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Rescuer Exertion from the Performance of One-Man Cardiopulmonary Resuscitation Technique

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RESCUER EXERTION FROM THE PERFORMANCE OF ONE-MAN

CARDIOPULMONARY RESUSCITATION TECHNIQUE

BY

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DEDICATION

To my wife Elaine, whose support, patience, and understanding made this endeavor possible.

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VITA

The author, Daryl J. Detwiler, is the son of Dale P. Detwiler and Jean E. (Joynson) Detwiler. He was born on March 22, 1950.

His elementary education was obtained in the public school system of Wichita, Kansas, and secondary education at Wichita High School East, where he graduated in 1968.

He entered Wichita State University, in August of 1968, and received the degree of Bachelor of Arts in 1974, with a double major in Psychology and Biology.

In September of 1975, he entered the graduate program in Oral Biology at the Loyola University Medical Center, Maywood, Illinois. While in this program, he served as a teaching assistant in the Department of Physiology and Pharmacology.

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INTRODUCTION AND STATEMENT OF PURPOSE

Since the early 1960's, countless numbers of lives have been saved by the modern method of cardiopulmonary resuscitation (CPR). The development of this technique over the last twenty years and the training of laymen and health care personnel in it's proper utilization are landmark accomplishments in modern medicine. Today, training in basic life support procedures is an integral part of the curriculum of medical, dental and allied health professions schools, and training of the general public is accomplished through organizations such as the American Heart Association, the American National Red Cross, the YMCA and YWCA, and Scouting groups.

The research and development of the technique of CPR has historically been concerned with it's effectiveness in supporting the life of the victim. Many studies have been done to perfect artificial ventilation and circulation techniques. Other studies have concentrated on the effectiveness of various training techniques and programs. The physical stress experienced by a rescuer as a result of performing CPR has received relatively little attention.

Physical exertion is required to perform mouth-to-mouth ventilation and external cardiac compression. Practical experience in teaching the CPR technique has shown the author that prolonged performance of CPR technique using the Resusci-Anne mannequin can lead to near physical exhaustion of the rescuer.

The purpose of this study is to determine the changes in the heart rate of a rescuer as a result of performing the technique of cardiopulmonary resuscitation on a training mannequin, and compare those changes with the rescuer's heart rate following a standardized type of exercise known to place the cardiovascular and respiratory systems under stress, in order to evaluate the degree of physical exertion experienced by a rescuer in the performance of CPR.

This study will compare the effect on the rescuer's heart rate of a three-minute period of performing the one-rescuer CPR technique with the effect of a three-minute period of performing the Harvard Step Test exercise, a constant-rate single-step exercise, known to be strenuous.

REVIEW OF THE LITERATURE

A review of the literature reveals only one study that specifically deals with the subject of physical exertion experienced by a rescuer during the performance of CPR. Abbott et al., (1978) evaluated cardiac patients' responses to the emotional and physical stress of CPR training. Using electrocardiographic telemetry to monitor heart rate, rhythm, and ECG waveform during practice and test sessions of CPR training, they found no detrimental changes in any of the 10 subjects. All subject's heart rates remained in or below target exercise heart range (the heart rate which establishes intensity of exercise within 70 to 85 percent of the functional capacity obtained on an exercise stress test) during all testing sessions. Abbott stated that there apparently was no ill effect from the learning experience in the group. No study has been published that compares the exertion involved in performing CPR to a known standard of physical exertion.

Literature in three general areas of investigation is relevant to the subject of this thesis: 1. The accepted technique of cardiopulmonary resuscitation; 2. The utilization of changes in heart rate as reliable indicators of response to physical exertion; and 3. The use of the Harvard Step Test exercise as a measure of physical exertion.

The history of the development of resuscitation techniques in cardiac arrest has been described most completely by Overbeck (1974). From the 16th century assertion of William Harvey that heart sounds exist, to the development of the external cardiac massage technique by Houvenhoven et al., in 1960, Overbeck has traced the many research developments that led to CPR techniques as they are known today.

The Supplement to the Journal of the American Medical Association, (1974) Standards for Cardiopulmonary (CPR) and Emergency Cardiac Care (ECC), presented standards for CPR that were developed and recommended at the National Conference on Standards for CPR and ECC, held in May 1973. This conference was co-sponsored by the American Heart Association and the National Academy of Sciences--National Research Council. The principles and techniques for basic and advanced life support, and CPR training and certification according to American Heart Association standards were prepared by leading authorities and represent a consensus of many qualified persons from a variety of disciplines. Techniques were described in detail for mouth-to-mouth artificial ventilation and external cardiac compression. One-rescuer CPR was described as consisting of two very quick lung inflations after each fifteen chest compressions. Proper timing of procedures and other details of acceptable, effective performance were also described in this supplement.

The fact that heart rate is increased during exercise is a matter of common observation. Morehouse and Miller (1971) state that in a given subject the maximal heart rate reached during exertion, especially if the subject is in a steady state, correlates fairly closely with work load. Also, the time required for the heart rate to return to normal after exercise depends on the work load of the exercise period and on the physical condition of the subject. Wilmore (1977) states that as workload is progressively increased, the heart rate will also increase, and a roughly linear relationship exists between the heart rate and workload. The relationship between heart rate per minute and the rate of oxygen consumption, or work rate, has been demonstrated by many investigators, including Astrand and Ryhming (1954), Asmussen and Nielsen (1955), and Datta and Ramanathan (1969).

Brouha (1960) stated that for the purpose of comparison between different work loads, various kinds of exercise or different individuals, the heart rate reactions can be conveniently expressed as the total number of heart beats above the pre-exercise resting level that is needed to perform the work. The cardiac cost of recovery is the total number of beats above resting level occurring between the end of exercise and the return to the pre-exercise rate. Brouha concludes by stating that utilizing heart rate recovery curves to evaluate the effects of muscular work, heat, and individual fitness is a simple and useful method.

In studying energy expenditure in industrial situations, Maxfield (1971) stated that when studying activity during which heart rate measurements are impractical, recovery heart rate data can provide the information needed to assess the activity. Also, she stated that heart rate recovery curves based on three pulse-rate determinations, strategically timed, provide very good estimates of the strain caused by an activity if the measurements are carefully made.

The muscular exercise involved in the performance of CPR is a dynamic type of exercise involving extensor and flexor muscle groups. A limited amount of isometric contraction during the performance of external cardiac compressions is also present. Bruce (1977) has described the physiologic differences between the major types of conventional tests of dynamic exercise. He states that these tests can be divided into two major categories: submaximal tests having predetermined, arbitrary end points, and maximal tests having individualized, self-determined symptomatic end points of maximal possible performances which permit a subject to attain his physiologic limit while signs and symptoms are observed. One of the tests commonly used is the constant-rate, single-step test. This type of test was developed by Johnson, Brouha and Darling (1942) as the Harvard Step Test exercise. In this test, a subject's physical fitness index is computed from the heart rate during the recovery period after a 5-minute period of stepping up and down 30 times per minute on a 20-inch platform. The step exercise is a type of exercise in which each subject works at a constant rate proportional to his body weight, and serves as a maximal type of exercise when the duration is such that the subject has difficulty maintaining the 30-step per minute rate during the exercise. Rochmis (1971) found in a survey of 73 medical centers that this test was among various standardized exercise tests being used to evaluate physical fitness.

MATERIAL AND METHODS

Subjects

Thirty (30) male volunteers, ranging in age from 23 to 29 years, served as subjects. All were students at Loyola University School of Dentistry, and had previously received training in the technique of CPR. As per the recommendation of the Institutional Review Board for the Protection of Human Subjects--Loyola University Medical Center, each subject was examined by a licensed physician to determine his ability to withstand the physical stress of the experiment. This examination included electrocardiographic and blood pressure evaluation. Informed consent was obtained from each subject.

Equipment

A Narco Physiograph was used to record the heart rate of each subject; a paper printout at 0.5 cm per second was made of Lead II (electrocardiogram), with markings for seconds and minutes. A Laerdal Resusci-Anne mannequin with the indicator lights visible to the subject was used in the performance of CPR technique. The Harvard Step Test exercise platform was built specifically for this experiment to the standardized height of 20 inches above ground, and was equipped with hand rails for safety purposes. A carpet was provided for pressure and thermal insulation while the subjects were lying supine or kneeling.

Experimental Procedure

Each subject was instructed as to the exact experimental procedure, and also that they were free to stop at any time during the procedure if injured or intolerably uncomfortable.

A five-minute control was taken initially with the subject lying supine and motionless on the carpeted floor. After this control period, one-half of the subjects first performed three minutes of CPR, while the other one-half first performed three minutes of the Harvard Step Test exercise.

Immediately after performing for three minutes, the subject returned to lying motionless on the floor. The heart rate was recorded during this period. Thirty minutes from the time the first exercise was started, the subject performed three minutes of the other exercise. This procedure of having one-half of the subjects perform CPR first and one-half perform the Harvard Step Test exercise first was designed to control for the residual effect of prior exertion. After the second exercise period, the subject again returned to lying motionless on the floor and the heart rate was recorded.

One-rescurer CPR was performed according to American Heart Association recommendations. Following an initial four quick breaths, external cardiac compressions and ventilations were performed in a 15 to 2 ratio for three minutes. The mannequin's timing metronome was audible to the subject, and the experimenter gave coaching instructions to insure standardized performance. Compressions were performed at the rate of 80 per minute.

The Harvard Step Test exercise involved stepping up and then down at the rate of 30 times a minute to a 20-inch platform. A timing metronone giving a one-second count was audible to the subject. Again, coaching was given by the experimenter to maintain the proper rate. Each subject wore street shoes during the test. Wrist and ankle leads (electrocardiogram) remained attached at all times during both testing periods.

RESULTS

Heart rate data were compiled from the Physiograph records for each subject. These raw data were then statistically analyzed with the assistance of the Data Processing Center at Loyola University Medical Center.

The data were analyzed using the ratio of each subject's heart rate following exercise or CPR performance to his heart rate during the preceeding control period. This was done to account for the normal variation in resting heart rates among normal individuals, and to express the degree of exertion experienced by each subject as a multiple of his control rate.

The temporal sequence of the experimental procedure was as follows: Group 1 refers to the 15 subjects that performed the Harvard Step Test exercise prior to performing CPR, while Group 2 refers to the subjects that performed CPR first:

Group 1: Control I → HST → Rest Period → Control II → CPR

Group 2: Control I → CPR → Rest Period → Control II → HST

Table 1 shows the mean control heart rate values for each group.

Table I

Mean Control Values
(expressed as beats per minute)

	Control I	Control II
Group 1	62 b.p.m.	82 b.p.m.
Group 2	61 b.p.m.	62 b.p.m.

The control II value for Group 1 was significantly greater than all of the other control values ($p<0.001$). The values were not significantly different in relation to each other.

The mean heart rates ratios following each exercise at the given time intervals, presented as a mean value for all 30 subjects, are shown in Table 2.

Table II

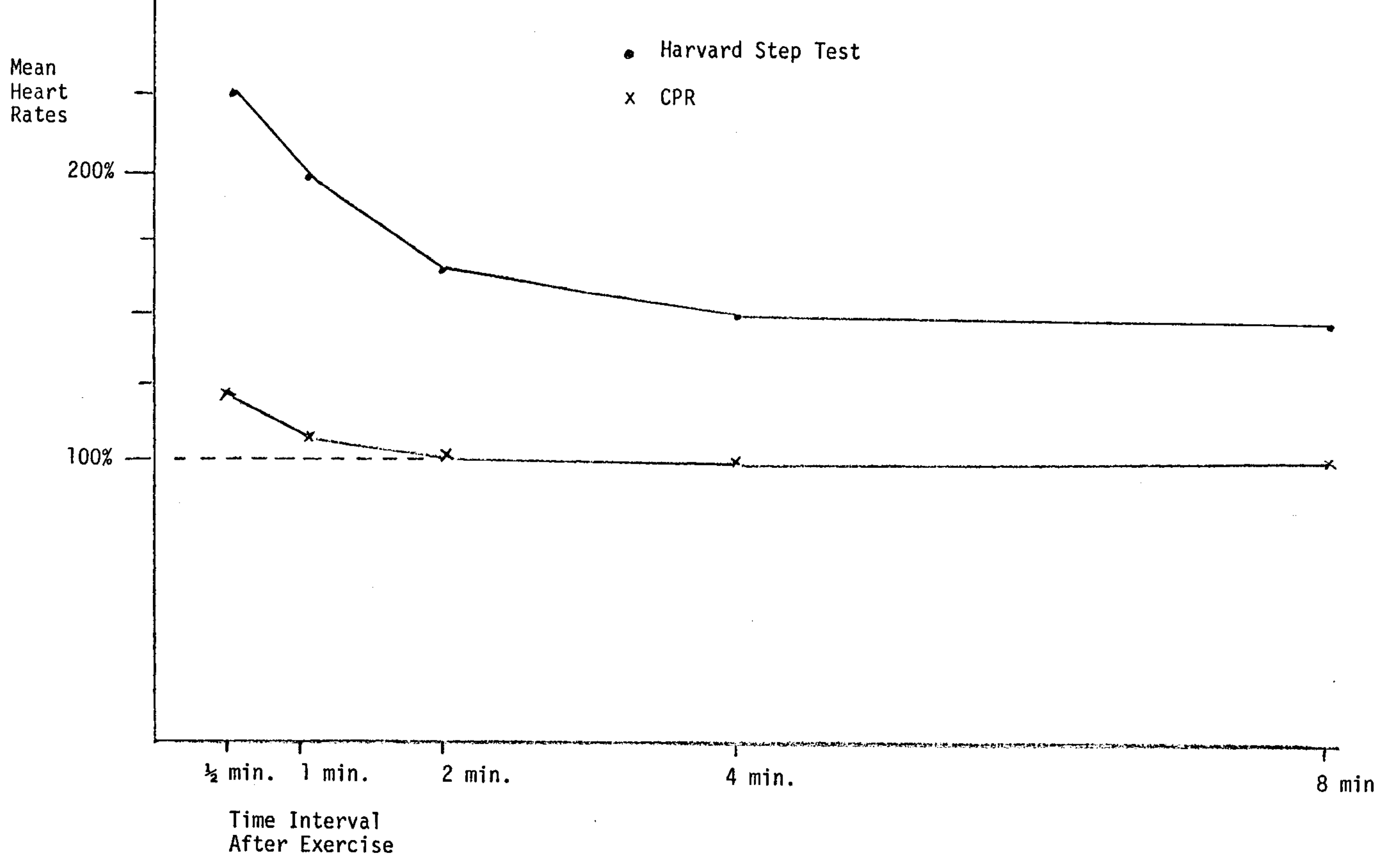
Mean Heart Rates During Recovery
(expressed as percentage of test heart rate/control heart rate)

	Time Interval following Cessation of Exercise				
Exercise	30 sec.	1 min.	2 min.	4 min.	8 min
HST	226%	198%	167%	151%	146%
CPR	120%	106%	101%	100%	100%

A graphic representation of the above is shown in Figure 1.

Statistical analysis by student - t test revealed significant differences between heart rates during recovery periods following each exercise at all time intervals.

Figure I - Mean Heart Rates During Recovery
Time Intervals - Percentage of $\frac{\text{test heart rate}}{\text{control heart rate}}$



DISCUSSION

These results utilize the kinetics of recovery from exercise to demonstrate differences between two different exercises. The muscular contraction during exercise causes increases in blood flow to the muscles to cover the needs of the increased muscle metabolism. In addition the regulation of body temperature puts extra strain on the circulatory system during work, because the extra heat produced by the contracting muscles must be eliminated. Consequently, muscular exercise requires a drastic adjustment of the circulatory functioning with increased cardiac output in addition to a scrupulous regulation of regional blood flow.

In the transition from rest to exercise the cardiovascular function undergoes remarkable changes. During the initial stage of rhythmic muscular work, the cardiac output increases, first rapidly and then more gradually from the resting state and up to a "steady state", the level of which is set by the intensity of work. Thus there appear to be two components in the kinetic adjustment of cardiac output to rhythmic muscular exercise, a fast one caused by a centrally induced nervous drive, and a slower secondary phase which may be a result of some unknown reflex mechanisms. The final level of cardiac output is closely related to the intensity of work.

In light and moderate work the duration of the adaptation phase lasts for 1 to 2 minutes, but is related to the intensity of work and becomes longer in heavy exercise. Fit subjects adapt more quickly to exercise than unfit subjects. It is this lag in the circulatory adjustment that causes the partly anaerobic conditions of the muscles at the beginning of work and which results in an oxygen deficit remaining at the end of exercise. After cessation of exercise, cardiac output does not promptly return, but decreases gradually toward the resting level. The recovery curve is close to exponential in shape.

The kinetics of circulatory recovery from exercise and the time taken before resting values are reached are thus related to the restoration of normal metabolic tissue homeostasis. The metabolism is however, not the only mechanism which governs the pattern of circulatory recovery from exercise. The oxygen debt after exercise is primarily due to the deficit developing at the beginning of exercise, which was caused by the lag in circulatory adaptation to the increased demands.

Figure 1 shows the exponential recovery curves following both exercises. The greater increase above resting heart rate levels following the Harvard Step Test exercise is indicative of greater oxygen debt due to greater muscular work intensity than that involved in the performance of CPR.

The central conclusion of this study is that the level of exertion experienced by a rescuer performing CPR is significantly less than the exertion required to perform a maximally-exerting exercise, the Harvard Step Test Exercise, for an equal period of time. Data presented in Table II, showing statistically significant ($p<0.001$) differences in test heart rate/control heart rate ratios during recovery following each type of exercise, are the basis of this conclusion.

Data presented in Table I further confirm the conclusion that CPR is an exercise involving limited, not maximal, physical exertion. The mean heart rate control values were still significantly elevated in Group I subjects following the rest period after the performance of the Harvard Step Test exercise, while no such increase appeared in the value for the Group 2 subjects. If the performance of CPR was indeed as strenuous as the performance of the Harvard Step Test exercise, a similar increase should have occurred, but it did not.

This finding of a continued elevation in heart rate at the end of the rest period after the performance of the Harvard Step exercise indicates the high degree of oxygen debt experienced during the performance of a maximally exerting form of exercise. The performance of CPR for the same amount of time did not produce a similar high degree of oxygen debt. A longer rest period that would allow for full recovery from this oxygen debt would be an interesting modification of this study.

The results of this study are similar to results obtained by other researchers. Lipskis (1981), while studying two-man CPR technique, found that all subjects were able to perform limited periods of CPR on a training mannequin without undue physical exertion. Myczek's (1980) study of two-man CPR technique also yielded similar results. Abbott et al. (1978), while studying cardiac patients' responses to the emotional and physical stress of CPR training, found that all subjects heart rates remained within 70 to 80 percent of the functional capacity for each subject during all testing sessions.

The validity of this study's design is based on known concepts of exercise measurement by observation of heart rate during the recovery period following exercise. This method provides a reasonably accurate measurement of subject exertion without resorting to methods which utilize extensive equipment such as that needed for oxygen consumption determinations or heart rate telemetry during exercise.

A possible follow-up to this study would involve a determination of the average duration of time a rescuer could comfortably perform one-man CPR. Such information would be useful to those involved in CPR training programs and emergency medical care delivery system planning.

An implication of these data is that the performance of the CPR technique on a practice mannequin such as the Laerdal Resusci-Anne[R] is well within the limits of cardiovascular stress for rescuers of normal health and physical condition. Of course, any type of physical exertion can lead to exhaustion if carried on for a lengthy period of time. If the training sessions for CPR technique do not allow adequate rest periods for the student to properly recover from the exertion of training, exhaustion could occur and have a negative effect on the training process. Also, the ability of the CPR trainee to withstand a moderate level of exertion with no ill effects should be ascertained prior to the beginning of training. However, the fact that CPR is not a maximally exerting form of exercise would indicate that trainees with limitations on their ability to withstand cardiovascular stress should not be barred from practicing the CPR technique on a mannequin, but instead should be closely monitored during practice. Post-myocardial infarction patients, for example, should therefore be allowed to participate in CPR training under proper supervision.

SUMMARY

The subject of the relative amount of physical exertion experienced by a rescuer performing cardiopulmonary resuscitation (CPR) has been studied by comparing heart rate recovery values following 3-minute periods of performing CPR on a training mannequin to values following 3-minute periods of a constant-rate, single-step exercise, the Harvard Step exercise. Heart rates of 30 male subjects were monitored on a polygraph, fifteen of the subjects performed CPR prior to performing the Harvard Step exercise, and the other fifteen performed the Harvard Step exercise first. Heart rate recovery values following CPR averaged 120% of the control heart rate at 30 seconds following cessation of exercise and returned to the control rate at 8 minutes post-exercise. Following cessation of the Harvard Step exercise, the average heart rate was 226% of the control rate at 30 seconds, and had fallen to 146% of the control rate at 8 minutes following exercise. Statistical analysis by student-t tests revealed significant differences between heart rates during recovery periods and control periods following each exercise at all time intervals.

The conclusion drawn from these results is that the performance of CPR involves significantly less exertion than that involved in performing a maximally exerting exercise such as the Harvard Step exercise. The implication of this conclusion is that a person of average health and

physical condition can perform limited periods of CPR on training mannequins without experiencing undue physical exertion or endangering his health. Follow-up studies could be performed to further quantify the amount of physical exertion involved in performing CPR, and to identify the effects of such variables as rescuer age, sex, training level, or physical statue. More sophisticated measurements systems could be utilized such as oxygen consumption determination and telemetry recording of physical variables. Information resulting from further study of rescuer exertion would be useful to instructors of CPR technique by helping prevent accidental physical injury resulting from overexertion during the training experience. Such information could also lead to improvements in the technique and clinical application of resuscitation procedures.

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APPENDIX

Individual Subject Data by Group

Group I - Harvard Step Test Exercise performed prior to CPR

Subject	Control I Heart Rate	Heart Rate after HST (% of control)					Control II Heart Rate	Heart Rate after CPR (% of control)				
		½ min.	1 min.	2 min.	4 min.	8 min.		½ min.	1 min.	2 min.	4 min.	8 min.
1	56.4	241	211	184	170	163	74.8	120	107	84	91	86
2	59.8	219	196	163	145	139	79.4	104	98	94	89	93
3	71.4	234	192	160	151	146	99.0	106	99	93	96	99
4	59.8	211	176	133	125	119	75.0	112	100	95	95	100
5	73.2	171	150	135	127	126	76.2	144	121	114	109	94
6	71.0	214	177	159	155	139	81.6	125	110	109	102	98
7	44.6	274	233	209	188	159	59.2	117	106	91	91	91
8	67.0	219	191	170	152	148	89.4	116	104	102	96	96
9	59.0	214	186	161	156	151	75.6	123	107	107	102	102
10	59.4	246	222	187	167	175	94.2	101	105	88	99	96
11	76.6	202	188	167	149	145	111.0	101	97	94	99	89
12	48.6	226	191	148	146	136	61.2	98	87	83	111	96
13	52.8	289	244	191	169	170	75.6	118	102	103	115	107
14	72.0	179	163	150	140	142	85.8	112	98	101	93	100
15	59.4	263	237	196	177	167	88.2	112	92	92	94	99

Individual Subject Data by Group

Group 2 - CPR Performed prior to Harvard Step Test Exercise

Subject	Control I Heart Rate	Heart Rate after CPR (% of control) ½ min.	1 min.	2 min.	4 min.	8 min.	Control II Heart Rate	Heart Rate after HST (% of control) ½ min.	1 min.	2 min.	4 min.	8 min.
16	62.0	111	105	90	95	92	58.2	201	184	144	124	132
17	63.0	119	113	105	105	103	69.6	207	177	151	136	134
18	74.8	123	104	104	107	92	71.6	201	184	166	147	137
19	68.2	130	114	109	100	97	68.4	213	178	145	127	121
20	55.4	119	101	92	90	103	54.6	264	220	185	158	158
21	87.8	116	112	99	95	91	75.0	191	172	140	119	116
22	47.0	138	106	109	113	106	47.2	254	216	169	165	178
23	67.6	105	101	89	92	96	60.0	223	195	165	138	138
24	56.2	139	117	105	110	101	57.8	208	196	151	164	145
25	47.4	139	127	139	112	108	53.4	213	184	167	140	140
26	70.0	141	106	107	110	111	76.8	202	185	164	145	137
27	53.2	145	122	107	100	102	53.2	263	235	201	179	175
28	62.8	113	104	104	91	119	61.2	225	199	167	141	141
29	63.8	121	107	102	108	108	64.6	232	204	172	153	135
30	49.2	138	120	110	102	114	49.2	280	250	213	183	183

STATISTICAL ANALYSIS

Test Heart Rate/Control Heart Rate Ratios at Various Time Intervals Following Cessation of Exercise

Time Interval	Exercise	Number of Cases	Mean	Standard Deviation	Standard Error	T Value	Degrees of Freedom	2-Tail Probability
30 sec.	HST	30	2.26	0.30	0.05	17.77	29	<0.001
	CPR		1.20	0.14	0.02			
1 min.	HST	30	1.98	0.25	0.04	18.77	29	<0.001
	CPR		1.06	0.09	0.02			
2 min.	HST	30	1.67	0.21	0.04	14.75	29	<0.001
	CPR		1.01	0.11	0.02			
4 min.	HST	30	1.51	0.18	0.03	14.21	29	<0.001
	CPR		1.00	0.08	0.01			
8 min.	HST	30	1.46	0.18	0.03	14.30	29	<0.001
	CPR		1.00	0.08	0.01			

STATISTICAL ANALYSIS

Variable	Number of Cases	Mean	Standard Deviation	Standard Error	F Value	2 Tail Probability
Control I - Average Pulse Rate						
Group 1	15	62.01	9.50	2.45	1.05	0.932
Group 2	15	61.39	9.28	2.40		
Control II - Average Pulse Rate						
Group 1	15	81.75	13.53	3.49	1.49	0.469
Group 2	15	61.89	11.10	2.87		

APPROVAL SHEET

This thesis submitted by Daryl J. Detwiler has been read and approved by the following committee:

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The final copies have been examined by the director of the thesis and the signature which appears below verifies the fact that any necessary changes have been incorporated and that the thesis is now given final approval by the Committee with reference to content and form.

The thesis is therefore accepted in partial fulfillment of the requirements for the degree of Master of Science in Oral Biology.

April 19, 1982
Date

Donald B. Doemling
Director's Signature