	9.048807

FFT peaks for subject 32

Before test ECG

location	magnitude
1	61.70364
6	11.51973
10	8.212085
15	6.83497

After test ECG

location	magnitude
1	94.68624
6	17.97731
9	12.747
13	9.228267

FFT peaks for subject 34

Before test ECG

location	magnitude
1	42.50766
8	10.16886
12	6.169032
14	6.091463

After test ECG

location	magnitude
1	43.89829
8	10.91332
14	7.78894
12	7.44284

FFT peaks for subject 35

Before test ECG

location	magnitude
1	56.98904
8	10.83311
12	8.002796
15	5.821486

After test ECG

location	magnitude
1	89.31499
5	17.82024
8	14.25595
12	10.31517

FFT peaks for subject 36

Before test ECG

location	magnitude
1	24.8387
7	8.547582
16	6.340016
12	5.894434

After test ECG

location	magnitude
1	40.69282
7	9.547144
12	5.86516
16	5.575188

FFT peaks for subject 37

Before test ECG

location	magnitude
1	45.83205
7	10.50504
12	7.170511
16	5.591485

After test ECG

location	magnitude
1	81.93528
9	11.40275
13	9.249628
16	6.311286

FFT peaks for subject 39

Before test ECG

location	magnitude
1	56.62267
6	11.15117
10	7.955989
15	7.549331

After test ECG

location	magnitude
1	48.02288
7	10.27425
13	7.209424
11	6.438886

FFT peaks for subject 40

Before test ECG

location	magnitude
1	44.48908
7	11.88415
11	8.744757
15	6.489708

After test ECG

location	magnitude
1	73.0969
6	16.47362
9	11.83269
14	8.401338

FFT peaks for subject 41

Before test ECG

location	magnitude
1	45.40687
5	9.85952
8	6.401562
12	4.989259

After test ECG

location	magnitude
1	88.45841
4	16.62348
6	12.30427
8	9.028452

FFT peaks for subject 42

Before test ECG

location	magnitude
1	36.06926
8	12.49931
13	12.07355
6	11.12022

After test ECG

location	magnitude
1	59.12558
8	13.93457
6	12.96417
12	12.54491

FFT peaks for subject 43

Before test ECG

location	magnitude
1	96.56789
5	19.87079
8	16.07839
11	11.1892

After test ECG

location	magnitude
1	109.8068
5	22.75027
8	18.02224
11	12.45059

FFT peaks for subject 44

Before test ECG

location	magnitude
1	93.89385
6	19.68481
10	12.15121
15	7.784383

After test ECG

location	magnitude
1	136.9511
8	19.30596
13	12.47811
16	8.31676

FFT peaks for subject 45

Before test ECG

location	magnitude
1	30.21466
7	9.309526
13	6.486506
16	5.297916

After test ECG

location	magnitude
1	47.99597
7	11.90241
10	7.594095
13	7.390525

FFT peaks for subject 46

Before test ECG

location	magnitude
1	123.2733
7	16.92921
10	11.64972
13	10.2166

After test ECG

location	magnitude
1	164.215
6	20.07065
8	15.98161
11	11.53318

FFT peaks for subject 47

Before test ECG

location	magnitude
1	36.27997
5	8.397836
8	7.285521
14	6.647973

After test ECG

location	magnitude
1	51.77831
7	10.70496
10	7.154322
16	6.278217

FFT peaks for subject 48

Before test ECG

location	magnitude
1	105.6396
6	22.20434
9	13.68291
14	8.006471

After test ECG

location	magnitude
1	120.8088
6	24.56489
9	14.39824
14	8.969992

FFT peaks for subject 49

Before test ECG

location	magnitude
1	37.95582
5	9.599245
8	9.414126
11	7.551324

After test ECG

location	magnitude
1	57.36099
6	13.51217
9	10.20433
14	6.919762

FFT peaks for subject 50

Before test ECG

location	magnitude
1	70.11561
5	16.40678
8	13.61474
12	12.05259

After test ECG

location	magnitude
1	107.6353
5	20.85959
7	15.98557
11	12.88044

Appendix K

DESCRIPTION OF CATEGORIES

	#	pk 2	pk 3	pk 4	amp 1	amp 2
A	5	up	up		inc	same
B	6	dwn	dwn		inc	same
C	7		dwn		inc	same
D	2	same	same	same	same	same
E	1	same	up	same	same	same
F	17	same	same	same	inc	same
G	2	same	up	up	dwn	same
H	2	up	same	same	inc	same
I	1	dwn	same	same	same	inc
J	1	same	same	up	same	inc

Appendix L

Individual Grade and Level of Change

Group A

Record #	Grade	quiz	1st harm % inc
7	c	b	39
11	b	a	151
12	b	a	50
44	b	a	45
47	a	a	44

Group B

Record #	Grade	quiz	1st harm % inc
10	d	c	112
14	c	c	126
15	b	b	158
30	d	c	100
31	d	f	66
35	c	b	56

Group C

Record #	Grade	quiz	1st harm % inc
1	c	b	91
17	a	b	76
23	f	b	32
40	b	c	65
41	d	b	95
45	b	a	60
46	b	f	33

Group D

Record #	Grade	quiz	1st harm % inc
3	c	d	-2
34	c	nq	2

Group E

Record #	Grade	quiz	1st harm % inc
13	c	b	-3

Group F

Record #	Grade	quiz	1st harm % inc
4	b	b	34
5	b	b	57
6	d	f	16
9	c	a	16
16	b	a	7
19	c	f	85
21	c	c	26
22	d	c	163
24	b	b	63
27	b	c	51
32	c	a	53
36	a	b	64
42	b	a	63
43	b	a	13
48	b	b	15
49	a	b	50
50	a	a	54

Group G

Record #	Grade	quiz	1st harm % inc
29	c	nq	-15
39	c	nq	-16

Group H

Record #	Grade	quiz	1st harm % inc
28	f	nq	98
37	d	d	78

Group I

Record #	Grade	quiz	1st harm % inc
3	c	d	-2
18	c	a	0

Group J

Record #	Grade	quiz	1st harm % inc
20	b	c	1

Appendix M

SUBJECT'S CLASS AVERAGES

	- A -	- B -	- C -	- D -	- F -
A	1	3	1		
B	2	3	2		
C	1	3	1		1
D	1		1		
E			1		
F	3	8	4	2	
G			C		
H				1	1
I			1		
J			1		

Appendix N

JUDGED PERFORMANCE ON QUIZ

	- A -	- B -	- C -	- D -	- F -	- NQ -
A	4	1				
B	1	2	3		1	
C	1	4	1		1	
D						2
E		1				
F	6	6	3		1	
G						2
H				1		1
I				1		
J			1			