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Cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise

Abstract In occupational work, continuous repetitive and isometric actions performed with the upper extremity primarily cause local muscle strain and musculoskeletal disorders. They may also have some adverse effects on the cardiorespiratory system, particularly, through the elevation of blood pressure. The aim of the present study was to compare peak cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise. The subjects were 21 untrained healthy men aged 24-45 years. The dynamic hand-grip exercise (DHGE) was performed using the left hand-grip muscles at the 57 (SD 4)% level of each individual’s maximal voluntary contraction (MVC) with a frequency of 51 (SD 4) grips · min⁻¹. The isometric hand-grip exercise (IHGE) was done using the right hand at 46 (SD 3)% of the MVC. The endurance time, ventilatory gas exchange, heart rate (HR) and blood pressure were measured during both kinds of exercise. The mean endurance times for DHGE and IHGE were different, 170 (SD 62) and 99 (SD 27) s, respectively (P < 0.001). During DHGE the mean peak values of the breathing frequency [20 (SD 6) breaths · min⁻¹] and tidal volume [0.89 (SD 0.34) l] differed significantly (P < 0.01) from peak values obtained during IHGE [15 (SD 5) breaths · min⁻¹, and 1.14 (SD 0.32) l, respectively]. The corresponding peak oxygen consumptions, pulmonary ventilations, HR and systolic blood pressures did not differ, and were 0.51 (SD 0.06) and 0.46 (SD 0.11) l · min⁻¹, 17.1 (SD 3.0) and 16.7 (SD 4.7) l · min⁻¹, 103 (SD 18) and 102 (SD 17) beats · min⁻¹, and 156 (SD 17) and 161 (SD 17) mmHg, respectively. The endurance times of both DHGE and IHGE were short (< 240 s). The results indicate that the peak responses for the ventilatory gas exchange, HR and blood pressure were similar during fatiguing DHGE and IHGE, whereas the breathing patterns differed significantly between the two types of exercise. The present findings emphasize the importance of following ergonomic design principles in occupational settings which aim to reduce the output of force, particularly in tasks requiring isometric and/or one-sided repetitive muscle actions.

Keywords Physiological strain · Muscle mass · Hand-grip · Dynamic exercise · Isometric exercise

Introduction

Repetitive and isometric types of muscular actions using the upper extremity have been shown to be common in industry, in the office and in many service jobs (Kilborn 1994a; Louhevaara et al. 1998). Repetitive and isometric actions have been found to be often associated with the use of hand tools (Kadefors et al. 1993) and data processing equipment (HLEG 1997, Nakasenko et al. 1982). Continuous repetitive and isometric actions have been found primarily to cause local muscle strain and musculoskeletal disorders (Bergqvist et al. 1995; Hales et al. 1994; Kadefors et al. 1993; Kilborn 1994b; Rempel et al. 1992) but they may also have some adverse effects on the cardiorespiratory system, particularly, through the elevation of blood pressure (Veiersted 1997).

Comparisons of the cardiorespiratory responses to repetitive and isometric actions has mostly been based on dynamic exercise of large muscle groups and isometric actions with small muscle groups when, for instance, two-legged cycling or walking on a treadmill have been compared with an isometric hand-grip action (e.g. Lind and McNicol 1967). During dynamic exercise, relatively large increases in oxygen consumption
(\(\dot{V}O_2\)), heart rate (HR), cardiac output, and systolic blood pressure with minor changes in diastolic pressure can be observed. In contrast, an isometric action has been shown to produce marked increases in the systolic and diastolic blood pressure with modest increases in \(\dot{V}O_2\), HR and cardiac output (Lind and McNicol 1967).

Only a few studies have compared cardiorespiratory responses to dynamic and isometric actions performed with muscle groups of similar size (Blomqvist et al. 1981; Lewis et al. 1983, 1985). In these studies, a gradual transition of the cardiorespiratory responses from “dynamic” to “isometric” has been observed with decreasing size of active muscle mass (Blomqvist et al. 1981). Thus, both Blomqvist et al. (1981) and Lewis et al. (1985) have suggested that the amount of the active muscle mass is a more marked determinant of cardiorespiratory responses than the type of muscle action. This phenomenon may be important when physiological strain, taken as a whole, is considered in occupational work including repetitive and isometric actions by the upper extremity which especially affect blood pressure and HR. Therefore, it was considered necessary to carry out a study to confirm and provide more details on the observations that have been reported by Blomqvist et al. (1981) and Lewis et al. (1985).

The aim of the present study was to compare the peak cardiorespiratory responses to fatiguing dynamic and isometric hand-grip exercise.

Methods

Subjects

The subjects were 21 untrained healthy men who worked as parcel-handlers in the Post Office. The mean age, height, body mass and body fat (Durnin and Rahaman 1967) were 33 (SD 6) years, 178 (SD 7) cm, 78 (SD 13) kg and 18 (SD 5)% respectively. The study procedures were accepted by the Ethics Committee of the Finnish Institute of Occupational Health. Each subject signed a statement of informed consent.

Protocol

The subjects were measured twice with a mean interval of 9 days in the exercise laboratory at an ambient temperature of 22–24 °C and a relative humidity of 30–40%. The subjects wore shorts during the measurements. During the occasion of the first test subjects were given a medical examination supplemented with the recording of an electrocardiogram and the measurement of blood pressure (BP) at rest. During both occasions the isometric maximal voluntary action, i.e. contraction (MVC) of the right and left hand-grip muscles was measured. The MVC was measured with the subject in a sitting position and the active arm extended to the side at a 10° angle to the vertical. The subject was instructed to produce a steady maximal grip for 2–3 s. The measurement was repeated after a 1-min rest. The higher force level attained was considered to be the MVC.

About 20 min after the MVC tests the dynamic hand-grip exercise (DHGE) was performed with the left hand at a target level of 50% of MVC with a target frequency of 50 grips·min\(^{-1}\). About 15 min after DHGE the isometric hand-grip exercise (IHGE) was done with the right hand at the same 50% target level of MVC. Both DHGE and IHGE were carried out in the same body position as the MVC measurements. The DHGE and IHGE were terminated when the subject was not able to produce force at the predetermined level and given frequency of grips or to maintain the predetermined isometric force level. The researcher carefully monitored each test performance and terminated it after one warning if the force or frequency level did not meet the criterion. During the second occasion the measurements were repeated.

Measurements

The hand-grip forces were measured with a dynamometer which included a water-filled rubber tube with a pressure transducer (Honeywell Microswitch-division 142P30G, USA) connected to an indicator and power supply (constructed at the Finnish Institute of Occupational Health). The pressure transducer had a built-in amplifier. Paper recordings of the measurements were taken with a chart recorder (Yokogawa 3057, Japan; Smolander et al. 1984). The 50% levels of the individual’s MVC and the frequency of the grips were continuously monitored on the paper of the recorder, which was placed in front of the subject at eye level.

Before both DHGE and IHGE the subject rested in a sitting position for 4 min and his baseline cardiorespiratory responses were recorded. After the termination of DHGE and IHGE the recovery was followed for 4 min. At rest, during DHGE and IHGE, and during the recovery, respiratory frequency, tidal volume, pulmonary ventilation, \(\dot{V}O_2\), production of carbon dioxide and respiratory exchange ratio were continuously measured and automatically printed every minute by a microprocessor-controlled respiratory gas exchange analyser (Morgan Exercise Test System. P.K. Morgan Ltd. UK). The measurement unit consisted of a flowmeter, a paramagnetic oxygen analyser (Morgan 500d), and an infrared carbon dioxide analyser (Morgan 800d). A low-resistance breathing valve (Modified Koegel Y-valve) with a mouthpiece and a nose clip was used continuously during the measurements. Before each measurement session the flowmeter was calibrated by four inspiratory strokes with a 1-l pump, and the gas analysers with two mixtures of gases of known oxygen and carbon dioxide concentrations. The values for the respiratory gas exchange were recorded every minute. The HR was continuously recorded with a telemetric Sport Tester PE 3000 Cardiac Monitor (Polar Electro, Finland). The results of HR were printed out with means for 15-s intervals. The systolic and diastolic BP were assessed using the conventional auscultatory technique, the cuff being located on the right arm during DHGE and on the left arm during IHGE. The BP was measured every minute. The mean time for attaining occlusion with a sufficient cuff pressure was about 15 s. The length of the BP measurement was about 30 s.

Analysis of the data

Peak cardiorespiratory responses of both DHGE and IHGE were determined. The data obtained during the 4th min of the rest and recovery periods were used as the rest and recovery values. Between the first and second test occasion, there were no statistically significant differences in the endurance times and peak cardiorespiratory responses of DHGE and IHGE according to the Student’s \(t\)-test for paired observations. Therefore, their mean values were used in the analysis of the data, which were first treated for conventional descriptive statistics. The significance of differences in the peak cardiorespiratory responses was evaluated using Student’s \(t\)-test for paired observations applying standard procedures. The differences were considered significant when \(P < 0.05\).

Results

The mean MVC were 102 (SD 22) kPa and 100 (SD 19) kPa for the right and left hand-grip muscles, respec-