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Effect of muscle mass and intensity of isometric contraction on heart rate

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Gálvez, José M., Juan P. Alonso, Luis A. Sangrador, and Gonzalo Navarro. Effect of muscle mass and intensity of isometric contraction on heart rate. *J. Appl. Physiol.* 88: 487–492, 2000.—The purpose of this study was to determine the effect of muscle mass and the level of force on the contraction-induced rise in heart rate. We conducted an experimental study in a sample of 28 healthy men between 20 and 30 yr of age (power: 95%, α: 5%). Smokers, obese subjects, and those who performed regular physical activity over a certain amount of energetic expenditure were excluded from the study. The participants exerted two types of isometric contractions: handgrip and turning a 40-cm-diameter wheel. Both were sustained to exhaustion at 20 and 50% of maximal force. Twenty-five subjects finished the experiment. Heart rate increased a mean of 15.1 beats/min [95% confidence interval (CI): 5.5–24.6] from 20 to 50% handgrip contractions, and 20.7 beats/min (95% CI: 11.9–29.5) from 20 to 50% wheel-turn contractions. Heart rate also increased a mean of 13.3 beats/min (95% CI: 10.4–16.1) from handgrip to wheel-turn contractions at 20% maximal force, and 18.9 beats/min (95% CI: 9.8–28.0) from handgrip to wheel-turn contractions at 50% maximal force. We conclude that the magnitude of the heart rate increase during isometric exercise is related to the intensity of the contraction and the mass of the contracted muscle.

skeletal muscle; exercise; maximal force; muscle endurance

IT IS WELL DOCUMENTED that isometric contraction causes a rise in heart rate (4–6, 30). However, the effect of contraction intensity and size of muscle mass involved is not clear. Various investigators have suggested that the rise in heart rate is contraction-intensity dependent (11, 23–26). Others have reported no relationship between the rise in heart rate and the level of force (5). The effect of the amount of active muscle mass on the rise in heart rate is not clear as well. In cats, Iwamoto and Botterman (9) found an increase in heart rate with more muscle mass involved, but this was not supported by Matsukawa et al. (13). In studies carried out in humans, some support an influence of muscle mass on heart rate responses (12, 16, 21, 27), whereas others do not (15, 31).

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Given the controversy about the effect of muscle mass and intensity of contraction on the increase in heart rate, we have conducted an experimental study with two objectives. First, we wanted to determine whether isometric contraction of one muscle group, sustained to exhaustion, increases heart rate more noticeably when the percentage of maximal force is greater. And second, we wanted to determine whether the rise in heart rate is influenced by muscle mass contracted.

METHODS

Study design. We used an experimental design similar in concept to a crossover clinical trial. The same subjects made different isometric contractions with a resting period between them, to recover muscle resistance. We measured the effect on heart rate by using a double-blind procedure: neither the participants nor the investigators knew its variations. Each participant performed two types of isometric contractions: dominant handgrip and turning a wheel with both hands to the dominant side. Each contraction was sustained at 20 and 50% of maximal force, giving four trials for each subject: handgrip at 20% of maximal force, handgrip at 50%, wheel turn at 20%, and wheel turn at 50%. The purpose of this study was to investigate the influence of the size of the active muscle mass and contraction intensity on the induced rise in heart rate.

Although we were interested in continuous heart rate variation in relation to continuous variation of muscle contraction intensity and size, we elected to take measurements at intermediate points for convenience. In the case of intensity of isometric contraction, as maximal force is approached, sustaining the contraction adequately is more difficult. We selected, then, 50% of maximal force as the highest measurable point. The lowest point was selected at 20% of maximal force, because it has been described that isometric contractions at 15% of maximal force sustained for 2 min do not increase heart rate (17).

Each participant performed the four trials in random order, to reduce the effect on measured heart rate. After each trial subjects rested quietly in the supine position for 20 min, to recover muscle endurance (29). Before performing the next trial, each subject waited for 1 min to stabilize heart rate, and both heart rate and blood pressure were tested to confirm that they were at basal levels.

Subjects. We considered healthy men between 20 and 30 yr of age, with systolic and diastolic blood pressure at rest under 140/90 mmHg, as the reference population. The study was performed only in men because muscle resistance has been found to be different as a function of gender (18). The largest increases in heart rate during isometric exercise are seen in subjects between 20 and 30 yr of age (19). A number of independent factors were taken into account in the selection of participants and performance of trials. The time to reach exhaustion is influenced by muscle temperature. Because of this, room temperature was maintained between 18 and 23°C, and all the subjects had their upper body exposed during the trials. Subcutaneous fat, because of its isolating properties, increases muscle temperature and diminishes muscle resistance (20). Individuals with a body mass index >27 were excluded for this reason (7). Subjects were asked to refrain from coffee, tea, and alcohol in the 12 h previous to the test. At least 90 min elapsed between the last meal and the beginning of the trials. We used the Stanford Physical Activity Assessment Questionnaire (22) to exclude individuals who participated regularly in vigorous leisure time activities requiring an estimated 6 metabolic equivalents (6 × resting caloric expenditure) or above, because physical fitness influences the cardiovascular response to exercise (28). The study population was formed by those individuals who accomplished the above criteria and agreed to participate, giving written informed consent. The study was approved by the Ethical Committee for Clinical Trials of the Hospital Clínico Universitario Lozano Blesa (Teaching Hospital), Zaragoza, Spain.

The sample size was estimated to detect differences in heart rate for the interventions planned, on the basis of published data. To detect a difference of at least 10 beats/min between interventions, with a power of 95%, a confidence level of 95%, and an expected follow-up loss of 10%, sample size was estimated to be 30 participants. Sample size was elected in a conservative way: variability figures entered were larger than those found in the literature, and power was kept high. Participants received a monetary reward for their participation.

Experimental measurements. To measure muscle force we used a Lido Work Set dynamometer (Loredan Biomedical, Davis, CA), and telemetric control of heart rate was done with a Polar Sport Tester 4000 (Polar Electro OY, Kempele, Finland). All trials were done in the seated position for all participants, because muscle force depends on position (14).

For handgrip contractions the elbow was maintained at 90° and the forearm at the neutral prono-supination angle. The width of the handle was 50% of the distance between wrist fold and the end of the middle finger (3). Height was regulated so that the shoulder was in neutral position. For wheel-turn contractions, arm, elbow, and forearm position were the same as before. The wheel grip was done with both hands placed on the horizontal diameter. The subjects tried to turn the wheel to the dominant side, but, because the wheel did not turn the muscles did not shorten, and the contraction was isometric.

Before the actual trials began, to measure the maximal force, each subject made three handgrip and three wheel-turn contractions in random order, leaving 3 min to rest between them (29). Forces were accepted as maximal when the coefficient of variation between them was <10% (8), with maximal force taken to be the greatest measurement in each set of three. Then, each subject was instructed on how to maintain 20 and 50% of maximal force contractions, using visual biofeedback with the aid of a video-display terminal. Respiration was monitored to detect inadvertent performance of a Valsalva maneuver or prolonged exhalation. After determining maximal force, each subject rested in the supine position for 20 min.

The trials were performed to exhaustion, defined as a fall in the intensity of the force of at least 10% during 2 s, even though the subjects were verbally encouraged to continue the exercise. When the effort is maintained to exhaustion, the metabolic state of the muscles is the same at the end of the trials for all the subjects (25). The contractions in this study were continued to the same end point for all the subjects and for both groups of muscles. When the contractions are exerted for a finite period, the end point is not the same for all the muscles because the time it takes a particular group of muscles to fatigue is different. Also, with the contractions sustained to exhaustion, it is possible to evaluate the effect of intensity and duration of the contraction on the development of muscle fatigue.

Data analysis. The effect measurement used was heart rate, monitored automatically to avoid observation biases. Mean maximum heart rates were computed for resting periods and the four trials performed. Differences in means with associated confidence intervals were computed for paired samples. Differences between heart rates in the resting periods were assessed by repeated-measurements ANOVA. A multiple linear regression analysis model was used to assess the effect on maximum heart rate of the following two variables: change in percentage of maximum force (dichotomous variable, from 20 to 50%) and change in muscle mass involved (dichotomous variable, from handgrip to wheel turn). We adjusted for the following continuous variables: basal heart rate, contraction duration (19), and contraction intensity (10).

RESULTS

Maximum heart rate increased with both the intensity of isometric contraction and the amount of muscle mass involved, in the conditions and for the subjects studied. The maximum heart rate occurred at or very near the end of the trial in all subjects.

Of the 30 initial subjects, 28 performed the trials. The remaining two did not fulfill all requirements. Results are based on data from 25 participants. Three subjects were rejected for analysis: one with blood pressure outside the range, and the other two with heart rate changes and contraction durations, respectively, much greater than those in the rest of the participants. The main features of the participants are presented in Table 1. Maximum torque had a mean value of 5,421 ± 1,009 N·cm for handgrip (mean coefficient of variation 4.8%) and 123.3 ± 27.3 N·m for wheel turn (mean coefficient of variation 4.2%). All participants had age and blood pressure within the defined range. Body mass index was within normal limits, except for one individual with a body mass index of 27.8 who was included. During the instruction period only one participant surpassed the limit for the established coefficient of variation (11.5%), but we decided to include him in the analysis. All the variables had a normal distribution, except age and heart rate in wheel turn to 50% of maximal force. All variables were

Table 1. *Age, height, weight, basal heart rate, and blood pressure of the participants*

Parameter		Minimum	Maximum
Age, yr	24.1 ± 3.48	20	30
Height, cm	178.8 ± 5.17	168	189
Weight, kg	74.2 ± 8.83	56	90
Basal heart rate, beats/min	69.9 ± 12.75	54	101
Systolic blood pressure, mmHg	113.8 ± 10.44	90	130
Diastolic blood pressure, mmHg	72.4 ± 8.31	55	90

Values are means ± SD.

considered to have a normal distribution for the analysis.

Mean basal and maximum heart rates and mean duration for each trial are shown in Table 2. The relationship between maximum heart rate and isometric contraction can be seen in Fig. 1. Basal heart rate is the mean of basal heart rate of all the trials, because repeated-measures analysis of variance showed that all basal heart rates could be considered equal ($P = 0.351$). Therefore, we determined that the four trials were made in the same basal condition. The other values in the figure are maximum heart rates measured in the trials (Table 2). Comparison of the mean maximum heart rates among the four trials, together with 95% confidence intervals, is shown in Table 3.

Multiple linear regression analysis of the relationship between maximum heart rate and percentage of maximum force, type of contraction, basal heart rate, and duration and force of the contraction is shown in Table 4. Maximum heart rate increased a mean of 30.1 beats/min from 20 to 50% contractions (95% confidence interval 18.7–41.5), and a mean of 20.7 beats/min from handgrip to wheel-turn contractions (95% confidence interval 13.0–28.4). Both basal heart rate and contraction duration had a significant effect on maximum heart rate. Force exerted in contractions, calculated (in N) from the torque had no linear relationship with maximum heart rate. The model is statistically significant ($P < 0.0001$) and explains more than one-third of the linear relationship of the independent variables to maximum heart rate (adjusted $r^2 = 0.36$). The assumptions of linear regression were fulfilled: residual analysis showed a normal distribution.

DISCUSSION

Our results showed an increase in maximum heart rate produced by isometric contraction, when both the percentage of maximal force was increased and the muscle mass involved was greater. Experimental conditions, double-blind measurement, and adjustment for possible confounding variables such as basal heart rate and contraction duration make us more confident than in previous studies, on the basis of descriptive analysis of small samples.

Our study, however, may have some limitations. First, it was difficult to assess the level of physical activity of the participants. We used the Stanford Physical Activity Questionnaire (22), which is not validated for the Spanish language and culture. In this questionnaire subjects are asked, "For at least the last three months, which of the following activities have you performed regularly?" and then are handed a card listing some leisure-time activities. If the activity performed is not in the list, or there are several activities performed but at a level of exercise below those established, the subject can be misclassified. We have not found an objective method to know whether participants sustained isometric contractions to exhaustion. We assumed they did, because they were all volunteers and the level of collaboration was good, with a coefficient of variation below certain limits. We have found no linear relationship between the intensity of the isometric contraction and maximum heart rate reached, but the force measured by the dynamometer is not the real force produced by the muscles; real force generated by muscle contraction produces joint movement through a complex lever system dependent on the orientation of tendons and distance from insertion to joint axis. We know of no method of exactly assessing the actual force produced by the muscles from the torque measured

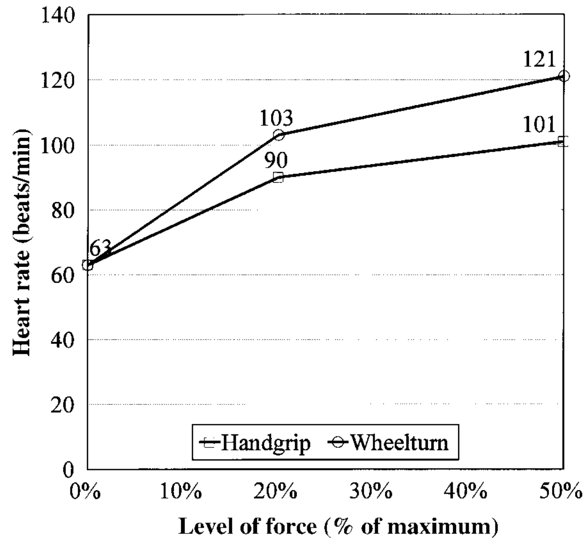

Fig. 1. Relationship between maximum heart rate and isometric contraction for handgrip and wheel-turn trials at 20 and 50% of maximal contraction.

Table 2. *Trial results*

	Basal Heart Rate, beats/min	Maximum Heart Rate, beats/min	Duration, s
Handgrip			
20%	64.5 ± 10.46	89.8 ± 16.1	224.5 ± 100.86
50%	62.6 ± 9	100.8 ± 15.4	53.4 ± 26.12
Wheel turn			
20%	62.8 ± 10.18	102.8 ± 16.16	164.9 ± 71.91
50%	63.4 ± 11.26	121.0 ± 30.33	35.0 ± 16.74

Values are means ± SD. Percentage denotes %maximal force of contraction.

Table 3. *Differences in mean heart rates between the trials*

	Difference in Mean Heart Rate, beats/min	95% Confidence Interval
Rest to 20% handgrip	25.3	19.1–31.5
Rest to 50% handgrip	38.2	32.3–44.1
Rest to 20% wheel turn	40.0	32.9–47.1
Rest to 50% wheel turn	57.2	45.2–69.3
20% Handgrip to 50% handgrip	15.1	5.5–24.6
20% Wheel turn to 50% wheel turn	20.7	11.9–29.5
20% Handgrip to 20% wheel turn	13.3	10.4–16.1
50% Handgrip to 50% wheel turn	18.9	9.8–28

Table 4. *Multiple regression analysis: independent variables related to maximum heart rate, with their slope, 95% confidence interval, significance, and correlation value*

	Slope, beats/min	95% Confidence Interval	*P* Value	*r* Value
Percentage of maximum force*	30.1	18.7–41.5	<0.0001	0.32
Muscle mass†	20.7	13.0–28.4	<0.0001	0.36
Basal heart rate	0.6	0.2–0.9	<0.01	0.26
Duration	0.1	0–0.2	<0.001	0.12
Constant	29.1	2.3–55.7	0.03	
Force			0.83	0.33

*Change from 20 to 50%. †Change from handgrip to wheel turn.

with the dynamometer during the handgrip and wheel-turn activites. Moreover, we think that the increment in heart rate depends on the percentage of maximum force of the contraction, rather than on the absolute value of the contraction force (11). The participants' age, gender, level of physical activity, and so on were not representative of the general population. This helped to enhance the internal validity, but we do not know whether these results can be generalized to other populations. Last of all, we measured two intermediate points of muscle force and two muscle groups. To know more about the continuous variation of heart rate in relation to isometric contraction, other muscles and other percentages of maximum force must be studied. The relationship as suggested by our results is not linear, although the analysis has helped to find the effect of both muscle mass and force on heart rate.

Two mechanisms could be responsible for the role that muscle mass and degree of tension play in the reflex increase in heart rate, the central command, and the exercise pressor reflex. The central command theory involves activation of higher brain centers on the volition and initiation of muscular contraction. Presumably, signals are irradiated to the cardiovascular control centers in the brain stem, and this information contributes to the cardiovascular changes. It is reasonable to expect that the greater the number of motor units that need to be activated to accomplish a particular contraction, the greater the integration of such a signal by central controlling neurons, the greater will be the central command input to the brain stem cardiovascular centers, and, therefore, the greater the cardiovascular response during isometric exercise.

The exercise pressor reflex theory suggests that there is a reflex stimulus originating in nerve endings in the contracting muscle, activated either by chemical substances presumably released during the contraction or by physical deformation. Thus during sustained isometric contractions the greater the number of motor units activated, the greater the activation of afferent nerve fibers. This suggests that the increase in heart rate is related to the muscle mass and the percentage of maximal force developed.

Previous studies show different results about the relationship between the rise in heart rate and the level of force or the amount of muscle mass involved in an isometric contraction. Studies conducted in animals showed evidence both in favor of and against this relationship, but they may not be directly applicable to humans (9, 13, 15).

Among the studies conducted in humans there is experimental work supporting our study. Scherrer et al. (23), in a study conducted in eight men and five women, found a relationship between the rise in heart rate and the level of force exerted in an isometric handgrip contraction. Seals (25) conducted an experimental study in a sample of 12 subjects of both genders who exerted isometric handgrip contractions sustained to exhaustion. He concluded that the rise in heart rate is contraction-intensity dependent. Seals et al. (27) in a study carried out in 12 men between 20 and 30 yr of age found an increase in heart rate with more muscle mass involved. The duration of the contraction was always 3 min.

We have observed discrepancies between our data and previously reported human studies. Gaffney et al. (5) studied four healthy men aged 20–24 yr and found that heart rate rose during static quadriceps contractions, but 25 and 50% maximal voluntary contractions sustained to exhaustion produced similar maximal values. There may be some explanations for the discrepancies between the above-presented data and our study: Gaffney et al. used knee extension as a model for static exercise, whereas the participants in our study performed handgrip and wheel-turn contractions; and the other study did not monitor respiration to detect inadvertent performance of a Valsalva maneuver or prolonged exhalation.

McCloskey and Streatfeild (15) investigated the reflex contributions to the cardiovascular drives during isometric contractions of muscle groups of different masses in animals and in humans. It is known that there are both central and reflex stimuli to the cardiovascular system in exercise, but this study examines only the muscular reflex stimuli. In the animal experiments isometric contractions were induced by spinal ventral root stimulation, as this allows the reflex part of the cardiovascular drive to be seen alone. In the experiments in human subjects, the pressor response is maintained beyond the conclusion of the exercise by using occlusion of the blood supply with a sphygmomanometer. This response is attributable to a reflex set up in the ischemic muscle by the action of chemical factors on sensory nerve endings.

The aforementioned authors concluded that the heart rate response to isometric exercise is not related to the bulk of the exercising muscle group, but the reflex stimulus they investigated is only part of the total reflex drive present during contractions as other factors also operate on heart rate. In particular, the baroreceptor-cardiodepressor reflex may be of importance here because, during a voluntary isometric effort in animals, the baroreflex sensitivity is reduced, but not during either the postexercise occlusion period or induced contractions; thus if a pressor response is maintained, the heart rate is slowed by the baroreceptor reflex.

Our data are different from the results reported by Williams (31), where muscle mass is not a determinant of the magnitude of the contraction-induced rise in heart rate. She measured heart rate in six healthy male subjects during voluntary isometric contractions of the forearm and quadriceps muscles at 70% of the maximum voluntary contraction until fatigue occurred. Because the subjects used contractions of very high tension, it is difficult to make any direct comparisons between these results and our study because we used contractions of submaximal tension, at 50 and 20% of the maximum voluntary contraction.

We found an important effect of endurance time on heart rate increase (0.1 beats $\cdot$ min^{-1} $\cdot s^{-1}$). We have no explanation for this as all isometric contractions were sustained until exhaustion.

Our results showed a relatively important effect of basal heart rate on maximum heart rate: an increase of 0.6 beats/min in maximum heart rate for each beat per minute of basal heart rate. Alexander et al. (1) did not find a relationship of this kind, but they did not control for gender or room temperature. Claytor et al. (2) had similar results, but significant differences among the subjects in age and weight may have affected the increment in heart rate.

The results of our study indicate that the magnitude of the heart rate increase during isometric exercise is related to the intensity of the contraction and the mass of the contracted muscle. Also, in this study we have established normal values of heart rate increase for healthy men between 20 and 30 yr old when they are performing handgrip and wheel-turn isometric contractions sustained to exhaustion at 20 and 50% of maximal force. Future investigations should be directed to know the relationship in other populations and other conditions of muscle mass and contraction intensity.

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