Effect of isometric hand-grip exercise on the carotid sinus baroreceptor reflex in man

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Summary

1. The changes in R–R heart interval that result from step-increase and step-decrease in carotid sinus transmural pressure induced by a variable-pressure neck chamber were measured in seven normal men. Observations were made at rest, and during isometric hand-grip exercise at 24%, 44% and 64% of maximal voluntary contraction.

2. The response of heart interval to increase in carotid sinus transmural pressure was progressively and markedly diminished according to the strength of hand-grip. This effect was fully developed from the moment of onset of the exertion.

3. The response of heart interval to decrease in carotid sinus transmural pressure was much less consistently affected by hand-grip exercise.

Key words: baroreceptors, blood pressure, carotid sinus, exercise, hand-grip, heart rate, pressoreceptors.

Introduction

In their classic description of the cardiovascular effects of isometric hand-grip exercise in man, Lind, Taylor, Humphreys, Kennelly & Donald (1964) observed a marked rise in mean systemic arterial pressure, associated with proportionate increases in heart rate and cardiac output but with little overall change in systemic vascular resistance. Cunningham, Petersen, Pero, Pickering & Sleight (1972) subsequently examined the effects of various forms of exercise on the characteristics of human arterial baroreceptor reflexes, estimating sensitivity of the baroreceptor reflex by the change in heart interval induced by the pressor stimulus of intravenously injected phenylephrine. They found that isometric hand-grip, sustained at 30% of maximal for 3 min, caused a profound reduction in reflex sensitivity.

However, Cunningham and his colleagues examined only one side of the baroreceptor reflex, the response to a rise in arterial transmural pressure, and that at only one strength of hand-grip. By making use of the variable-pressure neck chamber to elicit carotid sinus baroreceptor reflexes we set out to answer three questions: whether hand-grip causes a similar depression of sensitivity if the pressor stimulus is restricted to carotid baroreceptors; what effect hand-grip has on the response to the opposite, depressor, stimulus to the carotid baroreceptors; whether alterations in sensitivity are related in a progressive fashion to increasing strength of hand-grip. We have also studied the time relation between onset of exercise and change in sensitivity.

Methods

We studied seven volunteer normal male subjects, median age 25 (20–46) years. All observations were made in a constant-temperature (21.0–22.5°C) laboratory, with the subjects seated.
Isometric hand-grip exercise was performed by gripping with the left hand a low-compliance tennis ball. The pressure generated was recorded by strain gauge and penwriter, and at the same time displayed to the subject by means of a large-dial voltmeter. Preliminary calibration established the relationship between force applied (kg) and pressure generated (mmHg). Each subject first gripped the ball with maximum force on three occasions, the average of these values being defined as maximal voluntary contraction. During the study proper, subjects were instructed to maintain a hand-grip that was a median 24 (20-27)%, 44 (40-47)% or 64 (58-67)% of their maximal voluntary contraction, the individual percentages being marked on the voltmeter. Hand-grip was maintained for a median 27 (24-36) s before change in neck-chamber pressure was imposed, and for about 5 s after it was released. Rest periods of 5 min were allowed between hand-grips.

Measurable changes in carotid sinus transmural pressure were induced by means of a variable-pressure neck chamber (Ludbrook, Mancia, Ferrari & Zanchetti, 1977). In brief, pneumatic pressure changes within the chamber are transmitted in a predictable fashion to the outside of the carotid sinus, creating sudden changes in carotid sinus transmural pressure. Of positive applied pressure change, 86%, and 64% of negative, is registered in the tissues surrounding the carotid sinus, so that the change in carotid sinus transmural pressure can be calculated from the change in neck-chamber pressure as measured by strain gauge. In the present study the median pneumatic pressure changes created in the chamber were −32.5 (30.0–35.0) and +32.5 (30.0–34.0) mmHg. The corresponding values of transmural pressure changes were +20.8 (19.2–22.4) and −27.9 (25.8–29.2) mmHg. Pneumatic pressure change in the chamber was 90% complete in a median time of 0.21 (0.18–0.23) s, negative pressure change being sustained for 8.7 (5.0–10.1) s and positive for 12.3 (6.1–13.9) s. These durations were selected to encompass the maximal changes in heart rate, which occurred at a median 3.6 (1.9–5.8) s after step-increase, and 6.8 (2.3–9.2) s after step-decrease, in carotid sinus transmural pressure.

In each subject the R–R interval (heart interval) was calculated from heart rate recorded by a tachometer that was triggered by the R wave of the electrocardiograph, and expressed in ms. The response of heart interval to change in transmural pressure was calculated as the arithmetic difference (ΔHI) between a reference value for heart interval and heart interval at the time of maximum cardiac slowing or acceleration caused by the respective rise or fall in transmural pressure. Sensitivity of the carotid baroreceptor reflex with respect to heart interval was calculated as ΔHI/Δtransmural pressure (ms/mmHg). The values for sensitivity were averaged within each subject for each state (at rest, and at each level of isometric exercise).

In the resting state, reference heart interval was calculated from the average heart rate during the 10 s that preceded the imposition of change in transmural pressure. During hand-grip, however, heart rate was usually still rising when the latter change was imposed (cf. Fig. 2). Thus in the state of hand-grip we estimated reference heart interval as that which would have obtained at the time of maximum response of heart rate to change in transmural pressure, had this latter stimulus not been superimposed. The appropriate value of heart rate from which to calculate reference heart interval was obtained by linear extrapolation of the rising heart rate. In order to compare the effects of hand-grip on heart interval and on arterial pressure, the reference values for heart interval were averaged within each subject for comparable states.

Arterial pressure was measured intermittently in the right arm by sphygmomanometry, an automated method of cuff inflation-deflation and microphonic recording of Korotkow sounds being used. Mean arterial pressure was calculated as (diastolic pressure) + ⅓(systolic − diastolic pressure). As with reference heart interval, values for mean arterial pressure were averaged within subjects for comparable states.

In each subject the responses to increase and decrease of neck-chamber pressure were tested at separate sessions. At each session the baroreceptor reflex responses were elicited three times at each of the three levels of hand-grip, as well as during the interposed rest periods.

Distribution-free methods of data presentation and analysis have been used, because of the small number of subjects studied and consequent uncertainty about the form of distribution of the data. Medians have been used to describe the central tendency of samples, with ranges given in parentheses. Between-state comparisons were made by calculating the T statistic in the Wilcoxon matched-pairs sign rank sum test. Associations of variables measured in the seven subjects in the four states of isometric exercise (n = 28) were sought by calculating the Spearman rank order correlation coefficient (r.). The aim in testing for
these associations was to emphasize changes produced by the four states of isometric exercise, rather than inter-individual differences in absolute values. Thus before calculating $r_s$ the averaged data for each individual in each state were normalized by expressing them as a % of his mean value from all four states.

$$(r_s = 0.887; P < 0.001).$$

However, although the first association was near-linear, the second was not: 24% maximal voluntary contraction caused only a relatively small reduction in heart interval (Fig. 1). There was also a negative correlation between mean arterial pressure and reference heart interval ($r_s = 0.888; P < 0.001$).

**Results**

**Effect of hand-grip on heart interval and mean arterial pressure**

Hand-grip caused a tachycardia that reached a plateau within 27 s at 24% of maximal voluntary contraction, but heart rate at 44% and 64% of maximum voluntary contraction was still increasing at this time. When hand-grip was released heart rate fell rapidly to the control value, often with a transient undershoot (Fig. 2).

Each subject showed a fall in reference heart interval, and an increase in mean arterial pressure, with each increase in intensity of hand-grip (Fig. 1). The median values for mean arterial pressure at rest, and during hand-grip at 35%, 44% and 64% of maximum were 97, 110, 125 and 142 mmHg. The corresponding median values of reference heart interval were 848, 791, 677 and 588 ms. When the normalized data from all subjects in all four states of hand-grip were combined, strength of hand-grip was positively correlated with mean arterial pressure ($r_s = 0.933; P < 0.001$), and negatively correlated with reference heart interval ($r_s = 0.887; P < 0.001$). However, although the first association was near-linear, the second was not: 24% maximal voluntary contraction caused only a relatively small reduction in heart interval (Fig. 1). There was also a negative correlation between mean arterial pressure and reference heart interval ($r_s = 0.888; P < 0.001$).
Effect of hand-grip on carotid baroreceptor reflex sensitivity

Under resting conditions reflex sensitivity was greater when tested by a rise in carotid sinus transmural pressure than when tested by a fall, in six of the seven subjects (n = 7; T = 1; P < 0.05; Fig. 3).

Sensitivity as tested by increase in transmural pressure fell consistently and progressively with increase in force of hand-grip (Fig. 3). Within-subject paired comparisons showed that with increase in strength of hand-grip, from each state to the next there was always a fall in sensitivity (n = 7; T = 27 or 28; P always <0.05). There was likewise a strong negative association between normalized values for sensitivity and percentage of maximal voluntary contraction (r_s = 0.552; P < 0.01), and a similar negative association between sensitivity and mean arterial pressure (r_s = 0.557; P < 0.01). There was a positive, somewhat stronger, association between sensitivity and reference heart interval (r_s = 0.743; P < 0.001).

Time-relation of reduction in reflex sensitivity to onset of hand-grip

It is apparent from Fig. 4 that in the two subjects studied the initiation of 65–70% maximal voluntary contraction caused an almost instantaneous fall in sensitivity to a value that was sustained throughout the period of isometric exercise.

Discussion

We adopted our method of defining sensitivity of the carotid sinus baroreceptor reflex in terms of heart interval for two main reasons. Eckberg, Cavanaugh, Mark & Abboud (1975), who used a

Fig. 3. Magnitude of reflex sensitivity expressed as the ratio of change in heart interval (ΔHI in ms) to change in carotid sinus transmural pressure (ΔCSTMP in mmHg) from their respective reference values, according to median intensity of hand-grip for the group expressed as % of maximal voluntary contraction. Each data point at each level of hand-grip represents the average of three measurements for a single subject. Lines join median values of the appropriate data arrays: ···, reflex sensitivity to increase in carotid sinus transmural pressure; O-·-·O, reflex sensitivity to decrease in carotid sinus transmural pressure. Note the change in scale of vertical axis, indicated by shaded area.

Fig. 4. Magnitude of reflex sensitivity (see the legend to Fig. 3) in relation to the time of onset of isometric hand-grip exercise in two subjects. In each subject the calculated increase of carotid sinus transmural pressure from the reference level was 23 mmHg. The respective subjects exerted a hand-grip of 70% (●) and 65% (○) of maximal voluntary contraction. Shaded area: period of hand-grip. Interrupted line: one-sided 95% confidence limit (n = 49) of time from application of reduced neck-chamber pressure to maximum change in heart interval.
Carotid sinus reflex in isometric exercise

neck suction device in man, found a generally linear relation between the pressure change applied and the maximum transient change in heart interval; and in a previous study of 11 normal subjects we observed a close linear correlation between graded reduction, or graded increase, in carotid sinus transmural pressure and the corresponding maximum change in heart interval (Mancia, Ferrari, Gregorini, Valentini, Ludbrook & Zanchetti, 1977). Furthermore, the use of heart interval takes into account the altered heart rate caused by exercise on which the transient baroreceptor stimulus is superimposed, and is in this sense similar to the beat-to-beat method of analysis used by Pickering, Gribbin & Sleight (1972).

In the resting state, the sensitivity of the carotid baroreceptor reflex was generally greater when carotid sinus transmural pressure rose than when it fell (Fig. 2, Fig. 3); that is, for a rise of carotid sinus transmural pressure the reduction of heart rate was of greater magnitude than the increase of heart rate that followed an equivalent fall of carotid sinus transmural pressure. This is more evident in the present study than in our earlier one (Mancia et al., 1977), perhaps because on this occasion the subjects were younger and the rate of change of pressure in the neck chamber was faster. The phenomenon itself appears to be a genuine one: Pickering et al. (1972), who used vasoactive drugs to cause transient changes in blood pressure, found that the beat-to-beat changes in heart interval were less when blood pressure was falling below the control value than when it was rising.

We conclude that isometric hand-grip exercise consistently and markedly reduces the magnitude of the lengthening of heart interval that is induced by raising the carotid sinus transmural pressure. This finding is consistent with the observations reported by Cunningham et al. (1972), who stimulated the whole population of arterial baroreceptors by means of the blood pressure rise provoked by phenylephrine injection. We have also found that isometric exercise does not reduce the response to increased carotid baroreceptor stimulation in an all-or-none fashion, but on a degree that is related to the force exerted. From detailed analysis of the observations that they made on normal subjects during various forms of exercise Cunningham et al. (1972) suggested that this apparent suppression of reflex sensitivity to increased arterial baroreceptor stimulation may come about in part from central alteration of the characteristics of the reflex, and in part as an indirect effect of the increase of blood pressure and heart rate. We do not need to invoke this latter effect to explain our observations, because we found that reflex sensitivity was immediately and markedly depressed at the inception of hand-grip and before there had been more than a trivial change in blood pressure and heart rate.

We also found that isometric hand-grip had much less effect on the shortening of heart interval that follows lowering of carotid sinus transmural pressure (Fig. 2, Fig. 3). Thus while there was a tendency for this baroreceptor-induced response to diminish with increasing strength of hand-grip, this change could not be discerned with confidence. This suggests that the proposal advanced by Cunningham et al. (1972), that isometric hand-grip markedly depresses the sensitivity of the arterial baroreceptor reflexes, may not hold true for the carotid arterial baroreceptor reflex when the stimulus is a fall in arterial transmural pressure.

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