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...MUSCLE TEMPERATURE...ON GRIP STRENGTH.

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THE EFFECT OF ACTIVELY INCREASED MUSCLE TEMPERATURE ON GRIP STRENGTH

by

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A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES

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OF DOCTOR OF PHILOSOPHY

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EDMONTON, ALBERTA

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FACULTY OF GRADUATE STUDIES

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies for acceptance, a thesis entitled The Effect of Actively Increased Muscle Temperature on Grip Strength submitted by Peter Geoffrey King in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT

The problems were to determine the effect of a linearly increased duration of equally spaced maximal grip contractions on the degree of muscle and central temperature increases and to determine the effect of muscle temperature on grip strength.

The experiment was completed over five consecutive days for each of twelve normally active male subjects. An intramuscular thermocouple was inserted on the first day and remained in place for the duration of the experiment. The procedure for the remaining four days included a ten minute rest period, a pre-exercise period comprised of two contractions which were spaced by one minute, an exercise period comprised of fifteen or thirty or forty-five or sixty contractions which were spaced by five seconds and a post-exercise period comprised of ten contractions which were spaced by one minute. All contractions were maximal and were approximately one second in duration. The four experimental conditions were defined by the number of exercise contractions and did not differ in any other respect. Each subject was observed once under each condition. Muscle and central temperatures were measured at intervals during each period.

The degree of muscle temperature increase was found to be proportional to the duration of exercise. A systematic increase in response to the duration of exercise was not observed for central temperature. Mean muscle temperature ranged from 33.51°C to 35.58°C. Grip strength was not affected by this range of muscle temperature.

Acknowledgements

My thanks are extended to Dr. S. Mendryk who has served as my advisor in many capacities during the past several years. My thanks are also extended to Dr. R. B. Alderman, Dr. J. F. Alexander, Dr. W. H. Cottle, Dr. H. J. McLachlin and Dr. S. M. Hunka for their assistance in the completion of this thesis.

I was fortunate to have the support of Mr. R. R. Kelly and Mr. D. C. Reid. My success was largely due to their contribution to the method developed for intramuscular temperature measurement.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

STATEMENT OF THE PROBLEMS

Available evidence is insufficient either to support or to reject a relationship between forearm muscular function and actively increased muscle temperature. Sedgwick (2) concluded that dynamic grip endurance was unaffected by increased muscle temperature. Conversely, King *et al*. (1) reported a correspondence between greater grip strength and increased muscle temperature. Neither study systematically varied the load, rate and/or duration of exercise preceding the measurement of endurance and strength, respectively.

Problems

Two problems were established and were as follows:

1. To determine the effect of a linearly increased duration of equally spaced maximal grip contractions on the degree of muscle and central temperature increases and
2. To determine the effect of muscle temperature on grip strength.

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CHAPTER II

REVIEW OF THE LITERATURE

Exercise Effect on Muscle and Central Temperatures

Both quadriceps muscle and central temperatures have been determined to increase in a regulated manner during continuous bicycle exercise. Muscle temperature has been found to have the faster rate and the greater degree of increase. Whereas muscle temperature may be affected by environmental temperature (11), an independence has been established between central temperature and a wide range of environmental temperatures (10, 11). Saltin and Hermansen (12) concluded that central temperature and probably also muscle temperature are set according to the relative as opposed to the absolute metabolic rate of the individual. Neuromuscular factors and the degree of exercise anaerobicity have been found to have no effect on central temperature (9).

A regulated muscle temperature increase has also been observed during rhythmic exercise of the biceps brachii (2). For the same subject and a constant contraction rate, temperature increase was proportional to both the load and the duration of exercise. When one of these factors was varied, the other factor was held constant. The degree of temperature increase during exercise was reduced by circulatory occlusion. Conversely, an extended temperature increase followed circulatory restoration immediately after exercise. Muscle blood flow was discounted as an effective heat source and temperature increase was considered to be a function of metabolic processes alone.

Muscle and Central Temperature Effects on Muscular Function

Asmussen and Bøje (1) reported a greater force of plantar flexion to accompany a temperature increase in the soleus muscle produced by cycling. Although central temperature was also increased, no increase in either the temperature or the strength of the biceps brachii muscle was observed. Only muscle temperature was concluded to have an effect on muscular function.

Several studies have reported that the force and/or duration of a grip contraction may be affected by passively induced temperature change in the forearm flexors. The effects of various water temperatures on the duration of successive contractions held above one-third maximal were reported by Clarke et al. (5). Optimal results followed thirty minutes of forearm immersion in water at 18°C. The corresponding muscle temperature was approximately 27°C. Above and below these values, endurance was observed to progressively deteriorate. Strength was not affected by water temperatures beyond 18°C, whereas a rapid and systematic decrease occurred below 18°C. Under the assumption that muscular metabolic rate increases with temperature, reduced endurance at muscle temperatures greater than 27°C was attributed to earlier metabolite accumulation. At muscle temperatures less than 27°C, electromyography revealed a decrease in nervous or neuromuscular transmission. The results of Lind and Samueloff (8) were in agreement with those of Clarke et al. (5). Clarke and Stelmach (4) reported that forearm immersion in water at 10°C and 46°C had a different effect on function during a two minute maximal static contraction and during a ten minute recovery period in which grip strength was determined at one minute intervals. When compared to a control condition, both heat and cold were found to reduce strength in the initial phase of the static contraction, whereas the rate of work decrement was unaffected by heat and decreased by cold. Strength recovery was accelerated by heat and decelerated by cold. Conversely, no effect on strength recovery was observed when water immersion was limited to the recovery period (3). Similar results were reported by Grose (6) for dynamic muscular fatigue although heat was not found to affect initial strength. Sedgwick (14) observed no effect on dynamic grip endurance when muscle temperature was increased by short-wave diathermy.

Actively increased muscle temperature has also been considered as a determinant of forearm muscular function. Sedgwick (13) concluded that dynamic grip endurance was unaffected by increased muscle temperature. Conversely, King _et al_. (7) reported a correspondence between greater grip strength and increased muscle temperature.

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CHAPTER III

METHODS AND PROCEDURE

Measurements

Grip strength. Measurements were read directly from a mounted grip dynamometer that could be adjusted to accommodate differences in hand size.[1] The adjustment for hand size was constant for all measurements for a given subject. The dynamometer scale was marked and read in 1 kg units. The seated subject leaned forward until his upper arms were at 90° to his forearms which rested shoulder-width apart on a table. To eliminate shoulder extension and resultant elbow flexion as sources of error, the dynamometer was allowed free horizontal movement in the antero-posterior plane (4).

Muscle temperature. Advantages ascribed to intramuscular wire as compared to needle electrodes for electromyography include small diameter, considerable flexibility and consequent minimal impedence of muscular function through discomfort (6). These factors are equally important to the study of intramuscular temperature. Although both needle (5) and catheter (1, 5) techniques have been employed, neither would appear to be entirely satisfactory for temperature measurement during exercise. Conversely, a 40 gauge thermocouple has been stated to have no effect on function (2). Apart from functional considerations, thermocouple insertion may cause a local hyperaemic response with a

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[1]C. H. Stoelting Co.

resultant temperature increase. An elevated or variable reference point does not permit accurate evaluation of the temperature level or the rate of change produced by the treatment under study. To eliminate this potential source of error, an interval of several hours should separate insertion and measurement. Moreover, thermocouple insertion requires an appreciable period of time. A further interval of several days would enable a given subject to be observed under a number of conditions (e.g. loads, rates and/or durations of exercise), and would only necessitate a single insertion. Such an interval requires a durable thermocouple that can be readily accommodated by the subject. The presently reported method was developed in consideration of these factors.

Thermocouples were constructed of 36 gauge iron and constantan wires as shown in Figure 1.[2] Three mm of insulation were removed from the centre of each length of wire. While under moderate tension, the bared portions were given three and one-half turns about each other. Short strips of cellulose tape were employed to hold the wires parallel and to confine the length of wire which was turned. The wires were finally soldered at low heat over a minimal distance.[3] A 21 gauge hypodermic needle was used to insert the thermocouple as shown in Figure 2. Oblique insertion has been suggested in order to prevent wire distortion and to reduce discomfort during muscular contraction (2). When the needle was carefully removed, there was no noticeable tendency for the thermocouple to follow. The probability of simultaneous

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[2]Thermo Electric Canada Ltd.

[3]Certanium 34C, Certanium Alloys and Research Co.

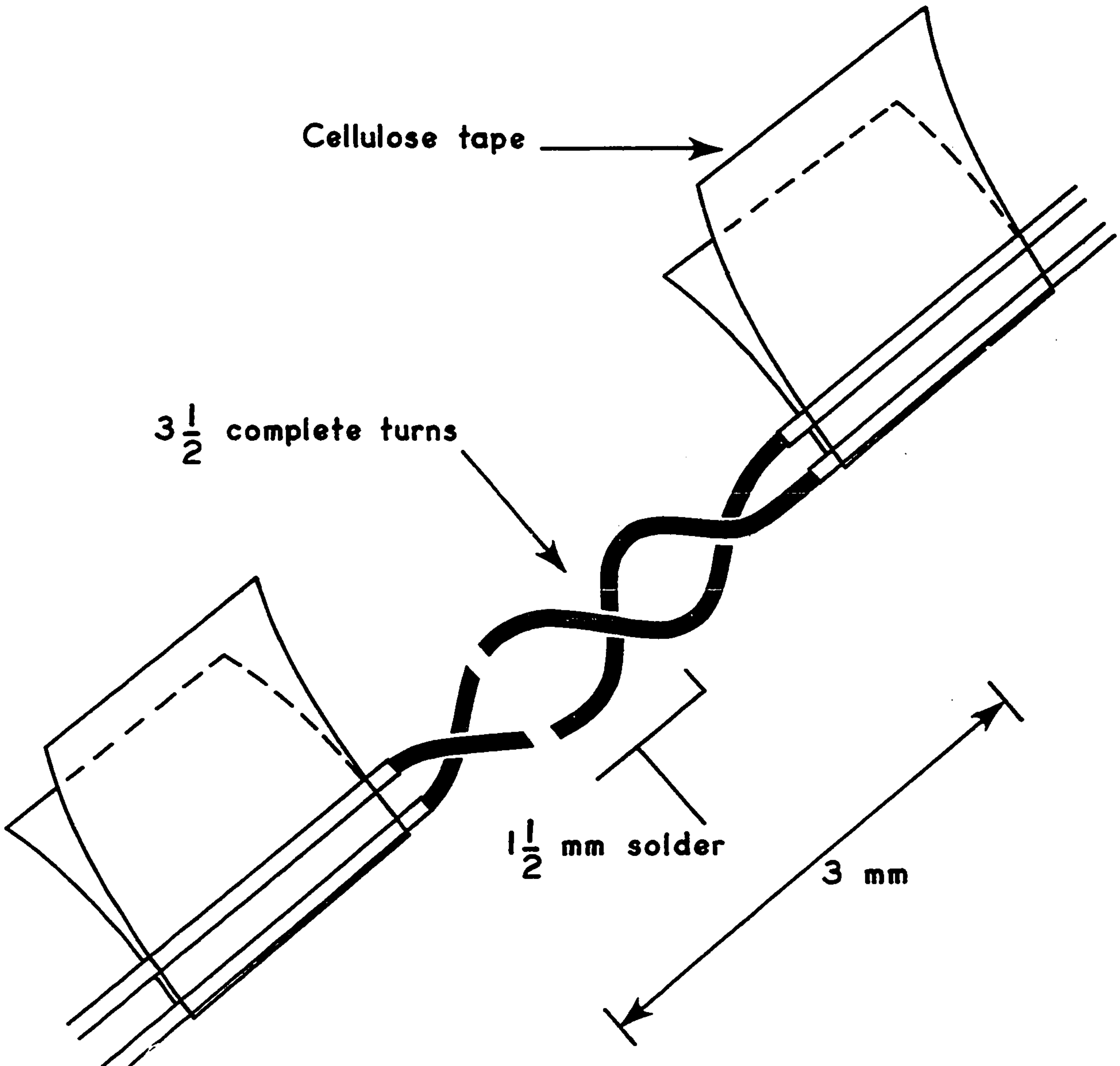

FIGURE 1. METHOD OF THERMOCOUPLE CONSTRUCTION

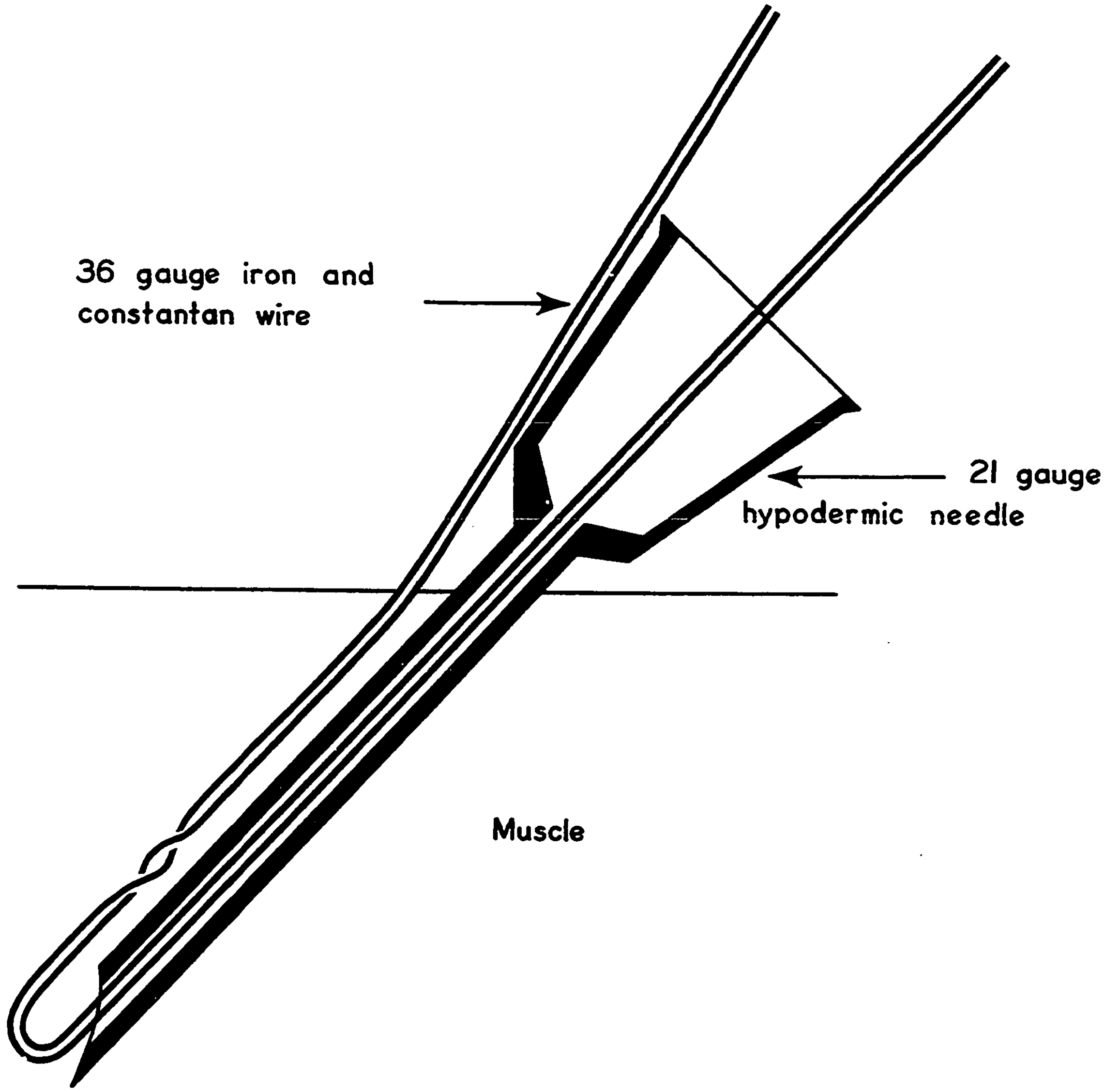

FIGURE 2. METHOD OF THERMOCOUPLE INSERTION

subcutaneous breakage of all four leads is relatively small. Should one or more leads remain intact, the entire thermocouple can be removed. While two leads may be deliberately separated on insertion (6), the selection of four leads was made in order to reduce the possibility of leaving a subcutaneous fragment. An intramuscular thermocouple may move independently of the skin during contraction. This movement may be accommodated where the leads remain slack between the points of insertion and attachment to the skin. The leads were covered to prevent damage. Each pair of leads was terminated by a miniature iron-constantan socket.[4] Instrument leads had a corresponding plug.

Thermocouple voltage was amplified by an Astrodata TDA-121 nanovoltmeter and recorded on a Hewlett-Packard 680M strip chart. The voltage produced by an iron-constantan thermocouple is approximately .05 mV/^{o}C. Measurement precision was determined by the selection of a 1 mV (20^{o}C) nanovoltmeter scale and the establishment of the recorder baseline at 30^{o}C. A .5 mV (10^{o}C) nanovoltmeter scale would have been preferable but was not available. The reference thermocouple was placed in a mixture of ice and water (0^{o}C). A second thermocouple in water at 30^{o}C as determined by a large scale Hg thermometer was employed to offset the baseline. The measurement error variance of this procedure was estimated from fifty repetitions to be .0042^{o}C. Baseline drift was not discernable during the period required by a series of measurements.

The thermocouple was inserted into the flexor digitorum superficialis muscle of the nonpreferred arm immediately distal to the

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[4]Thermo Electric Canada Ltd.

pronator teres muscle. The vertical depth of insertion was approximately 1 cm. Care was taken to avoid the ulnar nerve and major tributaries of the median vein. Insertion was guided by fascial resistance. In two subjects, biplane X-ray after five days indicated no tendency for the thermocouple to migrate from the muscle to subcutaneous tissue. A more convenient although less precise indicator of intramuscular location is thermocouple deflection at the point of insertion during contraction. Deflection was greatly reduced or not evident when a thermocouple was deliberately placed in the subcutaneous tissue.

Central temperature. A 36 gauge thermocouple was encased in polythene tubing and placed at the maximal comfortable depth into the external auditory meatus. A cotton wad was used to reduce meatal air volume and the ear was covered by moulded foam rubber. Cooper et al. (3) have suggested that meatal temperature adequately reflects temperature changes in the central arterial blood.

Design

The experiment was completed over five (or four) consecutive days for each of twelve normally active male subjects (age range twenty-one to thirty-nine years). The first day involved only thermocouple insertion. The thermocouple remained in place for the duration of the experiment. The procedure at approximately the same hour for the remaining four days included a ten minute rest period, a pre-exercise period comprised of two contractions, an exercise period comprised of fifteen or thirty or forty-five or sixty contractions and a post-exercise period comprised of ten contractions. The four experimental conditions were defined by the number of exercise contractions and did not differ in any other respect. The conditions were designated by the numbers 15, 30, 45 and 60. Each subject was observed once under each condition. Condition orders were randomly assigned to subjects. All contractions were maximal and were approximately one second in duration. Pre- and post-exercise contractions were considered as strength measurements (as opposed to exercise) and were spaced by one minute. Exercise contractions were spaced by five seconds. Correct intervals were assured by the use of taped instructions. Temperature measurements were spaced by one minute during the rest, pre- and post-exercise periods. During the exercise period, temperature measurements coincided with every fifth contraction.

In six subjects, one or more thermocouple leads broke subcutaneously between the third and fourth days and the experiment was completed on the fourth day. Such breakage did not affect the experiment since the thermocouple provided four combinations of paired iron and constantan leads. The two series of measurements on the last day were three hours apart. As condition orders were randomly assigned to subjects, no condition was considered to have been systematically affected.

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CHAPTER IV

RESULTS AND DISCUSSION

The data were analysed both graphically and statistically. In each of the several figures presented, mean points were approximated by a single smooth curve. Curve equations and standard errors of regression were computed and are given in Appendix B. The form of each curve was determined empirically. Since all individuals may not respond similarly under a given condition, a mean curve may falsely represent a relationship. Accordingly, the data were examined separately for each subject and mean curves were qualified by the inclusion in each figure of two individual curves which suggest the nature and/or extent of interindividual differences.[1]

Grip Strength

Due to the random assignment of condition orders to subjects, mean differences among conditions for a given contraction during either the pre-exercise or the exercise period were not expected and could only have been ascribed to error. Therefore, grip strength means for both of these periods included the data for all conditions. Pre-exercise means were comprised of forty-eight observations (12 subjects x 4 conditions or observations per subject). For contractions one to fifteen, sixteen to thirty, thirty-one to forty-five and forty-six to sixty, exercise means

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[1]Interindividual differences are differences between individuals. Intraindividual differences are differences within individuals.

were comprised of forty-eight, thirty-six, twenty-four and twelve observations (12 subjects x 4, 3, 2 and 1 observation per subject), respectively. Conversely, post-exercise means were calculated separately for each condition in consideration of possible differences among conditions at a given time following different durations of exercise. Post-exercise means were comprised of twelve observations (12 subjects x 1 observation per condition per subject).

Exercise. As shown in Figure 3, mean grip strength decreased over successive closely spaced contractions in the manner previously described for similar exercise by Grose (12). To simplify the figure, only every fifth mean was indicated whereas the equation given in Appendix B was based on the means for all contractions. The observed systematic strength decrement was assumed to indicate fatigue. Individual strength measurements were averaged over the last five contractions for each condition and these final levels were compared. Mean grip strength was significantly lower after thirty and sixty contractions than after fifteen contractions. Grip strength means and the critical mean difference are given in Table 1. The analysis of variance is presented in Table 2.

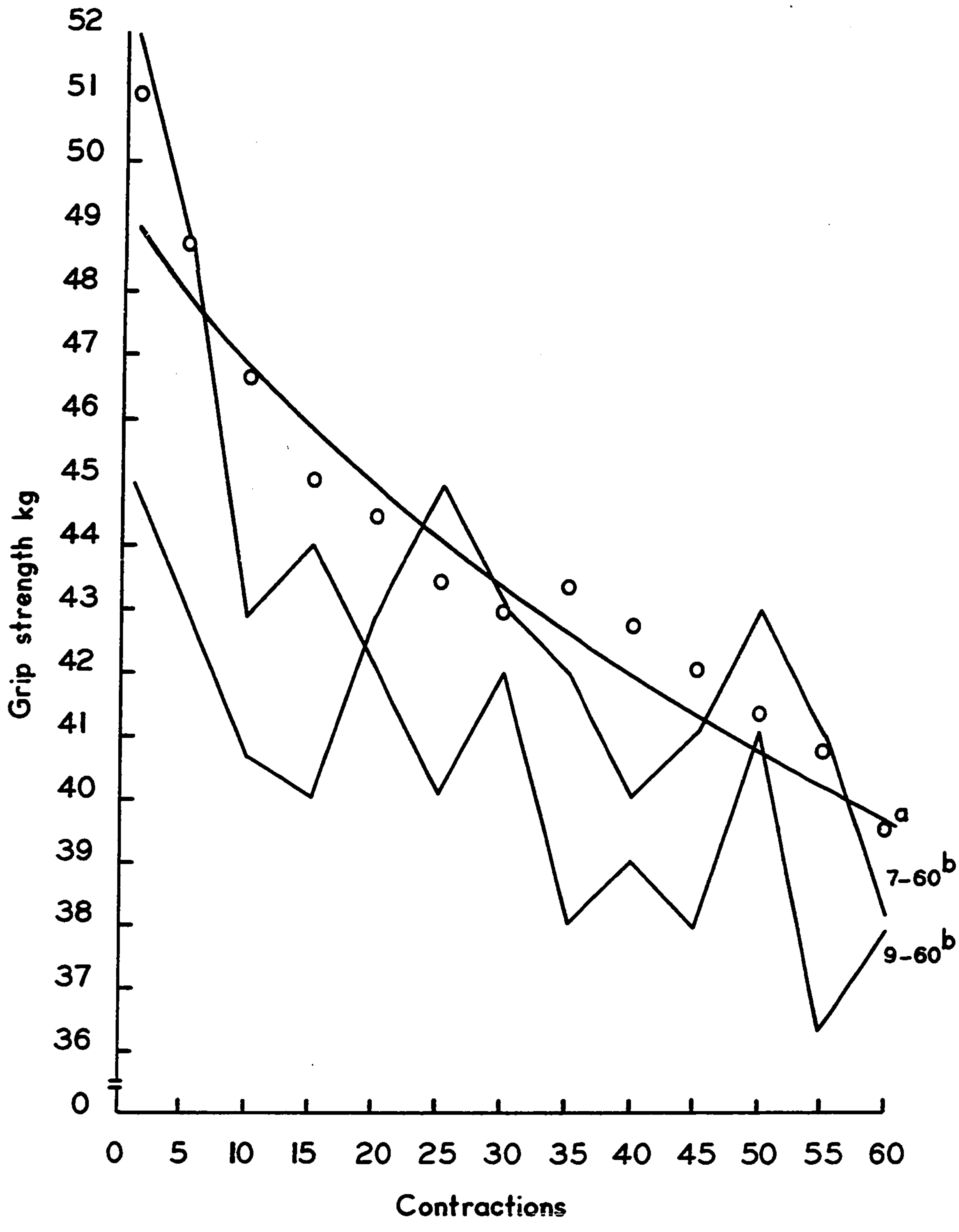

FIGURE 3. EXERCISE GRIP STRENGTH

[a] Mean of all conditions
[b] Subject-condition

TABLE 1. GRIP STRENGTH DESCRIPTIVE STATISTICS AND CRITICAL MEAN DIFFERENCE FOR THE END OF THE EXERCISE PERIOD

	Condition 15	30	45	60	Critical Mean Difference[a]
	Contractions 11-15	26-30	41-45	56-60	
$\bar{X}$	44.67	41.85	42.25	40.17	2.61
s	3.78	5.12	3.93	4.19	

[a]Subsequent to a significant F ratio, the Tukey (a) procedure was used to determine specific mean differences (16). A mean difference greater than the critical mean difference was significant ($\alpha = .05$).

TABLE 2. GRIP STRENGTH ANALYSIS OF VARIANCE FOR THE END OF THE EXERCISE PERIOD

Source of Variation	SS	df	MS	F	$F_{.95}$
Between subjects	698.06	11			
Within subjects	307.31	36			
Conditions	123.94	3	41.31	7.43	2.89
Residual	183.38	33	5.56		

<u>Pre- and post-exercise</u>. Individual pre- and post-exercise grip strength measurements were averaged over groups consisting of two consecutive contractions for each condition. These data were analysed to determine the absolute effects (compared to pre-exercise) of each duration of exercise and the relative effects of different durations of exercise on post-exercise grip strength. No significant effects were determined. Whereas mean differences in grip strength were observed after different durations of exercise, a functional recovery from the fatigue of exercise was largely completed during the first two minutes

of the post-exercise period regardless of the duration of the preceding exercise. Grip strength means are given in Table 3. The analysis of variance is presented in Table 4. Mean curves are shown in Figure 4.

TABLE 3. GRIP STRENGTH DESCRIPTIVE STATISTICS FOR THE PRE- AND POST-EXERCISE PERIODS

Condition		Pre- 0-1	Post-exercise Minutes 1-2	3-4	5-6	7-8	9-10
15	$\bar{X}$	49.79	50.21	51.63	51.71	51.88	50.79
	s	6.19	3.51	4.04	4.23	3.92	4.71
30	$\bar{X}$	50.96	49.38	50.58	50.38	50.33	50.29
	s	5.34	4.30	4.52	4.26	4.40	4.99
45	$\bar{X}$	52.75	49.92	51.29	51.92	51.75	51.13
	s	5.68	4.85	5.18	5.48	5.54	5.49
60	$\bar{X}$	51.08	49.63	51.33	52.08	51.21	51.71
	s	5.35	4.70	4.91	4.60	5.44	5.54

TABLE 4. GRIP STRENGTH ANALYSIS OF VARIANCE FOR THE PRE- AND POST-EXERCISE PERIODS

Source of Variation	df	MS	F^a	$F_{.95}$
Conditions	3	16.83	.66	2.90
Minutes	5	18.25	2.25	2.39
Subjects	11	472.09		
Conditions x minutes	15	4.44	1.46	1.73
Conditions x subjects	33	25.53		
Minutes x subjects	55	8.12		
Conditions x minutes x subjects	165	3.04		

[a]The denominators in the F ratios for conditions, minutes and conditions x minutes were the mean squares for the respective interactions with subjects.

Muscle and Central Temperatures

Muscle and central temperature measurements were transformed

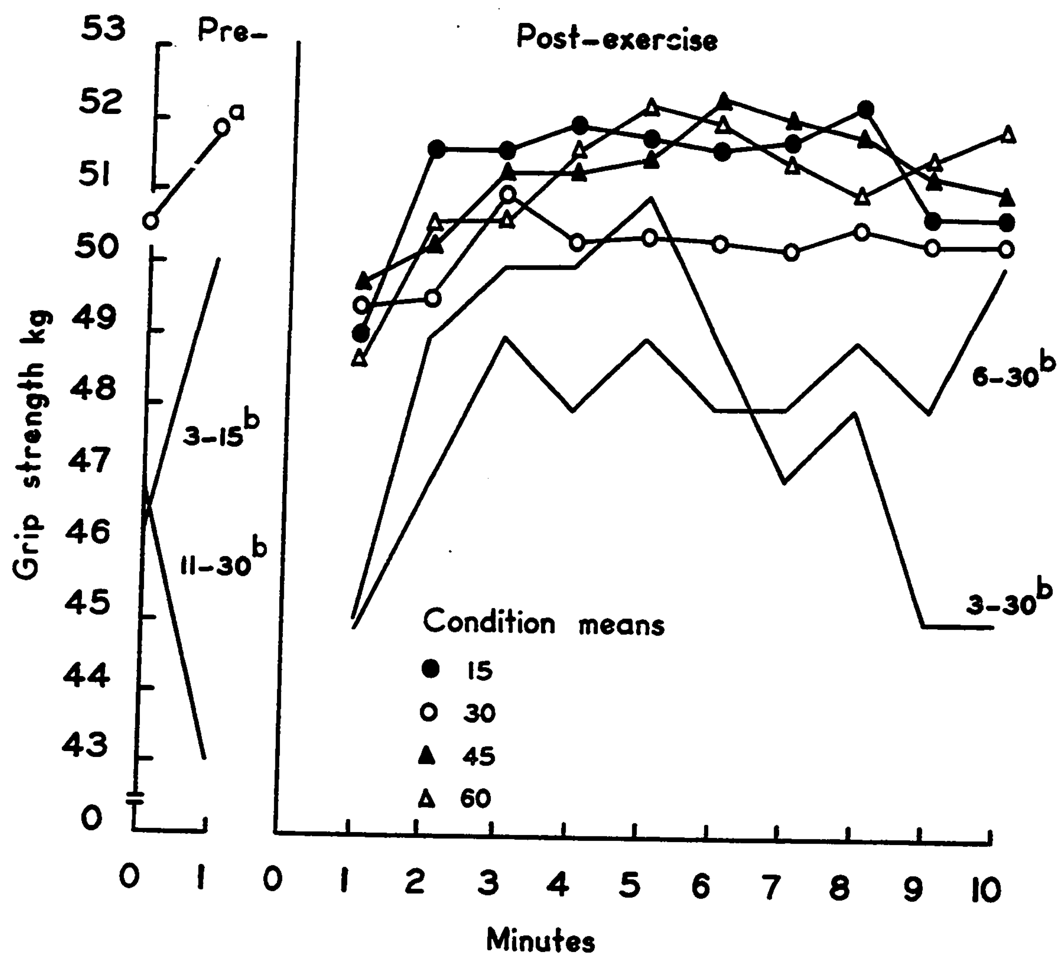

FIGURE 4. PRE- AND POST-EXERCISE GRIP STRENGTH

[a] Mean of all conditions

[b] Subject-condition

from actual to deviation values in degrees centigrade and were designated as Δ-temperatures. For each individual and each occasion, values of muscle Δ-temperature were obtained by subtracting the actual value of muscle temperature at zero minutes of the rest period from the actual values of muscle temperature subsequently measured. Values of central Δ-temperature were similarly obtained. Significant differences in an analysis of variance for repeated measures are dependent on intraindividual differences in response to different conditions. Both muscle and central temperatures were observed to vary intraindividually from one occasion to another in a manner unrelated to conditions. Such variation was eliminated as a source of error by the use of Δ-temperature values. Although regarded as a source of error, the observed intraindividual variation in muscle and central temperatures was expected. Buchthal et al. (6) reported that the temperature of a given muscle may vary intraindividually from day to day. Cooper et al. (9) found a considerable temperature gradient along the length of the external auditory meatus and suggested that central temperature estimates at this location should be expressed in deviation form to eliminate errors due to differences in thermocouple location when repeating a procedure.

Muscle and central Δ-temperature means for the pre-exercise, exercise and post-exercise periods were computed in the manner previously described on page 16 for grip strength. Muscle and central Δ-temperature means for the rest period were computed in the same manner as those for the pre-exercise period. The mean curves for both Δ-temperatures and each condition were based on every measurement. Conversely, individual

Δ-temperature measurements for the rest and post-exercise periods were averaged over periods of two minutes for the purpose of statistical analysis. Delta-temperature means may be transformed to actual values by adding the appropriate entry in Table 5.

TABLE 5. MEAN MUSCLE AND CENTRAL TEMPERATURES FOR ZERO MINUTES OF THE REST PERIOD

Temperature	Condition			
	15	30	45	60
Muscle	33.88	34.51	34.49	34.29
Central	36.33	36.47	36.67	36.27

Rest. During the rest period, mean muscle Δ-temperature decreased linearly as shown in Figure 5. The ambient temperature was 19.1 ± .5°C. Barcroft and Edholm (4) also reported an approximately linear decrease in muscle temperature in the exposed resting forearm at an ambient temperature of 18.5°C. Mean muscle Δ-temperature was significantly lower during the fifth and sixth, the seventh and eighth and the ninth and tenth minutes than during the first and second minutes. Mean muscle Δ-temperature was significantly lower during the seventh and eighth and the ninth and tenth minutes than during the third and fourth minutes. Mean muscle Δ-temperature was significantly lower during the ninth and tenth minutes than during the fifth and sixth minutes. Muscle Δ-temperature means and the critical mean difference are given in Table 6. The analysis of variance is presented in Table 7.

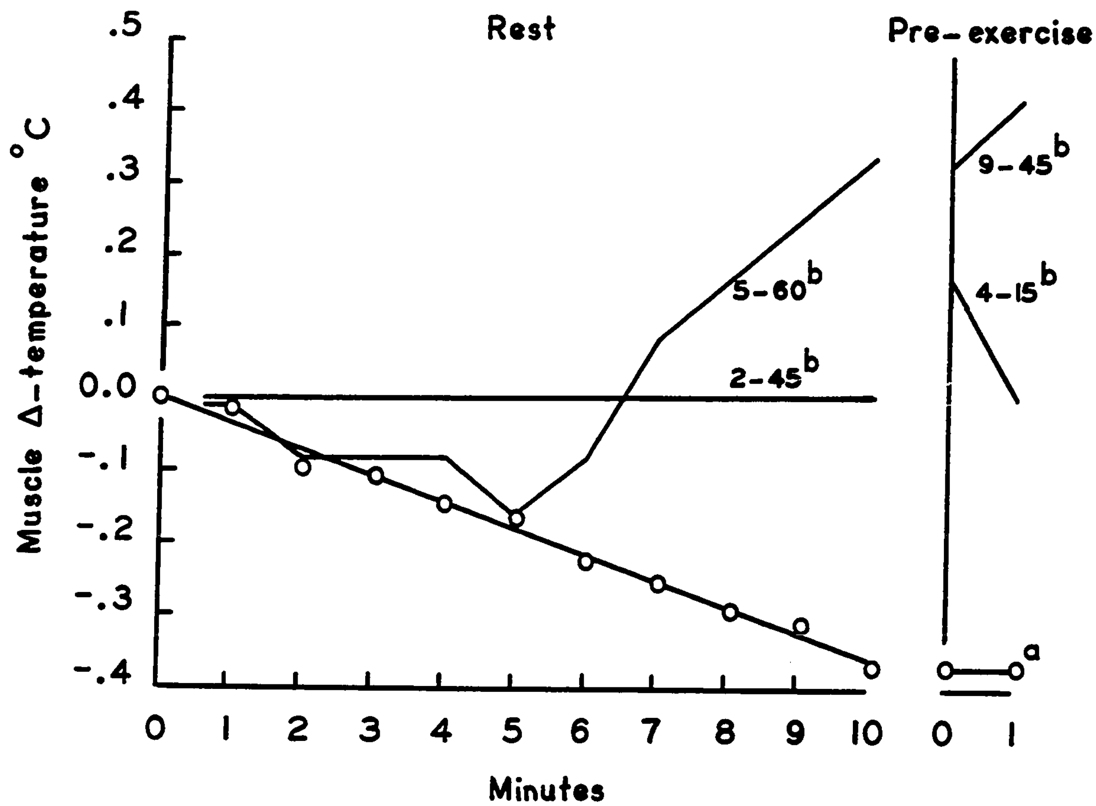

FIGURE 5. REST AND PRE-EXERCISE MUSCLE Δ-TEMPERATURE

[a] Mean of all conditions
[b] Subject-condition

TABLE 6. MUSCLE AND CENTRAL Δ-TEMPERATURE DESCRIPTIVE STATISTICS AND CRITICAL MEAN DIFFERENCES FOR THE REST PERIOD

Δ-temperature		Minutes 1-2	3-4	5-6	7-8	9-10	Critical Mean Difference[a]
Muscle	$\bar{X}$	-.05	-.13	-.20	-.28	-.35	.14
	s	.07	.14	.21	.27	.33	
Central	$\bar{X}$	.03	.12	.21	.29	.36	.07
	s	.03	.06	.10	.12	.13	

[a]A mean difference greater than the critical mean difference was significant ($\alpha = .05$).

TABLE 7. MUSCLE Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE REST PERIOD

Source of Variation	SS	df	MS	F	$F_{.95}$
Between subjects	2.4303	11			
Within subjects	1.2875	48			
Minutes	.6707	4	.1677	11.96	2.59
Residual	.6168	44	.0140		

During the rest period, mean central Δ-temperature increased linearly as shown in Figure 6. All mean differences in central Δ-temperature were significant. Central Δ-temperature means and the critical mean difference are given in Table 6. The analysis of variance is presented in Table 8.

TABLE 8. CENTRAL Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE REST PERIOD

Source of Variation	SS	df	MS	F	$F_{.95}$
Between subjects	.3927	11			
Within subjects	.9528	48			
Minutes	.7983	4	.1996	56.81	2.59
Residual	.1546	44	.0035		

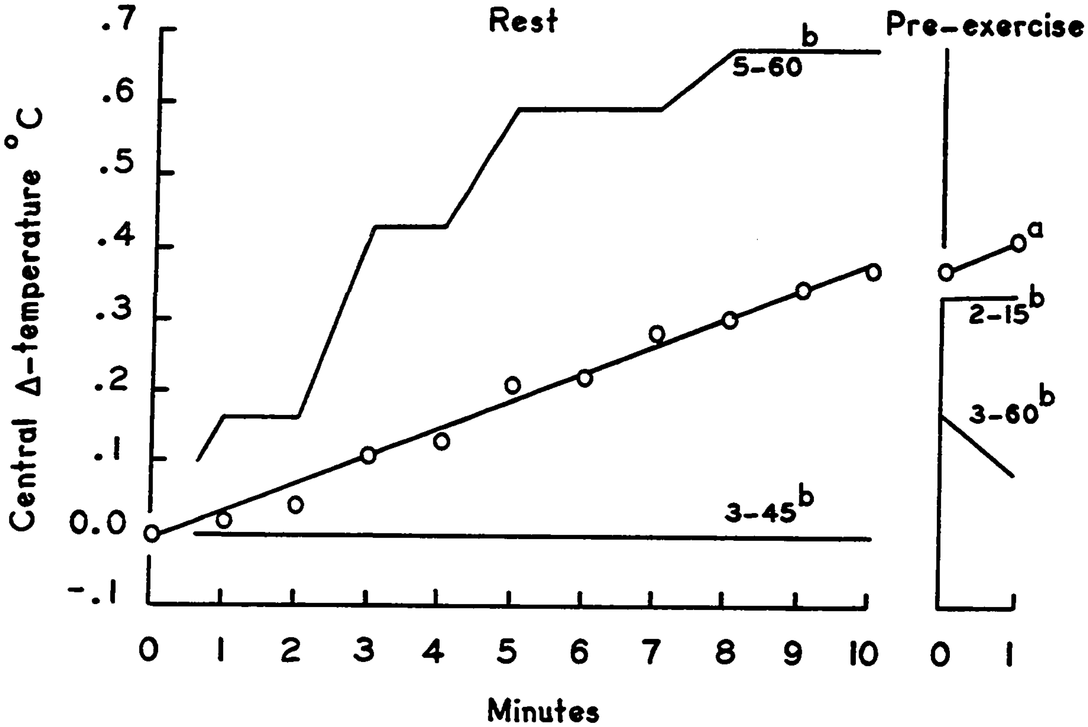

FIGURE 6. REST AND PRE-EXERCISE CENTRAL Δ-TEMPERATURE

[a] Mean of all conditions
[b] Subject-condition

Pre-exercise. As shown in Figure 5, mean muscle Δ-temperature did not fall beyond the first pre-exercise contraction. Mean central Δ-temperature continued to increase during the pre-exercise period as shown in Figure 6.

Exercise. Mean muscle Δ-temperature increased at a progressively increasing rate during the exercise period as shown in Figure 7. Buchthal et al. (6) determined that for the same subject and a constant contraction rate, temperature increase in the biceps brachii muscle was proportional to both the load and the duration of exercise. For the present load and rate of exercise, the degree of muscle temperature increase was proportional to the duration of exercise. Mean muscle Δ-temperature was significantly higher after forty-five and sixty contractions than after fifteen contractions and was significantly higher after sixty contractions than after thirty contractions. Muscle Δ-temperature means and the critical mean difference are given in Table 9. The analysis of variance is presented in Table 10.

TABLE 9. MUSCLE AND CENTRAL Δ-TEMPERATURE DESCRIPTIVE STATISTICS AND MUSCLE Δ-TEMPERATURE CRITICAL MEAN DIFFERENCE FOR THE END OF THE EXERCISE PERIOD

Δ-temperature		Condition 15	30	45	60	Critical Mean Difference[a]
Muscle	$\bar{X}$	-.35	.03	.23	.64	.44
	s	.40	.61	.60	.81	
Central	$\bar{X}$	.55	.43	.45	.66	
	s	.19	.36	.23	.36	

[a]A mean difference greater than the critical mean difference was significant ($\alpha = .05$).

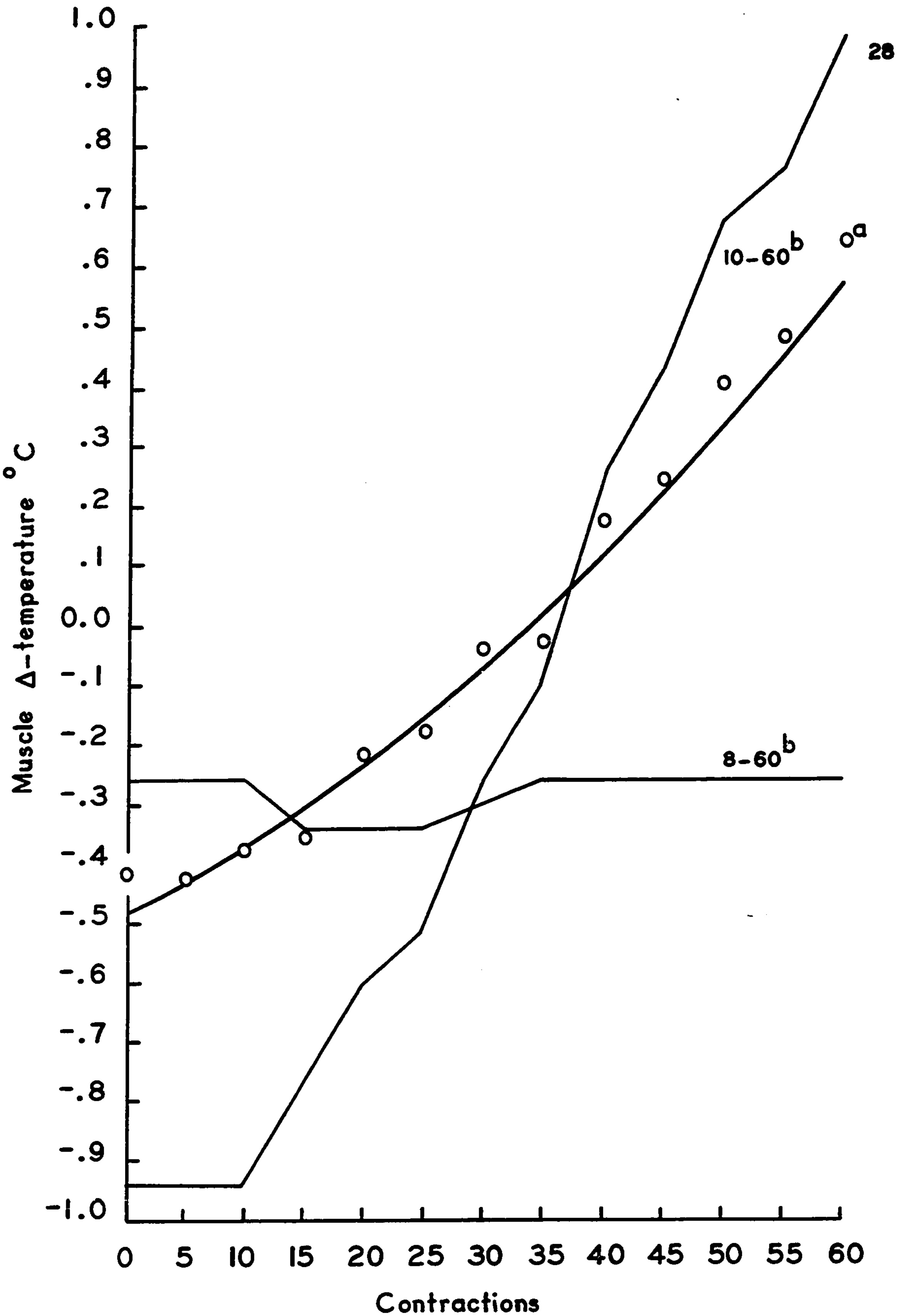

FIGURE 7. EXERCISE MUSCLE Δ-TEMPERATURE

[a] Mean of all measurements for the given contraction
[b] Subject-condition

TABLE 10. MUSCLE Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE END OF THE EXERCISE PERIOD

Source of Variation	SS	df	MS	F	$F_{.95}$
Between subjects	13.2444	11			
Within subjects	11.4195	36			
Conditions	6.1195	3	2.0398	12.70	2.89
Residual	5.3000	33	.1606		

During the exercise period, mean central Δ-temperature increased in a manner similar to mean muscle Δ-temperature although the latter had the faster rate and the greater degree of increase. The mean curve for central Δ-temperature is shown in Figure 8. No mean differences in central Δ-temperature were significant. Central Δ-temperature means are given in Table 9. The analysis of variance is presented in Table 11.

TABLE 11. CENTRAL Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE END OF THE EXERCISE PERIOD

Source of Variation	SS	df	MS	F	$F_{.95}$
Between subjects	2.1949	11			
Within subjects	2.3386	36			
Conditions	.3991	3	.1330	2.26	2.89
Residual	1.9396	33	.0588		

Post-exercise. Following each duration of exercise, mean muscle Δ-temperature increased at a progressively decreasing rate as shown in Figure 9. Mean muscle Δ-temperature was significantly higher following forty-five and sixty contractions than following fifteen contractions and was significantly higher following sixty contractions than following thirty contractions. In the analysis of mean muscle Δ-temperature as a function of minutes following exercise, the only nonsignificant increase

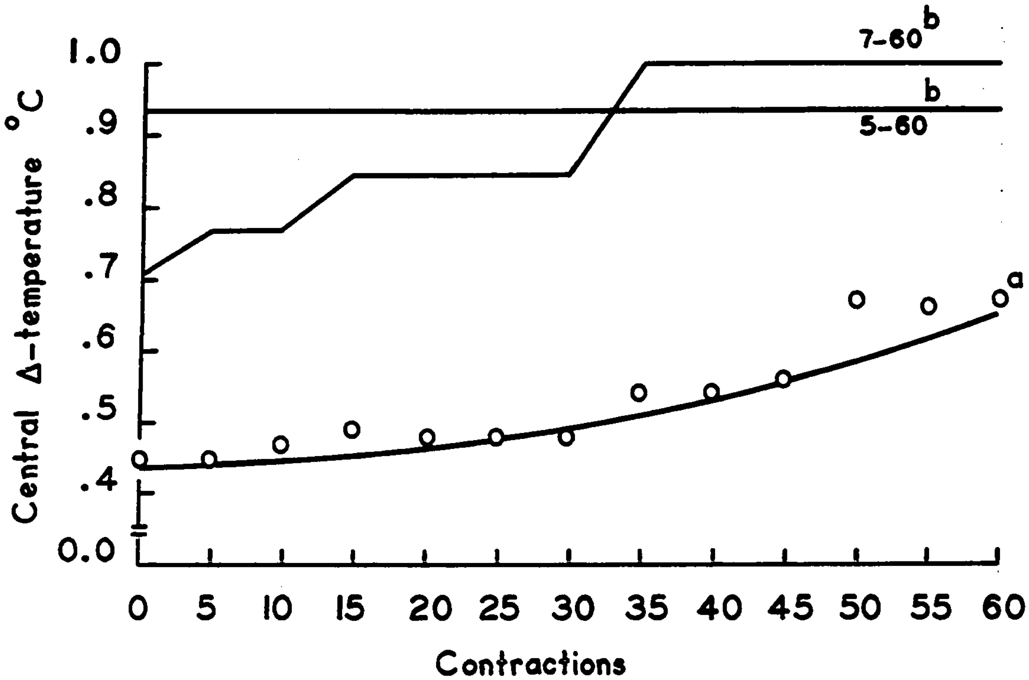

FIGURE 8. EXERCISE CENTRAL Δ-TEMPERATURE

[a] Mean of all measurements for the given contraction
[b] Subject-condition

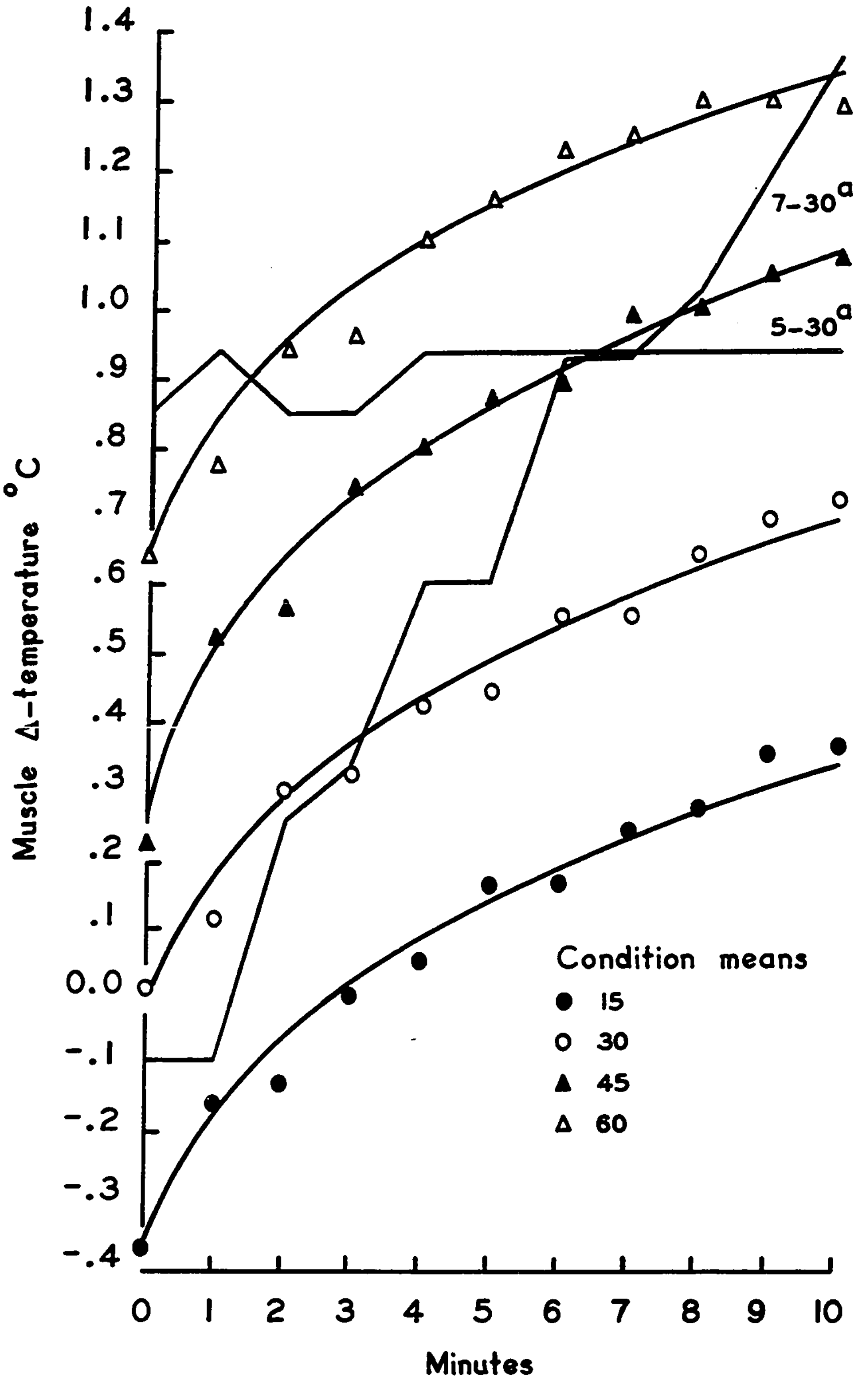

FIGURE 9. POST-EXERCISE MUSCLE Δ-TEMPERATURE

[a] Subject – condition

was between the seventh and eighth and the ninth and tenth minutes. Muscle Δ-temperature means and the critical mean differences are given in Table 12. The analysis of variance is presented in Table 13.

TABLE 12. MUSCLE AND CENTRAL Δ-TEMPERATURE DESCRIPTIVE STATISTICS AND CRITICAL MEAN DIFFERENCES FOR THE POST-EXERCISE PERIOD

Condition		Minutes 0	1-2	3-4	5-6	7-8	9-10	Condition $\bar{X}$
Muscle Δ-temperature								
15	$\bar{X}$	-.37	-.14	.02	.16	.25	.35	.05
	s	.49	.50	.55	.55	.59	.60	
30	$\bar{X}$	.01	.20	.37	.49	.60	.70	.40
	s	.68	.69	.69	.71	.70	.72	
45	$\bar{X}$	.22	.54	.77	.88	1.00	1.06	.74 [a]
	s	.57	.56	.52	.52	.49	.53	
60	$\bar{X}$	.64	.85	1.03	1.20	1.27	1.29	1.05
	s	.81	.75	.71	.69	.66	.67	
Minutes[b]	$\bar{X}$	.12	.36	.55	.68	.78	.85	
Central Δ-temperature								
15	$\bar{X}$	.55	.56	.58	.63	.64	.68	.60
	s	.19	.20	.24	.30	.32	.33	
30	$\bar{X}$	.43	.49	.47	.49	.55	.56	.50
	s	.36	.38	.39	.40	.42	.43	
45	$\bar{X}$	.45	.48	.50	.54	.56	.57	.52
	s	.23	.23	.22	.24	.26	.28	
60	$\bar{X}$	.66	.70	.77	.76	.79	.83	.75
	s	.36	.43	.41	.42	.42	.44	
Minutes[c]	$\bar{X}$	.52	.56	.58	.60	.63	.66	

Critical mean differences [a].54 [b].10 [c].04 A mean difference greater than the critical mean difference was significant ($\alpha = .05$).

TABLE 13. MUSCLE Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE POST-EXERCISE PERIOD

Source of Variation	MS	df	F[a]	$F_{.95}$
Conditions	13.4979	3	14.40	2.90
Minutes	3.6245	5	86.41	2.39
Subjects	7.0630	11		
Conditions x minutes	.0163	15	.87	1.73
Conditions x subjects	.9375	33		
Minutes x subjects	.0419	55		
Conditions x minutes x subjects	.0187	165		

[a]The denominators in the F ratios for conditions, minutes and conditions x minutes were the mean squares for the respective interactions with subjects.

Following each duration of exercise, mean central Δ-temperature increased linearly as shown in Figure 10. The duration of the preceding exercise did not significantly affect mean central Δ-temperature. Mean central Δ-temperature was significantly lower immediately after exercise than during any subsequent two minute period. Mean central Δ-temperature was significantly higher during the fifth and sixth, the seventh and eighth and the ninth and tenth minutes than during the first and second minutes. Mean central Δ-temperature was significantly higher during the seventh and eighth and the ninth and tenth minutes than during the third and fourth minutes. Mean central Δ-temperature was significantly higher during the ninth and tenth minutes than during the fifth and sixth minutes. Central Δ-temperature means and the critical mean difference for the analysis of central Δ-temperature as a function of minutes following exercise are given in Table 12. The analysis of variance is presented in Table 14.

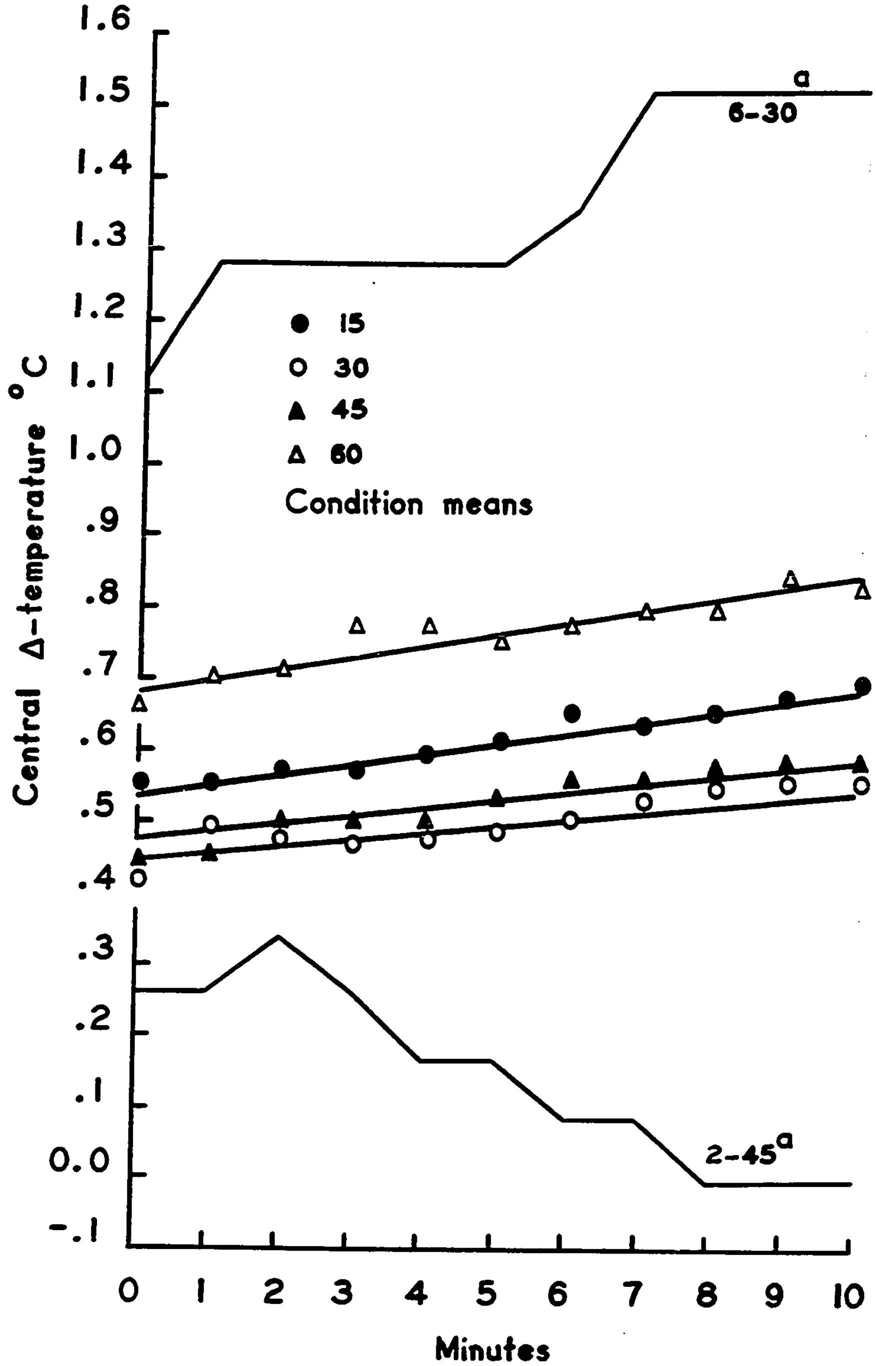

FIGURE 10. POST-EXERCISE CENTRAL Δ-TEMPERATURE

[a] Subject-condition

TABLE 14. CENTRAL Δ-TEMPERATURE ANALYSIS OF VARIANCE FOR THE POST-EXERCISE PERIOD

Source of Variation	MS	df	F^a	$F_{.95}$
Conditions	.9630	3	1.94	2.90
Minutes	.1249	5	15.53	2.39
Subjects	1.4135	11		
Conditions x minutes	.0031	15	.68	1.73
Conditions x subjects	.4968	33		
Minutes x subjects	.0080	55		
Conditions x minutes x subjects	.0046	165		

[a]The denominators in the F ratios for conditions, minutes and conditions x minutes were the mean squares for the respective interactions with subjects.

Muscle Temperature Regulation

Two sources of heat are available to a muscle. These are the metabolic heat produced during the contraction and recovery phases of the muscle and the heat brought to the muscle by the arterial blood. The muscular metabolic rate was increased during the exercise period and may have also been increased during the post-exercise period as complete strength recovery was not observed between contractions during the exercise period. Mean muscle temperature was presently observed to decrease systematically during the rest period but was not observed to decrease beyond the first pre-exercise contraction. The metabolic heat produced by this contraction may not have been sufficient to prevent a further decrease in muscle temperature. A more probable explanation was that greater heat was available to the muscle as a consequence of an increased muscle blood flow during and after the contraction. Muscle blood flow may be increased during a contraction although vasodilatation of the muscle blood vessels would not be complete due to the compressive force exerted on them by the muscle during contraction (2, 3, 11). A further increase in muscle blood flow may occur immediately following a contraction (1, 10, 11, 14, 15). Whether a muscle is warmed or cooled by an increased muscle blood flow is dependent on the direction of the gradient between the temperatures of the arterial blood and the muscle. The explanation offered to account for no further muscle temperature decrease after the first pre-exercise contraction assumed that the temperature of the arterial blood was the greater. Bazett et al. (5) reported a progressive decrease in the temperature of the arterial blood along the length of the arm. The assumed temperature gradient between the arterial blood and the muscle during the pre-exercise period may not have been large and may have been reversed by the accumulation of metabolic heat in the muscle during the exercise and post-exercise periods. While an increase in muscle blood flow was assumed during these periods, the effect on muscle temperature was unknown since the temperature of the arterial blood was unknown. Simultaneous measurements of forearm blood flow and arterial blood temperature would be necessary in order to determine the effect of muscle blood flow on temperature regulation in the flexor digitorum superficialis muscle during and after rhythmic exercise.

Grip Strength and Muscle Temperature

Several studies have considered the effect of increased muscle temperature on grip strength. Clarke et al. (8) compared grip strength before and after thirty minutes of forearm immersion in water at 34°C and 42°C. Following forearm immersion, the respective temperatures in the brachioradialis muscle measured 4 cm below the elbow were approximately 36°C and 38°C. Grip strength was not affected by increased muscle temperature. Grose (12) found that eight minutes of forearm immersion in water at 48°C did not cause grip strength to differ significantly from a control condition. The second in a series of 180 maximal contractions which were spaced by two seconds was unaffected by fatigue and was used as the estimate of grip strength. Conversely, Clarke and Stelmach (7) reported that grip strength was significantly lower after ten minutes of forearm immersion in water at 46°C than for a control condition at the beginning of a two minute maximal static contraction. King et al. (13) measured grip strength at one minute intervals for ten minutes following an exercise period comprised of twenty-five maximal grip contractions which were spaced by five seconds. The first contraction during the exercise period was unaffected by fatigue and was assumed to be representative of pre-exercise grip strength. Grip strength was significantly greater during the last eight minutes of the post-exercise period than at the beginning of the exercise period. The temperature in the flexor digitorum superficialis muscle remained unchanged during the exercise period but increased by approximately .5°C during the post-exercise period. Greater grip strength and increased muscle temperature appeared to be related. In the present study, mean muscle temperature ranged from 33.51°C to 35.58°C. No significant differences in mean grip strength were found.

Whether passively or actively induced, an increase in muscle temperature has not been found to consistently affect grip strength.

While the differences in grip strength reported by Clarke and Stelmach (7) and by King *et al*. (13) may have been due to an increase in muscle temperature, the possibility also exists that a psychological factor may have either contributed to or caused the differences. A more definitive statement of this possibility cannot be made on the basis of present knowledge.

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CHAPTER V

SUMMARY AND CONCLUSIONS

Summary

The problems were as follows:

1. To determine the effect of a linearly increased duration of equally spaced maximal grip contractions on the degree of muscle (flexor digitorum superficialis) and central (external auditory meatus) temperature increases and

2. To determine the effect of muscle temperature on grip strength.

The experiment was completed over five consecutive days for each of twelve normally active male subjects. An intramuscular thermocouple was inserted on the first day and remained in place for the duration of the experiment. The procedure for the remaining four days included a ten minute rest period, a pre-exercise period comprised of two contractions which were spaced by one minute, an exercise period comprised of fifteen or thirty or forty-five or sixty contractions which were spaced by five seconds and a post-exercise period comprised of ten contractions which were spaced by one minute. All contractions were maximal and were approximately one second in duration. The four experimental conditions were defined by the number of exercise contractions and did not differ in any other respect. Each subject was observed once under each condition. Muscle and central temperatures were measured at intervals during each period.

Conclusions

Two conclusions may be stated in reference to the specified load and rate of grip contractions.

1. The degree of muscle temperature increase is proportional to the duration of exercise.

2. The degree of central temperature increase is not systematically affected by the duration of exercise.

Mean muscle temperature ranged from 33.51°C to 35.58°C. A third conclusion may be stated in reference to this range of muscle temperature.

3. Grip strength is not affected by muscle temperature.

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APPENDIX A

ADVISED CONSENT FORM

Participants are advised of the following:

1. Slight discomfort is anticipated during thermocouple insertion.

2. Principal arteries and nerves are located deep to the required depth of insertion.

3. There may be an inflammatory reaction to the needle and/or thermocouple (i.e., redness and/or tenderness).

4. The thermocouple will be removed should undue discomfort be experienced.

5. The thermocouple will be removed should infection result.

6. A low-reactive tape will be employed in consideration of possible allergies.

7. Subcutaneous breakage of the thermocouple is a possibility but represents no immediate danger.

UNIVERSITY OF ALBERTA

FACULTY OF PHYSICAL EDUCATION

CONSENT TO PARTICIPATE IN A RESEARCH STUDY

Subject .... Date .... Time ........A.M./P.M.

1. I hereby agree to participate in an investigation and in relation to this hereby authorize Dr. _______ and/or such assistants as may be selected by him to perform the following procedure.

   A thermocouple (36 gauge iron and constantan) will be placed approximately 1/8 inch deep in the flexor digitorum superficialis at a point approximately 2 inches below the origin and will remain inserted for a period of 4 days. Insertion will be via a 21 gauge $1\frac{1}{2}$ inch hypodermic needle.

2. The purpose of this study has been explained to me by _______ and I understand the procedure outlined above. I recognize the dangers inherent in such a procedure and hereby specifically agree to hold The University of Alberta or any participant in this study legally blameless for any injury I may incur.

I HAVE READ AND FULLY UNDERSTAND THE ABOVE.

....

Witness and Date of Signing — Signature and Date

APPENDIX B

MEAN CURVE EQUATIONS AND STANDARD ERRORS OF REGRESSION

TABLE 15. MEAN CURVE EQUATIONS AND STANDARD ERRORS OF REGRESSION

Figure	Dependent Variable	Period	Equation	Standard Error
3	Grip strength	Exercise	$\log Y = 1.6828 - .0014X$	.0083[a]
4		Post-exercise 15	$Y = 50.22 + 1.56 \log X$	.73
4		30	$Y = 49.55 + .98 \log X$	.35
4		45	$Y = 49.94 + 1.93 \log X$	.49
4		60	$Y = 49.50 + 2.58 \log X$	.57
5	Muscle Δ-temperature	Rest	$Y = .0047 - .0380X$	.0133
7		Exercise	$\log Y = -.0247 + .0008X$	.0028[a]
9		Post-exercise 15	$Y = -.0133 + .2355 \log X$	.1090
9		30	$Y = .3376 + .2258 \log X$	.1188
9		45	$Y = .6744 + .2833 \log X$	.1031
9		60	$Y = .9886 + .2327 \log X$	.1060
6	Central Δ-temperature	Rest	$Y = -.0183 + .0401X$	.0131
8		Exercise	$\log Y = .0174 + .0002X$	.0013[a]
10		Post-exercise 15	$Y = .5372 + .0145X$	.0085
10		30	$Y = .4435 + .0124X$	.0167
10		45	$Y = .4586 + .0127X$	.0112
10		60	$Y = .6835 + .0153X$	.0180

[a]Expressed as log Y

APPENDIX C

DATA

DATA FORMAT

Subject

Period	Dependent Variable	Data	Independent Variable
Condition/Order 15/1			
Rest	Muscle temperature	0 1 2 3 4 5 6 7 8 9 10	Minutes
	Central temperature	0 1 2 3 4 5 6 7 8 9 10	Minutes
Pre-exercise	Grip strength	0 1	Minutes
	Muscle temperature	0 1	Minutes
	Central temperature	0 1	Minutes
Exercise	Grip strength	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15	Contractions
	Muscle temperature	0 5 10 15	Contractions
	Central temperature	0 5 10 15	Contractions
Post-exercise	Grip strength	1 2 3 4 5 6 7 8 9 10	Minutes
	Muscle temperature	0 1 2 3 4 5 6 7 8 9 10	Minutes
	Central temperature	0 1 2 3 4 5 6 7 8 9 10	Minutes

The rest, pre- and post-exercise periods were identical for each condition.

30/2

Period	Dependent Variable	Data	Independent Variable
Rest			
Pre-exercise			
Exercise	Grip strength	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30	Contractions
	Muscle temperature	0 5 10 15 20 25 30	Contractions
	Central temperature	0 5 10 15 20 25 30	Contractions
Post-exercise			

45/3

Period	Dependent Variable	Data	Independent Variable
Rest			
Pre-exercise			
Exercise	Grip strength	1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45	Contractions
	Muscle temperature	0 5 10 15 20 25 30 35 40 45	Contractions
	Central temperature	0 5 10 15 20 25 30 35 40 45	Contractions
Post-exercise			

60/4

Rest													
Pre-exercise													
Exercise	Grip strength		1	2	3	4	5	6	7	8	9	10	
			11	12	13	14	15	16	17	18	19	20	
			21	22	23	24	25	26	27	28	29	30	
			31	32	33	34	35	36	37	38	39	40	
			41	42	43	44	45	46	47	48	49	50	
			51	52	53	54	55	56	57	58	59	60	Contractions
	Muscle temperature	0	5	10	15	20	25	30	35	40	45	50	
		55	60										Contractions
	Central temperature	0	5	10	15	20	25	30	35	40	45	50	
		55	60										Contractions
Post-exercise													

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15/3

35.00 34.97 34.90 34.78 34.79 34.80 34.86 34.77 34.73 34.73 34.70
35.87 35.96 35.96 36.13 36.13 36.04 36.13 36.13 36.13 36.13 36.30
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34.70 34.69
36.30 36.38
55 55 55 54 53 5[illegible] 53 51 51 51
55 50 50 48 49
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53 52 56 54 55 55 54 54 54 55
33.84 34.02 33.98 34.09 34.08 34.21 34.24 34.37 34.35 34.42 34.44
36.47 36.55 36.64 36.64 36.81 36.81 36.81 36.81 36.81 36.89 36.98

30/4

35.64 35.61 35.56 35.47 35.48 35.49 35.48 35.40 35.31 35.30 35.25
36.04 36.04 36.04 36.13 36.13 36.04 36.13 36.13 36.13 36.13 36.30
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57 56 55 54 55 52 53 55 56 54
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35.07 35.07 35.15 35.05 35.15 35.25 35.18
36.47 36.47 36.47 36.47 36.47 36.47 36.47
57 60 61 61 58 60 57 61 62 62
34.78 34.83 34.97 34.96 35.02 35.05 35.19 35.25 35.29 35.34 35.38
36.47 36.64 36.64 36.64 36.64 36.64 36.72 36.72 36.81 36.89 36.89

45/2

35.11 35.02 34.85 34.85 34.77 34.77 34.77 34.77 34.68 34.60 34.51
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36.47 36.64 36.64 36.64 36.64 36.47 36.47 36.64 36.64 36.72
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34.68 34.77 34.77 34.94 35.02 35.19 35.19 35.36 35.45 35.45 35.45
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6C/1

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15/3

33.66 33.57 33.40 33.32 33.40 33.32 33.15 33.06 32.89 32.89 32.72
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32.38 32.38 32.72 32.72 32.98 32.98 33.06 33.15 33.32 33.40 33.40
37.40 37.40 37.40 37.32 37.40 37.40 37.40 37.40 37.40 37.49 37.49

45/4

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37.74 37.74 37.83 37.74 37.66 37.66 37.57 37.57 37.49 37.49 37.49

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33.40 33.40 33.23 33.23 33.06 33.06 32.89 32.81 32.72 32.64 32.55
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15/4

32.98 32.95 32.89 32.85 32.70 32.71 32.68 32.67 32.63 32.63 32.85
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33.26 33.36 33.33 33.43 33.59 33.72 33.67 33.80 33.86 34.02 34.03
37.15 37.15 37.15 37.15 36.98 36.98 37.06 37.06 36.98 36.98 37.06

30/3

33.40	33.40	33.23	33.23	33.23	33.23	33.15	33.23	33.23	33.23	33.23
36.72	36.72	36.72	36.72	36.81	36.81	36.81	36.81	36.81	36.89	36.81
48	54									
33.23	33.23									
36.81	36.81									
	52	49	51	49	51	50	48	46	48	47
	45	46	43	43	46	44	40	41	41	39
	38	38	36	36	35	39	36	39	36	34
33.15	33.06	33.06	33.06	33.40	33.49	33.49				
36.81	36.81	36.81	36.81	36.81	36.81	36.81				
	45	49	50	50	51	49	47	48	45	45
33.49	33.49	33.66	33.66	34.08	34.08	34.17	34.17	34.34	34.34	34.60
36.81	36.89	36.89	36.89	36.89	36.81	36.81	37.06	37.06	37.06	37.06

45/2

34.68	34.68	34.51	34.43	34.43	34.43	34.34	34.34	34.08	34.17	34.08
37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15
53	57									
34.08	34.08									
37.15	37.23									
	57	53	54	52	50	50	49	48	48	47
	46	47	47	46	43	41	41	39	38	39
	40	40	38	39	39	41	41	40	40	41
	40	41	40	41	41	41	38	38	38	38
	38	39	41	38	38					
34.08	34.08	34.08	34.08	34.43	34.43	34.51	34.60	34.68	34.77	
37.32	37.15	37.15	37.23	37.23	37.32	37.32	37.40	37.40	37.40	
	51	51	48	50	50	52	52	48	45	46
34.77	34.94	35.11	35.28	35.36	35.45	35.45	35.53	35.53	35.62	35.62
37.40	37.40	37.49	37.49	37.49	37.49	37.49	37.49	37.49	37.49	37.49

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33.40	33.40	33.40	33.40	33.23	33.23	33.15	33.15	33. .6	33.06	33.23
36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.98	36.98
47	53									
33.23	33.23									
36.98	36.89									
	52	51	51	50	49	49	48	48	49	48
	50	50	49	48	50	49	47	45	48	47
	45	45	44	45	45	44	42	45	43	43
	45	44	45	43	43	44	45	44	43	42
	43	43	43	41	43	41	41	40	40	39
	38	40	40	38	41	38	41	40	42	40
33.06	33.06	33.23	33.23	33.40	33.40	33.40	33.40	33.74	33.83	34.08
34.34	34.68									
36.89	36.98	37.06	37.06	37.06	37.06	37.06	36.98	36.98	37.06	37.06
37.15	37.15									
	50	51	53	54	54	52	49	49	49	52
34.68	34.68	34.77	34.77	35.02	35.11	35.11	35.19	35.28	35.36	35.36
37.15	37.06	37.06	37.15	37.15	37.15	37.15	37.23	37.23	37.23	37.23

15/3

34.08 34.08 34.08 34.08 34.08 34.08 34.08 34.08 34.43 34.43 34.25
36.13 36.13 36.13 36.21 36.30 36.30 36.38 36.38 36.47 36.47 36.47
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      59 50 51 48 50 45 47 44 45 45
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30/1

36.47 36.47 36.47 36.47 36.21 36.21 36.30 36.21 36.13 36.13 35.79
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      51 46 47 44 40 42 36 36 40 42
      42 45 43 45 43 44 43 40 42 43
      42 41 43 43 40 40 39 38 42 39
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      51 48 50 46 44 47 49 48 46 50
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37.40 37.32 37.40 37.40 37.49 37.40 37.40 37.40 37.49 37.40 37.40

45/4

34.94 34.94 34.77 34.77 34.68 34.68 34.60 34.51 34.34 34.34 34.43
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37.06 37.15
      48 55 54 51 50 49 49 48 46 48
      47 44 46 48 46 45 43 41 41 44
      44 43 43 44 43 44 42 44 44 42
      42 43 38 42 39 37 39 41 41 40
      37 40 37 37 34
34.43 34.34 34.43 34.43 34.68 34.68 34.77 34.77 34.85 35.02
37.15 37.06 37.15 37.15 37.15 37.15 37.15 37.15 37.15 37.15
      42 51 54 54 52 52 51 55 53 51
35.02 35.19 35.28 35.45 35.45 35.45 35.45 35.79 35.79 35.79 35.79
37.15 37.23 37.40 37.40 37.32 37.40 37.40 37.40 37.40 37.40 37.49

60/2

35.11 35.11 34.85 34.94 35.11 35.11 35.28 35.19 35.36 35.36 35.11
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35.53 35.70 35.79 35.79 35.87 36.04 36.04 36.04 36.13 36.13 36.13
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15/2

34.72 34.72 34.81 34.81 34.72 34.72 34.89 34.89 34.89 34.89 34.89
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34.98 35.15 35.15 35.23 35.23 35.23 35.23 35.32 35.32 35.57 35.57
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30/4

35.19 35.19 35.11 35.11 35.28 35.28 35.36 35.36 35.36 35.36 35.36
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46 43 40 42 40 39 43 40 41 39
40 44 42 41 41 42 41 40 42 44
35.45 35.45 35.53 35.53 35.79 35.79 36.04
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36.98 37.06 36.98 36.81 36.81 36.89 36.89 36.98 36.98 36.89 36.89

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34.72	34.72	34.72	34.72	34.72	34.72	34.72	34.81	34.98	35.06	34.98
36.13	36.13	36.13	36.30	36.30	36.21	36.21	36.38	36.38	36.30	36.38
57	57									
34.98	34.98									
36.38	36.47									
	54	55	55	54	53	48	46	49	48	43
	42	46	47	43	40	41	40	40	40	42
	42	42	42	44	45	43	43	45	46	45
	46	45	47	44	44	40	41	42	47	45
	43	44	42	44	45					
34.98	34.98	34.89	34.89	34.89	34.89	35.06	35.06	35.15	35.15	
36.47	36.47	36.47	36.47	36.47	36.47	36.47	36.47	36.47	36.47	
	50	49	54	54	55	60	54	57	52	54
35.15	35.23	35.32	35.40	35.40	35.40	35.40	35.40	35.40	35.57	35.57
36.47	36.47	36.64	36.64	36.64	36.64	36.72	36.64	36.64	36.64	36.64

60/3

34.25	34.25	34.17	34.17	34.17	34.08	34.17	34.34	34.43	34.51	34.60
35.19	35.36	35.36	35.62	35.62	35.79	35.79	35.79	35.87	35.79	35.87
51	58									
34.60	34.43									
35.87	35.96									
	58	54	58	54	51	49	50	50	50	50
	48	46	42	45	47	44	41	43	43	45
	45	44	43	45	43	40	41	41	41	42
	40	46	42	38	44	41	44	43	40	45
	41	42	40	38	37	34	40	37	37	37
	42	38	40	39	40	38	40	43	41	39
34.43	34.43	34.60	34.77	34.94	35.02	35.28	35.45	35.70	35.79	36.13
36.13	36.21									
36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.13
36.13	36.13									
	55	52	53	54	55	57	55	54	51	56
36.21	36.21	36.47	36.47	36.47	36.64	36.64	36.64	36.64	36.64	36.64
36.13	36.13	36.30	36.30	36.30	36.38	36.38	36.38	36.47	36.47	36.47

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15/3

34.60	34.51	34.34	34.25	34.08	34.08	34.08	34.00	33.91	33.83	33.74
35.36	35.45	35.45	35.53	35.53	35.70	35.70	35.79	35.79	35.87	35.87
38	37									
33.74	33.74									
35.87	36.04									
	36	40	38	42	41	37	39	38	38	40
	39	35	38	38	36					
33.66	33.66	33.74	33.74							
36.13	36.13	36.13	36.13							
	45	49	47	47	48	47	48	50	47	49
33.74	34.08	34.08	34.34	34.34	34.43	34.43	34.60	34.60	34.60	34.68
36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.13	36.30	36.30	36.38

30/4

33.91 33.91 33.66 33.66 33.49 33.40 33.23 33.23 33.06 33.06 32.89
34.51 34.60 34.68 34.77 34.77 35.02 35.02 35.11 35.11 35.19 35.28
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47 47 46 46 45 41 43 41 40 40
42 41 41 39 39 34 41 41 39 38
39 37 39 38 39 39 35 36 35 39
32.81 32.89 32.98 32.98 33.23 33.23 33.40
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45 47 49 48 49 48 48 49 48 50
33.40 33.74 34.17 34.17 34.43 34.43 34.51 34.51 34.68 34.68 34.68
35.62 35.79 35.79 35.79 35.79 35.79 35.87 36.04 36.04 36.04 36.04

45/1

35.28 35.28 35.11 35.02 35.11 35.02 34.85 34.77 34.77 34.68 34.51
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38 37 37 36 37 34 36 35 37 40
38 35 36 39 38 37 35 36 38 35
33 37 34 35 35 35 35 35 35 35
36 35 34 36 35
34.17 34.17 34.25 34.25 34.08 34.17 34.43 34.43 34.60 34.60
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40 43 45 43 46 43 40 40 44 41
34.60 35.11 35.11 35.45 35.45 35.45 35.45 35.70 35.70 35.62 35.70
36.64 36.64 36.64 36.64 36.64 36.64 36.72 36.72 36.64 36.64 36.72

60/2

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35.19 35.28 35.28 35.36 35.36 35.45 35.53 35.70 35.70 35.79 35.79
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38 36 36 33 35 34 37 37 38 38
36 37 38 37 36 37 35 34 35 33
35 33 38 39 37 40 36 38 34 33
34 36 36 36 35 37 36 35 36 35
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34.94 35.11
35.79 35.96 35.96 35.87 35.96 36.04 36.04 36.04 36.04 36.13 36.13
36.13 36.13
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35.11 35.45 35.70 35.70 35.70 35.70 35.79 35.79 35.79 35.79 35.79
36.13 36.13 36.13 36.13 36.13 36.13 36.13 36.13 36.13 36.13 36.13

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36.81 36.81 36.81 36.89 36.89 37.06 37.06 37.15 37.15 37.15 37.15
47    48
32.72 32.72
37.15 37.15
      48    47    46    45    46    45    44    43    43    45
      45    47    47    45    44
32.64 32.64 32.72 32.72
37.15 37.40 37.40 37.49
      49    51    52    51    52    54    53    52    51    48
32.72 32.98 33.06 33.40 33.40 33.74 33.74 33.83 33.91 34.08 34.08
37.49 37.49 37.49 37.49 37.40 37.40 37.49 37.49 37.49 37.49 37.49
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30/2

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52    49
33.06 33.06
36.98 36.98
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      43    43    45    43    43    43    40    41    41    42
      44    42    43    42    42    39    42    40    42    42
33.06 33.06 33.06 33.06 33.06 33.15 33.40
36.98 36.98 36.98 37.15 37.15 36.98 36.98
      45    44    45    45    47    46    46    45    47    47
33.40 33.40 33.74 33.83 34.08 34.08 34.43 34.43 34.51 34.68 34.85
36.98 37.15 37.15 37.06 37.06 37.15 37.15 37.15 37.15 37.15 37.15
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45/3

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49    50
33.49 33.49
36.64 36.72
      48    50    50    50    49    51    49    50    50    49
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      46    44    45    45    42    44    45    46    46    47
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33.66 33.66 33.57 33.57 33.66 33.74 33.83 33.83 34.08 34.08
36.81 36.81 36.81 36.81 36.81 36.81 36.81 36.81 36.81 36.98
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34.08 34.43 34.60 34.77 34.94 35.02 35.02 35.11 35.11 35.11 35.11
36.98 36.98 37.06 37.06 36.98 36.98 36.98 36.98 37.15 37.15 37.15
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33.74 33.74 33.74 33.74 33.74 33.74 33.74 33.74 33.66 33.66 33.40
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45/4

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60/3

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15/4

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34.00 34.25 34.34 34.43 34.51 34.77 34.77 34.85 34.85 34.94 34.94
37.15 37.15 37.23 37.23 37.40 37.40 37.49 37.49 37.49 37.49 37.49

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33.76	33.90	34.11	34.10	34.19	34.21	34.11	34.12	34.11	34.10	34.05
37.23	37.23	37.23	37.23	37.23	37.32	37.32	37.32	37.32	37.32	37.32
51	52									
34.05	34.14									
37.32	37.32									
	52	53	52	49	48	47	46	45	48	47
	44	43	42	45	44	45	44	45	45	44
	44	41	45	45	47	46	44	45	45	45
34.21	34.22	34.38	34.37	34.64	34.65	35.00				
37.32	37.32	37.40	37.40	37.40	37.40	37.40				
	48	49	49	49	50	49	48	47	48	46
35.20	35.25	35.30	35.30	35.44	35.39	35.52	35.50	35.55	35.60	35.63
37.40	37.40	37.40	37.49	37.49	37.49	37.49	37.49	37.49	37.49	37.49

45/2

33.83	33.98	34.20	34.19	34.30	34.31	34.23	34.23	34.24	34.26	34.15
36.81	36.81	36.81	36.89	36.98	37.06	37.15	37.15	37.15	37.23	37.23
52	54									
34.15	34.25									
37.23	37.32									
	53	51	51	49	49	47	50	49	48	50
	47	48	47	47	47	44	44	48	44	45
	45	43	45	45	44	41	39	42	44	41
	43	41	42	43	43	41	42	42	45	45
	44	45	44	43	45					
34.36	34.35	34.47	34.46	34.68	34.67	34.95	35.06	35.32	35.56	
37.32	37.23	37.32	37.32	37.32	37.32	37.32	37.40	37.40	37.40	
	44	49	49	51	48	50	49	51	51	46
35.41	35.67	35.57	35.72	35.81	35.82	35.86	35.94	35.91	35.96	35.98
37.40	37.40	37.40	37.40	37.40	37.49	37.49	37.49	37.49	37.49	37.57

60/3

33.57	33.74	34.00	34.00	34.08	34.08	34.00	34.00	34.00	34.00	33.91
35.79	35.96	36.04	36.13	36.13	36.38	36.38	36.38	36.47	36.64	36.64
45	51									
33.91	34.00									
36.64	36.72									
	52	52	50	51	49	48	47	44	45	43
	42	45	43	44	44	44	43	42	40	42
	42	40	41	42	40	40	41	42	43	42
	38	41	37	38	38	44	41	41	40	39
	39	37	39	37	38	37	38	38	34	41
	39	39	40	37	36	38	36	37	40	38
34.08	34.08	34.25	34.25	34.43	34.43	34.77	34.85	35.19	35.45	35.53
35.62	35.70									
36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.98	36.98
36.98	36.98									
	41	43	44	42	45	46	44	44	45	45
35.70	35.79	35.79	35.79	35.96	35.96	36.04	36.04	36.04	36.04	36.04
36.98	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.32	37.32

15/1

33.57	33.66	33.66	33.57	33.57	33.66	33.66	33.74	33.74	33.74	33.74
35.79	35.79	35.96	35.96	36.04	36.13	36.13	36.13	36.30	36.38	36.47
56	55									
33.74	33.74									
36.47	36.47									
	54	53	53	51	51	51	51	49	50	51
	49	49	49	48	50					
33.74	33.57	33.57	33.66							
36.64	36.64	36.55	36.55							
	51	52	53	56	56	57	56	55	57	57
33.66	33.74	33.74	33.74	34.00	34.00	34.00	34.00	34.08	34.08	34.08
36.55	36.55	36.55	36.64	36.64	36.81	36.81	36.72	36.72	36.72	36.72

30/2

34.77	34.77	34.77	34.77	34.94	34.94	34.77	34.77	34.94	34.77	34.77
36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.89	36.89	36.89	36.89
53	54									
34.77	34.77									
36.89	36.89									
	53	55	54	54	53	51	53	53	53	53
	51	50	50	49	50	50	49	49	51	48
	52	48	49	50	48	49	50	49	49	48
34.77	34.77	34.77	34.77	34.77	34.77	34.77				
36.89	36.81	36.81	36.81	36.81	36.81	36.81				
	54	55	55	55	55	55	55	55	56	55
34.77	34.77	35.02	35.11	35.11	35.11	35.36	35.36	35.45	35.45	35.45
36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81	36.81

45/4

34.77	34.77	34.68	34.68	34.77	34.77	34.68	34.68	34.51	34.51	34.43
37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.23	37.23	37.15	37.15
55	58									
34.43	34.43									
37.15	37.23									
	59	58	59	58	58	56	57	58	56	57
	55	55	54	56	55	54	54	54	52	53
	52	53	54	53	53	52	52	52	54	52
	51	51	51	51	52	51	52	49	49	51
	51	50	49	50	47					
34.43	34.43	34.43	34.43	34.34	34.34	34.34	34.43	34.51	34.51	
37.23	37.15	37.15	37.15	37.15	37.15	37.15	37.32	37.32	37.15	
	54	57	59	59	60	60	60	60	60	60
34.51	34.94	34.94	35.11	35.36	35.62	35.62	35.79	35.79	35.96	35.96
37.15	37.23	37.23	37.32	37.32	37.32	37.49	37.49	37.40	37.40	37.40

60/3

35.36 35.36 35.28 35.28 35.19 35.19 35.19 35.19 35.19 35.19 35.11
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55 57
35.11 35.11
36.98 36.98
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36.98 36.98
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35.11 35.28 35.45 35.53 35.79 35.96 35.96 36.04 36.13 36.13 36.13
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11

15/3

33.74 33.74 33.49 33.49 33.49 33.40 33.40 33.32 33.06 33.06 32.98
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32.98 32.98
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37.40 37.32 37.32 37.32 37.32 37.32 37.32 37.23 37.23 37.32 37.32

30/4

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36.64 36.64 36.64 36.98 36.98 37.15 37.15 37.15 37.32 37.49 37.49
47 43
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37.49 37.49
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37.49 37.40 37.49 37.49 37.49 37.57 37.57 37.57 37.57 37.49 37.49

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33.40	33.40	33.40	33.40	33.32	33.32	33.23	33.23	33.06	33.23	33.23
37.15	37.15	37.15	37.15	37.23	37.32	37.32	37.32	37.32	37.40	37.40
48	50									
33.23	33.23									
37.40	37.49									
	47	49	45	45	43	44	47	43	42	46
	43	45	44	42	43	44	47	45	45	42
	45	45	42	43	42	40	39	42	43	41
	40	40	42	42	42	41	41	40	42	40
	43	40	42	41	42					
33.23	33.15	33.06	33.06	33.40	33.40	33.49	33.49	33.66	33.83	
37.49	37.66	37.66	37.49	37.49	37.66	37.66	37.49	37.49	37.49	
	47	46	46	45	45	48	50	48	47	47
33.83	34.25	34.34	34.60	34.60	34.68	34.77	34.77	34.77	34.94	34.94
37.49	37.49	37.49	37.49	37.57	37.66	37.66	37.66	37.74	37.74	37.66

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34.68	34.68	34.68	34.68	34.60	34.60	34.34	34.25	34.17	34.17	34.00
36.47	36.47	36.47	36.64	36.64	36.72	36.72	36.81	36.81	37.06	37.06
51	50									
34.00	34.00									
37.06	37.15									
	46	48	45	50	48	49	49	48	48	49
	47	48	48	48	46	48	48	49	45	46
	45	45	44	46	43	44	41	40	42	40
	43	44	44	43	45	43	44	40	42	41
	41	42	42	42	42	44	43	42	38	40
	38	40	38	38	39	40	38	38	40	35
34.00	33.91	34.00	34.00	34.08	34.08	34.43	34.43	34.68	34.68	34.77
34.94	35.19									
37.15	36.98	37.06	37.15	37.15	37.23	37.15	37.32	37.32	37.32	37.32
37.32	37.32									
	49	53	50	51	50	48	48	46	45	44
35.19	35.36	35.45	35.45	35.62	35.62	35.79	35.79	35.79	35.79	35.70
37.32	37.49	37.49	37.49	37.49	37.49	37.49	37.49	37.49	37.57	37.57

12

15/1

33.74	33.74	33.57	33.57	33.40	33.40	33.32	33.32	33.40	33.32	33.32
36.64	36.64	36.64	36.72	36.81	36.89	36.98	36.98	37.06	37.15	37.15
46	47									
33.32	33.32									
37.15	37.15									
	48	48	47	46	46	45	46	44	44	45
	43	44	44	43	44					
33.32	33.32	33.49	33.57							
37.15	37.15	37.15	37.15							
	47	51	50	50	49	50	51	50	50	52
33.57	34.00	34.00	34.00	34.00	33.91	33.91	33.91	33.91	34.00	34.00
37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15	37.15

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45/3

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60/4

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