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## Chapter 11

### Exercise Performance

Source: 1973 Report, Chapter 7, pages 237 - 249.

## Contents

	Page
Introduction.....	611
Studies of Smokers.....	611
Studies Comparing Smokers to Nonsmokers:	
<i>Athletic Performance</i> .....	613
<i>Bicycle Ergometer Performance</i> .....	614
<i>Treadmill Performance</i> .....	615
<i>Performance in Other Tests of Fitness</i> .....	615
Discussion.....	616
Biomechanisms.....	616
Summary.....	617
References.....	618



## Introduction

Although it has long been held by athletes and coaches that cigarette smoking is associated with "shortness of wind" and impaired performance, until recently there has been little scientific evidence to support this view. In the past few years, a variety of studies have appeared dealing with the effect of cigarette smoking on the response of man to exercise. The following is a review of these studies.

Age, sex, training, health, weight, and other factors are known to influence exercise performance. Because most of the investigations were carried out in healthy, young male volunteers, the groups were quite comparable with regard to age, sex, and health; however, weight, training, and other factors were often inadequately controlled. Furthermore, problems in study design and statistical analysis limit the value of several of these studies.

Many forms of exercise were performed in these experiments, including: pedaling a bicycle ergometer, running on a treadmill, running on a track, swimming, step climbing, gripping a hand dynamometer, and doing several different exercise activities as part of a battery of tests. Small to maximum amounts of work were carried out in the various studies reviewed.

## Studies of Smokers

Most of the studies of habitual cigarette smokers followed a similar format with respect to smoking: (a) The subjects refrained from smoking for a few hours prior to testing, and (b) two test runs were performed, one without smoking and one in which smoking immediately preceded the exercise or was incorporated with the exercise protocol.

Several investigators (1, 15, 28) studied the effect of smoking on maximum grip strength. Willgoose (28) reported a greater mean percent recovery of grip strength after the nonsmoking trial than after the smoking trial. Kay and Karpovich (15) and Anderson and Brown (1) all followed a protocol similar to that of Willgoose except that they randomized the smoking and nonsmoking trials, and substituted

a "placebo" cigarette for the nonsmoking trial. In neither of these studies were statistically significant differences observed between the grip scores for the smoking and nonsmoking trials.

Reeves and Morehouse (24) administered a battery of tests to 15 college students. The tests were: A tapping test, a strength test, a jumping test, and the short form of the Harvard step test. No statistically significant differences in performance were noted under conditions of smoking or nonsmoking.

A total of 32 college students from intermediate swimming classes abstained from smoking for 15 minutes, 2 hours, and 12 hours in a study conducted by Pleasants, et al. (23). Following the abstinence, they swam distances of 100 and 200 yards. Although actual swimming times were not published, the authors reported no statistically significant differences between the mean swimming times after the different periods of abstinence for either distance.

In 1946, Juurap and Muido (13) carried out several experiments in which three young cigarette smokers exercised on a Krogh's bicycle ergometer. Smoking was found to increase the pulse rate at rest as well as during exercise. Although the effect was less consistent than on the heart rate, smoking was also associated with elevated blood pressure. Smoking had no effect on oxygen consumption. Henry and Fitzhenry (12), in 1949, using the bicycle ergometer, also found that smoking exerted no effect on oxygen consumption. In the same year, Karpovich and Hale (14) studied bicycle ergometer performance in eight young men. In all subjects, the average riding time was better in nonsmoking tests than in smoking tests; however, the results were statistically significant for only three of the eight subjects.

Kerrigan, et al. (16) more recently measured direct arterial blood pressure, heart rate, and cardiac output in 25 habitual smokers at rest and after exercise. Smoking two cigarettes produced statistically significant ( $P < 0.01$ ) increases in cardiac index, heart rate, and arterial mean pressure compared to the immediately preceding control period. Exercise after smoking resulted in an increase in cardiac index over either the resting period or the exercise period which followed abstinence; the resultant cardiac index appeared to be approximately the sum of the exercise and smoking effects. Exercise tests preceded by smoking were also associated with significantly higher ( $P < 0.01$ ) and more prolonged elevations of blood pressure than those not preceded by smoking.

In the study by Goldbarg, et al. (11) of nine habitual smokers performing submaximal exercise on a bicycle ergometer, cardiovascular responses were measured via pulmonary and subclavian artery catheters. At rest, after smoking, the mean cardiac index and mean heart rate increased. During successively increasing levels of exercise, the heart rate was greater and stroke index lower than values for

comparable work before smoking. The net effect of smoking was to decrease the efficiency of the heart during exercise in the upright position by causing a smaller stroke volume and a higher heart rate.

Rode and Shephard (26) investigated near maximal treadmill exercise performance in six habitual smokers. A 1-day abstinence from cigarette smoking was associated with a 13- to 79-percent decrease in the oxygen cost of breathing. Abstinence was also followed by a slowing of the heart rate and a decrease in expiratory minute volume after exercise.

The study of Krumholz, et al. (18) is different from those cited previously in that bicycle ergometer exercise performance was measured in habitual smokers both before and after 3 to 6 weeks of abstinence. Among the 10 subjects who abstained from smoking for 3 weeks, there was a statistically significant ( $P < 0.05$ ) decrease in heart rate, oxygen debt, and ratio of oxygen debt to total increase in oxygen uptake produced by the 5 minutes of exercise.

Using a "double 9-inch progressive step test" Rode and Shephard (25) studied several hundred participants of a smoking withdrawal clinic at the time of entry and at a 1-year followup. Among those who returned for the followup and who gave up smoking, absolute aerobic power increased insignificantly; however, the relative aerobic power diminished in both sexes among those who quit smoking because of the weight gain experienced.

## Studies Comparing Smokers to Nonsmokers

### *Athletic Performance*

In 1968 Cooper, et al. (6) evaluated 419 airmen during their initial 6 weeks on active duty in the USAF. A 12-minute maximum running test was performed at least 1 hour after cigarette smoking. The mean distance covered in 12 minutes by the nonsmokers was significantly greater ( $P < 0.05$ ) than that covered by the smokers at the beginning, the middle, and the end of training. All categories of smokers and nonsmokers improved their performance at the end of training; however, the maximum change in performance of those smoking 10 to 30 cigarettes per day was significantly ( $P < 0.001$ ) less than that of nonsmokers.

David (7) administered a battery of tests to 88 military personnel, aged 19 to 39 years. A 1-mile run was included in the testing, and cigarette smoking was associated with a significant decrease in performance in this event.

Some 45 special forces soldiers were investigated at sea level and 13,000 feet above sea level by Fine (8). The subjects were randomly assigned to a placebo group or an acetazolamide treated group. Cigarette smoking was positively correlated to decrements in 600-yard running performance from sea level to altitude in both groups.

Pleasants (22) studied 106 students from intermediate university swimming classes. Swimming times were measured for 100- and 200-yard distances before and after training and for 800-yard distances after training. The mean swimming times of nonsmokers were less than those of smokers in six of seven listed categories, but these differences were not statistically significant.

#### *Bicycle Ergometer Performance*

Chevalier, et al. (5) investigated cardiovascular parameters in 32 young physicians after a standard 5-minute ergometer test. Oxygen debt accumulation among smokers was significantly ( $P < 0.01$ ) greater than among nonsmokers. The heart rate at rest and 3 minutes after exercise was significantly ( $P < 0.02$ ) faster in smokers than in nonsmokers.

Using a 5-minute ergometer test, 18 housestaff physicians, half of whom smoked, were investigated by Krumholz, et al. (17). They noted the following: Oxygen debt accumulation after exercise was significantly ( $P < 0.02$ ) greater in smokers than non-smokers, the ratio of the oxygen debt to total increased oxygen uptake during exercise was significantly ( $P < 0.001$ ) greater in smokers than in nonsmokers, and the diffusing capacity at rest and with exercise was significantly ( $P < 0.05$ ) decreased in smokers compared to nonsmokers.

Kerrigan, et al. (16) studied cardiovascular parameters in smokers and nonsmokers at rest, during, and after a 5-minute bicycle ergometer ride. Cardiac index and blood pressure values obtained during exercise performed immediately after smoking were greater than those found in nonsmokers performing the same exercise. Similarly, heart rate and blood pressure remained elevated for longer periods in those who exercised immediately after smoking than in nonsmokers performing the same task.

Aerobic capacity scores were examined in 60 university student volunteers by Peterson and Kelley (20). Subjects worked at submaximal levels on a bicycle ergometer before, during, and after a training program. At all of these intervals, nonsmokers had significantly ( $P < 0.05$ ) higher mean aerobic capacity scores than smokers. Both groups increased their aerobic capacity during training but nonsmokers consistently performed better throughout training.

### *Treadmill Performance*

In 1960 Blackburn, et al. (4) carried out several measurements of cardiovascular function after different amounts of treadmill exercise were performed by 233 professional men, 159 university students, and 414 railroad workers. The differences between the smokers and nonsmokers were of small magnitude. Basal oxygen consumption was slightly higher in smokers than in nonsmokers. Also, resting pulse rates were higher in smokers of most groups.

Cooper, et al. (6) studied 47 out of 419 airmen with treadmill testing. Cardiopulmonary indices measured on the treadmill, including maximum indices, were comparable in smokers and nonsmokers except for a significant ( $P < 0.01$ ) reduction in the maximum minute volume among the smokers.

A total of 277 prospective Canadian firemen performed the Balke-Ware test of work capacity in treadmill studies carried out by Glassford and Howell (10). The mean performance scores of nonsmokers were significantly ( $P < 0.01$ ) greater than those of smokers.

The effect of vitamin C supplementation on treadmill exercise performance was investigated in 40 male volunteers by Bailey, et al. (3). Significant differences in oxygen utilization and ventilatory function between smokers and nonsmokers were noted in only two of the 24 separate analyses of variance performed.

Maximal oxygen intake during treadmill exercise was examined by McDonough, et al. (19) in 86 healthy, middle-aged male volunteers. Cigarette smoking was one of six variables which together provided a multiple correlation coefficient of 0.73.

### *Performance in Other Tests of Fitness*

When physical fitness tests were administered to 88 military personnel by David (7), cigarette smoking was found to be associated with a significant ( $P < 0.001$ ) decrease in performance in the dodge and jump test, and a significant ( $P < 0.02$ ) decrease in performance in the crawling test.

Using a step test, a breath holding test, and an ergometer test, Franks (9) examined 58 middle-aged men. Nonsmokers were able to hold their breath longer and had greater vital capacity residual after the step test than the smokers.

In 1971, Wysokinski (29) studied 200 young Polish soldiers using Letunov's test which included 20 knee-bending exercises, a fast run for 20 seconds, and a run for 3 minutes. Cigarette smoking was associated with a significant ( $P < 0.01$ ) reduction in the vital capacity and a

marked rise in the pulse rate at rest and after exercise. Intense exercise also caused a greater rise in the systolic blood pressure in smokers than in nonsmokers.

### Discussion

Most of the studies in habitual cigarette smokers compared exercise performance in "smoking" and "nonsmoking" runs after only a few hours of abstinence. In some studies, smoking adversely affected performance (11, 13, 14, 16, 18, 26, 28), while in others it did not (1, 12, 15, 23, 24). Some of these apparently discrepant results are due to differences in methodology and in amounts and types of work performed. In all of the more recent studies of habitual smokers in which moderate to near maximal amounts of work were performed and sophisticated measurements of oxygen transport and cardiopulmonary function were made, impairment of function during smoking trials was found (11, 16, 18, 26).

The data of Krumholz, et al. (18) also raise the question of whether residual effects of cigarette smoking influence "nonsmoking" trials performed after a few hours of abstinence; they found statistically significant decreases in heart rate and oxygen debt produced by exercise after 3 weeks of cessation.

The work of Rode and Shephard (25) suggests that physical fitness improves with cessation, but this improvement may be negated if the subject gains a substantial amount of weight after giving up smoking.

Several investigators compared exercise performance or postexercise cardiopulmonary function of smokers to nonsmokers. Although only minor differences between smokers and nonsmokers were found in a few of these studies (3, 4, 22), in most of them (5, 6, 7, 8, 10, 16, 17, 20, 29) the performance or function of the nonsmokers was better than that of the smokers. Both nonsmokers and smokers improved their performance with training, but nonsmokers maintained their advantage throughout training (6, 20).

### Biomechanisms

The cited studies indicate that cigarette smoking exerts its adverse effect on exercise performance through several mechanisms. Cigarette smoking appears to impair cardiac performance during exercise by increasing the heart rate and exerting a variable effect on cardiac

output (5, 11, 13, 16, 18, 26, 29). Cigarette smoking is associated with an increased oxygen debt after exercise (5, 18). Also, one study indicated that the oxygen cost of hyperventilation was greater among smokers than among nonsmokers (26).

Some of these adverse effects of smoking on oxidative metabolism are mediated by the elevated carboxyhemoglobin levels found in smokers. CO exerts these effects through one or more of the following mechanisms: (a) Reduction of the amount of hemoglobin available for oxygen transport, (b) shift of the oxygen-hemoglobin dissociation curve to the left with consequent interference in oxygen release at the tissue level, (c) induction of arterial hypoxemia, and (d) possible interference with the homeostatic mechanism by which 2,3,DPG controls the affinity of hemoglobin for oxygen (27). Because carboxyhemoglobin has a half life in the body of at least 3 to 4 hours, its influence may still be measurable several hours after abstinence from smoking (27).

A recent investigation of maximal muscular exercise during CO intoxication in five male volunteers demonstrated reduced maximal O<sub>2</sub> consumption in spite of a much higher heart rate and a relative hyperventilation (21).

Astrand and Rodahl (2) commented recently on the adverse effect of cigarette smoking on oxygen transport: "All other factors being equal, a reduction in the oxygen-transporting capacity is associated with a corresponding reduction in physical performance capacity during heavy or maximal work \* \* \*. Because a regular physical training program only increases the maximal oxygen uptake by some 10 to 20 percent, a 5- to 10-percent reduction in maximal aerobic power due to smoking may play a significant role in many types of athletic events and in very heavy work."

Other studies cited in this review document the adverse effect of smoking on pulmonary diffusing capacity (18) and on pulmonary function with exercise (6, 29).

### Summary

Clinical studies in healthy, young men have shown that cigarette smoking impairs exercise performance, especially for many types of athletic events and activities involving maximal work capacity. Some of these effects are mediated by reduced oxygen transport and reduced cardiac and pulmonary function.

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## Chapter 12

### Harmful Constituents of Cigarette Smoke

Source: 1972 Report, Chapter 9, pages 137 - 150.

## Contents

	<i>Page</i>
The Dose Relationship .....	625
References .....	630

### LIST OF TABLES

Table 1.—Compounds in cigarette smoke judged most likely to contribute to the health hazards of smoking .....	627
Table 2.—Compounds in cigarette smoke judged as probable contributors to the health hazards of smoking .....	628
Table 3.—Compounds in cigarette smoke judged as suspected contributors to the health hazards of smoking .....	629

## HARMFUL CONSTITUENTS OF CIGARETTE SMOKE\*

Cigarette smoke contains a large number and a wide variety of compounds which may result in complex and multiple pathophysiological effects on various tissues and organ systems. Although the constituents of cigarette smoke are usually divided for convenience into the two categories of particulate and gas phases,\*\* many of them exist in a distribution equilibrium, that is, they are present partially in the gas phase and partially in the particulate phase. This review concerns itself with judgments concerning the harmful constituents of cigarette smoke whether these are found primarily in the gas phase or in the particulate phase.

Constituents of cigarette smoke may enter the body by a variety of routes. Theoretically, the route of entry and subsequent absorption could affect the degree to which various organs are subjected to specific cigarette smoke constituents. Some constituents, particularly the water soluble components of the gas phase, may be absorbed by the nasal and oropharyngeal mucous membranes, or may be dissolved in the saliva and swallowed, thus allowing for possible gastric or intestinal absorption. Other constituents are absorbed along the tracheobronchial tree, and the distance which they reach before being absorbed or deposited depends on such factors as the depth of inhalation and the particle size. The absorption of gases in the tracheobronchial tree appears to be in part dependent on the adsorption of gases to particulate matter. Another factor affecting the route and degree of absorption is the adequacy of pulmonary clearance by which constituents deposited or dissolved in the mucous sheath are delivered to the pharynx and then usually swallowed.

Of the hundreds of compounds identified in cigarette smoke, some occur in the smoke in concentrations which may be considered sufficient to present hazards to health. Other compounds appear in

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\* This report attempts to summarize the areas of general consensus reached in a special one-day conference of experts in this field which met in June 1970. This is not to imply that there was unanimous agreement on all statements contained herein. A list of participants in the meeting appears in the Acknowledgments.

\*\* It should be noted that there is, at present, no available instrumentation permitting the separation and individual collection of the particulate and gas phases which duplicates the precise physicochemical conditions prevailing in cigarette smoke as it is inhaled. A widely accepted arbitrary distinction between the two phases is as follows: If 50 percent or more of a given constituent is retained on a Cambridge filter (CM-113) during standardized machine smoking of a cigarette, then the compound is considered to belong to the particulate phase; if on the other hand more than 50 percent of the compound passes through the Cambridge filter under these conditions, then the constituent is considered to belong to the gas phase.