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Cardiac Fitness Index based on Treadmill Heart Rate monitoring and it's Mathematical Simulation

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Abstract: In a clinic, cardiologists use the heart rate variation to determine the cardiac fitness of a patient. For this purpose, they monitor their heart rate while on the treadmill and after the patient has gone off the treadmill. However, they only monitor their heart rate values, and not the trend of the heart rate variation. In order to characterize the cardiac fitness, we need to develop an index which describes the trend of heart rate variation while on and off the treadmill. In this paper, we have determined the heart rate variation equation. The equation for on the treadmill is given by: HR = HRe*t^-k2. The range of k1 was found to be 0.2 to 0.25. The range of k2 was found to be -0.2 to -0.3. Then we formulated the Cardiac Fitness Index (CFI) Formula:

$$CFI = \frac{k2}{k1} \times \frac{HRo}{HRe - HRo} \times \frac{HRe - HRf}{HRe} \times 100$$

HRo is the initial rate at the time of getting on the treadmill, HRe is the heart rate at the end of 10 minutes on the treadmill, and HRf is the final value of the heart rate at 10 minutes after getting off the treadmill.

In this evaluated four patients and calculated their values of their CFIs. Based on this, we found the range of CFI to be from 87 to 34 with 87 being the highest and 34 being the lowest. Our intent is to monitor more subjects and find out the ranges for normal subjects and find out the ranges for normal subjects and subjects with cardiac symptoms. This can enable the cardiologist to diagnose a subject with cardiac issues and recommend the subject for further tests, to determine the precise nature of the cardiac problem. Now our Cardiac Fitness Index can be employed by cardiologists to make that decision. In fact, it can also be used at home to determine the cardiac fitness, and stay fit. Thus, our paper will enable both medical and non-medical people to assess their cardiac fitness and hence will have a wide range of applications.

I. INTRODUCTION

Based on what goes on in medical clinics, cardiologists have their patients get on the treadmill and monitor their Heart Rate. Then, if their heart rate goes up very fast, and to very high values, it is an indication of cardiac dysfunction. However, in our opinion, we need to know the rate at which the heart rate keeps increasing while walking on the treadmill and the rate at which it keeps decreasing off of the treadmill, to help us determine how fit a person's heart is. For this purpose, we need to fit mathematical equations to simulate the monitored heart rate vs time data.

Then the parameters of these two equations along with the initial and final values of the monitored heart rate are combined to formulate a cardiac fitness index. So in this project, we have monitored the heart rate of four subjects, (i) starting with the initial heart rate to while they were on the treadmill for ten minutes walking at three miles per hour, to (ii) after they got off the treadmill for ten minutes.

We have then simulated equations to fit the monitored heart rate data while on and off the treadmill. The parameters of the simulated equations are determined to minimize the percentage error between the monitored and simulated heart rates We have then characterized their cardiac fitness by formulating the Cardiac Fitness Index (CFI). The values of CFI are employed to characterize the cardiac fitness of monitored subjects. In our opinion, this is a novel way to diagnose cardiac dysfunction and possible risk of heart failure.

II. HEART RATE DATA OF RK

Now we are presenting RK's treadmill test data. In this table, we can see the monitored heart rate values over ten minutes, from initial Heart Rate (HRo) to end Heart Rate (HRe) in ten minutes. In the next row, we are seeing the values of the simulated equation HR = HRo t^0.23, which was derived to minimize the sum of the differences between the calculated and monitored HR values, as shown in the next row.

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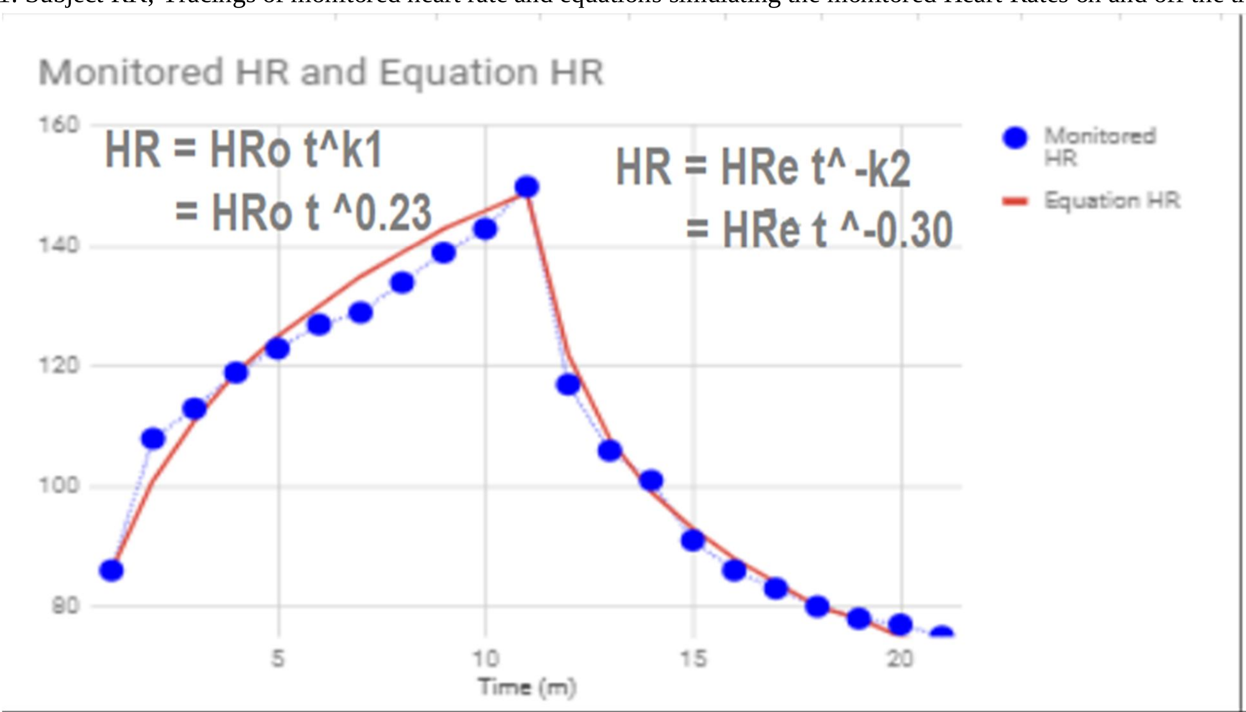
Table 1: RK on and off the treadmill

RK on the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	86	108	113	119	123	127	129	134	139	143	150	
HR = HRo t^0.23	86	101	111	119	125	130	135	139	143	146	149	
Difference	0	7	2	0	-2	-3	-6	-5	-4	-3	1	Sum = -13; Error = 10 %; Error per time = 1.3

RK off the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	150	117	106	101	91	86	83	80	78	77	75	
HR = HRe t^-0.3	150	122	108	99	93	88	84	80	78	75	73	
Difference	0	-5	-2	2	2	2	2	0	0	2	2	Sum = 5; Error = 2.3%; Error per time = 0.5

Next, we are seeing the monitored HR values, going down from HRe = 150 to HRf = 75. The simulated equation is HR = HRe t^-0.3, for which we are seeing that the sum of the differences is very small.

Figure 1: Subject RK; Tracings of monitored heart rate and equations simulating the monitored Heart Rates on and off the treadmill.



Now in **Figure 1**, we are showing RK's (i) Heart Rate data tracings while on and off the treadmill, (ii) Equation of Heart Rate fitting the data, (iii) Difference between monitored heart rate and heart rate given by the equation, as expressed by the percentage error in Table 1.

In figure 1 we are seeing the graph of RK's monitored values as blue dots and the simulated curve depicted in red. There is a close correspondence between the two graphs. While on the treadmill the simulated curve is HR = HRo t ^k1 for k1 is 0.23. After getting off the treadmill, the simulated equation is HR = HRe t ^-k2 for which k2 is 0.3.

Now let us look at the cardiac fitness index formulation. In this formula, the terms that correspond to fitness (such as k2) are in the numerator, while the terms corresponding to unfitness, are in the denominator. After substituting all the values, we get CFI = 87.

$$CFI\ (RK) = \frac{k_2}{k_1} \times \frac{HR_o}{HR_e - HR_o} \times \frac{HR_e - HR_f}{HR_e} \times 100$$

$$= \frac{0.3}{0.23} \times \frac{86}{150 - 86} \times \frac{150 - 75}{150} \times 100$$

$$= 87$$

This formula for CFI is based on two premises. The difference between HRe-HRo reflects unfitness off a subject, while HRE-HRf reflects fitness of a subject. Likewise, the parameter k2 reflects fitness of a subject and parameter k1 reflects unfitness of subject. After formatting this equation, which takes all of the aspects of heart rate into concern, RK's CFI is 87.

III. HEART RATE DATA OF NK

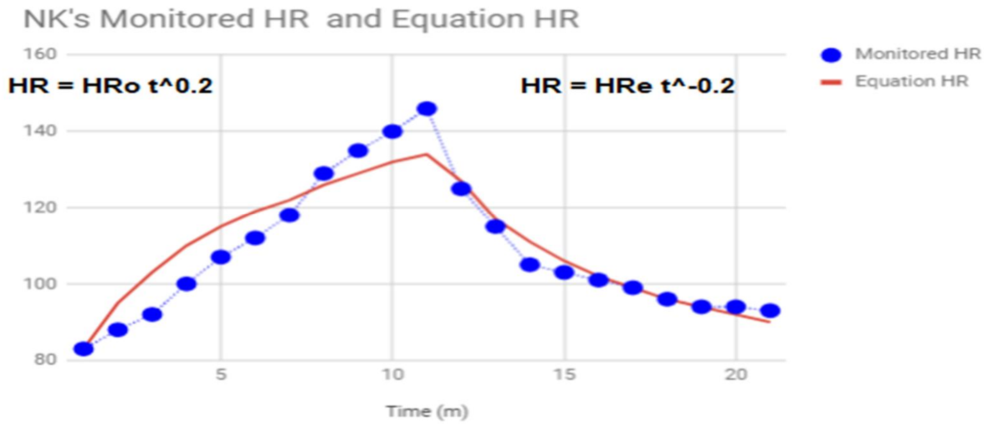
Now we are showing NK's treadmill test data. In this table, we can see the monitored heart rate values from initial Heart Rate (HRo) to end Heart Rate (HRe) in ten minutes. In the next row, we are seeing the values of the simulated equation HR = HRo t^0.20, which was derived to minimize the sum of the differences between the calculated and monitored HR values, as shown in the next row.

Table 2: NK on and off the treadmill

NK on the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	83	88	92	100	107	112	118	129	135	140	146	
HR = HRo t^0.20	83	95	103	110	115	119	122	126	129	132	134	
Difference	0	-7	-11	-10	-8	-7	-4	3	6	8	12	Sum = -18; Error = 6.3 %; Error per time = 1.64
NK off the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	146	125	115	105	103	101	99	96	94	94	93	
HR = HRe t^-0.20	146	127	117	111	106	102	99	96	94	92	90	
Difference	0	-2	-2	-6	-3	-1	0	0	0	2	3	Sum = -9; Error = 0.99 %; Error per time = 0.82

Next, after NK got off the treadmill, we are seeing the monitored HR values going down from HRe = 146 to HRf = 93. The simulated equation is HR = HRe t^-0.2, for which we are seeing that the sum of the differences between the monitored and equation-simulated heart rate is very small.

Figure 2: Subject NK; Tracings of monitored heart rate and equations simulating the monitored Heart Rates on and off the treadmill.



Now in Figure 2, we are showing for NK (i) Heart Rate data while on and off the treadmill, (ii) Equation of Heart Rate fitting the data, (iii) Difference between monitored heart rate (as blue dots) and heart rate given by the equation (as a red curve). The values of k1 and k2 are determined to minimize the error between the monitored and simulated heart rates as expressed by the percentage error in Table 2.

The formulated Cardiac Fitness Index (CFI) is shown below and its value is also shown.

$$CFI\,(NK) = \frac{k_2}{k_1} \times \frac{HR_o}{HR_e - HR_o} \times \frac{HR_e - HR_f}{HR_e} \times 100$$

$$= \frac{0.2}{0.2} \times \frac{83}{146-83} \times \frac{146-93}{146} \times 100$$

$$= 48$$

Now we are seeing the main difference between RK and NK is in HRe-HRf / HRe. That is what makes the difference between value of CFI of RK and NK.

IV. HEART RATE DATA OF VR

Now we are showing VR's treadmill test data. In Table 3, we can see the monitored heart rate values from initial Heart Rate (HRo) to end Heart Rate (HRe) in ten minutes. In the next row, we are seeing the values of the simulated equation HR = HRo t^0.20, which was derived to minimize the sum of the differences between the calculated and monitored HR values.

Then after VR got off the treadmill, we are showing the monitored HR from HRe to HRf over a ten minute period. We are then showing the HR values based on the simulated equation: HRe t^-0.2. In the last row we are showing the difference between monitored and simulated values of HR.

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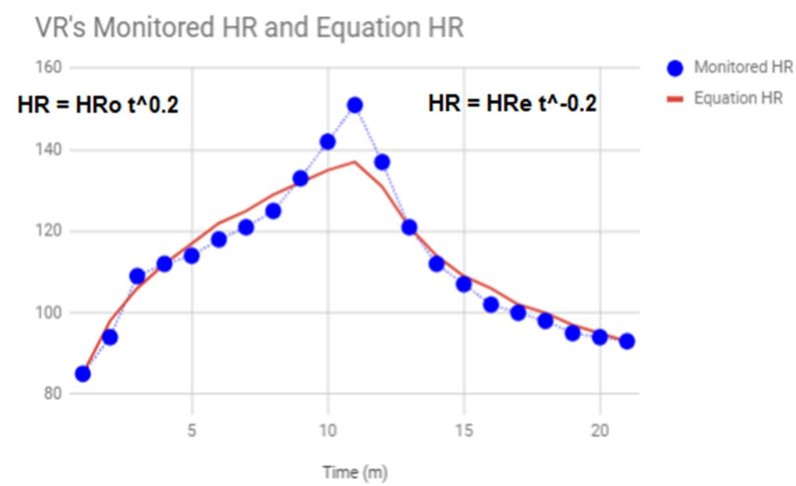
Table 3: VR on and off the treadmill

VR on the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	85	94	109	112	114	118	121	125	133	142	151	
HR = HRo t^0.20	85	98	106	112	117	122	125	129	132	135	137	
Difference	0	-4	3	0	-3	-4	-4	-4	1	7	14	Sum = 6; Error = 3.4 %; Error per time = 0.55

VR off the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	151	137	121	112	107	102	100	98	95	94	93	
HR = HRe t^-0.20	151	131	121	114	109	106	102	100	97	95	93	
Difference	0	6	0	-2	-2	-4	-2	-2	-2	-1	0	Sum = -9; Error = 3.9 %; Error per time = 0.82

Next, after VR got off the treadmill, we are seeing the monitored HR values going down from HRe = 151 to HRf = 93. The simulated equation is HR = HRe t^-0.2, for which we are seeing that the sum of the differences between the monitored and equation-simulated heart rate is very small.

Figure 3: Subject VR; Tracings of monitored heart rate and equations simulating the monitored Heart Rates on and off the treadmill.



In figure 3, we are showing for VR (i) Heart Rate data while on and off the treadmill, (ii) Equation of Heart Rate fitting the data, (iii) Difference between monitored heart rate (blue dots) and simulated heart rate (in red curve).

Now we are showing below the Cardiac Fitness Index formula and its values for VR. The value of CFI for VR is obtained as 49.

$$CFI\ (VR) = \frac{k_2}{k_1} \times \frac{HR_o}{HR_e - HR_o} \times \frac{HR_e - HR_f}{HR_e} \times 100$$

$$= \frac{0.2}{0.2} \times \frac{85}{151 - 85} \times \frac{151 - 93}{151} \times 100$$

$$= 49$$

V. HEART RATE DATA OF NR

Now we are showing NR's treadmill test data. In this Table 4, we can see the monitored heart rate values, from initial Heart Rate (HRo) to end Heart Rate (HRe) in ten minutes. In the next row, we are seeing the values of the simulated equation HR = HRo t^0.20, which was derived to minimize the sum of the differences between the calculated and monitored HR values

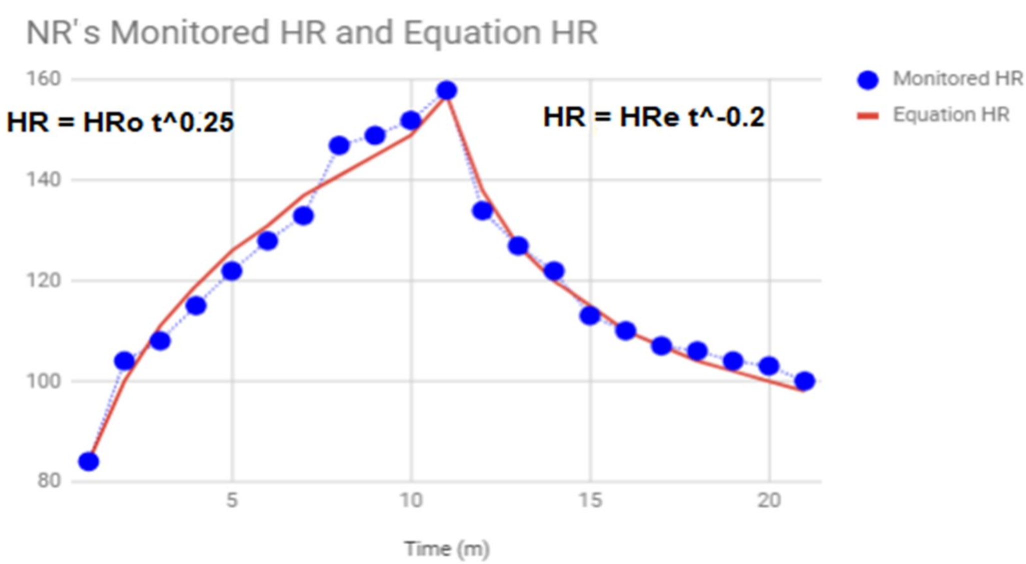
Then after NR got off the treadmill we are showing the monitored HR from HRe to HRf over a ten minute period. We are then showing the HR values based on the simulated equation: HRe t^-0.2. In the last row we are showing the difference between monitored and simulated values of HR.

Table 4: NR on and off the treadmill

NR on the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	84	104	108	115	122	128	133	147	149	152	158	
HR = HRo t^0.25	84	100	111	119	126	131	137	141	145	149	157	
Difference	0	4	-3	-4	-4	-3	-4	6	4	3	1	Sum = -12; Error = 2.3 %; Error per time = 1.09
NR off the treadmill												
Time (m)	1	2	3	4	5	6	7	8	9	10	11	
Monitored HR	158	134	127	122	113	110	107	106	104	103	100	
HR = HRe t^-0.20	158	138	127	120	115	110	107	104	102	100	98	
Difference	0	-4	0	2	-2	0	0	2	2	3	2	Sum = -5; Error = 0.36 %; Error per time = 0.45

Next, after NR got off the treadmill, we are seeing the monitored HR values going down from HRe = 158 to HRf = 98. The simulated equation is HR = HRe t^-0.2, for which we are seeing that the sum of the differences between the monitored and equation-simulated heart rate is very small.

Figure 4: Subject NR; Tracings of monitored heart rate and equations simulating the monitored Heart Rates on and off the treadmill.



In figure 4, (i) Heart Rate data while on and off the treadmill, (ii)Equation of Heart Rate fitting the data, (iii) Difference between monitored heart rate and heart rate given by the equation, as expressed by the percentage error.

Now we are showing below the Cardiac Fitness Index formula and its values for NR. The value of CFI for VR is obtained as 34.

$$CFI\,(NR) = \frac{k_2}{k_1} \times \frac{HR_o}{HR_e - HR_o} \times \frac{HR_e - HR_f}{HR_e} \times 100$$

$$= \frac{0.25}{0.2} \times \frac{84}{158 - 84} \times \frac{158 - 100}{158} \times 100$$

$$= 34$$

VI. HEART RATE DATA OF ALL THE SUBJECTS

In figure 5, we are showing the monitored and simulated curves for HR of all the four subjects.
For RK, it is seen that in the first graph, HR comes down significantly from 150 to 75. However, for NR the heart rate came down from 158 to only 100. This is why the CFI value of RK is much greater than that of NR.

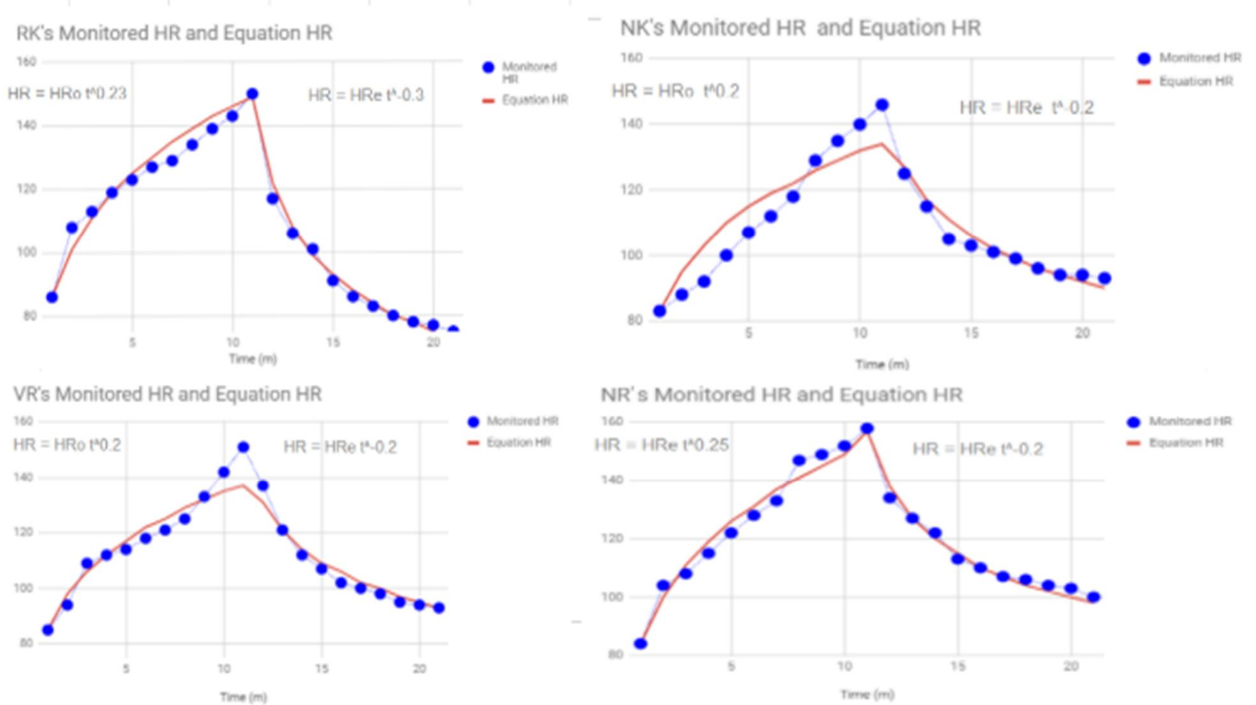


Figure 5: The graphs of monitored and simulated Heart Rate of all four subjects.

A. *Computed CFI results of all the four subjects*

Now in Table 5 we are showing for all the four subjects, k2 and k1, HRo / (HRe - HRo) and (HRe - HRf) / HRe, and then final values of CFI. We can see that the main difference between the subjects is in the value of (HRe - HRf) / HRe. In other words, for RK, the heart rate came down to its normal value in ten minutes, whereas for the other subjects, HRf did not come down to the normal value of HRo.

So now if we apply this formulation of CFI to a wide range of subjects and especially elderly subjects, we will be able to see how their heart rate goes up while on the treadmill, and comes down when off the treadmill, and how it affects the value of their CFI. This simple formulation will help cardiologists to differentiate normal and fit subjects and unfit subjects who may have a cardiac dysfunction, such as, high blood pressure, arrhythmias, coronary artery disease, and myocardial ischemia.

Table 5: Results of the four subjects, showing the values of the parameters and variables used to formulate CFI.

Index Results					
Name	k2	k1	HRo / (HRe - HRo)	(HRe - HRf) / HRe	Final
RK	0.3	0.23	1.34	0.5	87
NK	0.2	0.2	1.32	0.36	48
VR	0.2	0.2	1.29	0.38	49
NR	0.2	0.25	1.14	0.37	34

VII. CONCLUSION

So far, we have monitored four young subjects and even for them we have been able to show a big range in the values of CFI. If now, we were to monitor adults, and even people in a high age group, we feel that our cardiac fitness index will have a big range of values for adults.

It is now our decision that we apply this formulation of CFI to a wide range of adult subjects. We will hence be able to show that our cardiac fitness index is able to distinctly depict healthy subjects, unhealthy subjects, and subjects who are at risk of heart failure. Now this formulation will be helpful to cardiologists world-wide, in enabling them to detect patients that are at risk for heart failure.